21 JANUARY 2022

Report of the Inquiry Committee for the accident at Stars Engrg Pte Ltd on 24 February 2021

(PART I – MAIN REPORT)

Inquiry Committee Members

Chairman

Mr. Ong Hian Sun

Senior District Judge

State Courts Singapore

Assessor

Er. Lucas Ng Hong Kiang

General Manager of Plant

Petrochemical Corporation of Singapore (PCS)

Assessor

Dr. Peter Nagler

Chief Innovation Officer

Agency for Science, Technology and Research

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Part I – Main Report

CHAPTER 1 CONDOLENCES

1. The Chairman and Members of the Inquiry Committee ("IC") express their deepest sympathies and heartfelt condolences to the families and friends of the deceased Anisuzzaman MD ("Anis"), Shohel MD ("Shohel") and Subbaiyan Marimuthu ("Marimuthu") (*in alphabetical order*) who were involved in this accident.

2. They had left their hometowns for Singapore in search of a better livelihood but tragically lost their lives while at work. As we grieve their loss, we acknowledge their contributions to Singapore.

3. Besides the deceased, there were other injured workers who have suffered much pain, and several have sustained permanent scars and injuries. The IC wishes to put on record its gratitude for their contributions, and wish them a speedy recovery.

CHAPTER 2 EXECUTIVE SUMMARY

Introduction

4. On 24 February 2021, a large explosion occurred at Stars Engrg Pte Ltd's ("Stars Engrg") premises located at 32E Tuas Ave 11 Singapore 636854 ("the worksite"). This tragic and preventable accident had major repercussions, and regrettably resulted in three deaths, five major injuries, two minor injuries, and severe property damage.

5. The worksite was used to manufacture fire-retardant wraps, termed by the workers as "fire wrap". One of the main work processes involved using a heated mixer machine to make "fire clay" which was a main component of the fire wrap. The mixer machine was similar to other mixer machines commonly used to mix ingredients but came with an external oil jacket for heat transfer fluid and built-in heaters for heating of the contents. A key ingredient for the "fire clay" was potato starch powder.

6. In gist, workers were required to use the mixer machine to first heat up water in its mixing chamber, then mix potato starch and other ingredients with the heated water within the mixing chamber until they achieve a pasty consistency otherwise known as "fire clay". This fire clay will then be wrapped with other components such as ceramic fibre and fibreglass within aluminium sheets to form the end product, "fire wrap".

Causes and Circumstances Leading to the Explosion

7. The explosion occurred across two steps:

    a. Over-pressure in the mixer machine's oil jacket caused mechanical failure and fracture of the welds. This over-pressure was a result of over-heating of the heat transfer oil and use of the oil jacket as a closed system when it was designed to be operated as an opened system; and

    b. When the welds fractured from over-pressure within the oil jacket, liquid thermic oil was forced out and aerosolised into an oil mist / fine droplets, which were ignited, leading to the explosion. This eventually ignited the accumulated potato starch powder that were suspended in the air, resulting in the subsequent flash fires.

8. The accident was rooted in the unsafe use of the mixer machine as follows:

a. The temperature within the oil jacket was not monitored. The temperature sensor that came with the mixer machine to specifically measure and regulate the temperature within the oil jacket was used interchangeably with the other temperature sensor to measure only the temperature within the mixing chamber.

b. Insufficient thermic oil used in the mixer machine's oil jacket caused inefficient heat transfer and overheating of the thermic oil. The temperature of the thermic oil went beyond its safe operating temperature leading to thermal degradation, which significantly reduced its flash point.

c. The mixer machine was used as a closed system with the two vents sealed off, without monitoring of the pressure within the oil jacket, resulting in inevitable over-pressurisation of the oil jacket.

d. The repeated heating and cooling cycle with each operation of the mixer machine also stressed the oil jacket's integrity, resulting in the oil jacket eventually losing its mechanical strength. This was exacerbated by the weakening of the weld seams due to poor quality repair welds done by Stars Engrg's workers. As a consequence, the oil jacket ruptured outwards at the weak points, fracturing at the weld seams.

9. The initial rupture of the oil jacket had resulted in the primary catastrophic explosion, which caused the most significant damage and injuries. However, there were also subsequent flash fires which were most likely due to combustion of the potato starch powders which were allowed to accumulate at the worksite.

10. Combustible dust explosions can occur if the following five elements are present: (i) fuel (combustible dust), (ii) air, (iii) dispersion, (iv) confinement, and (v) ignition source. Without (iv) confinement, combustible dust flash fires can also occur. When the mixer machine ruptured and the subsequent explosion occurred, the resultant overpressure lifted and suspended the combustible potato starch powders into the environment and was ignited, causing multiple subsequent combustible dust flash fires.

11. Other gaps were also identified that have contributed to the accident or worsened the injuries sustained by the workers. In particular, several red flag events that served as warning signs of an impending failure early into the operation of the mixer machine were not adequately understood and dealt with, which could have prevented the accident. Some gaps observed are:

a. Lack of competent personnel to commission and operate the mixer machine, identify the problems arising from the operation of the machine, and understand and remedy the issues appropriately;

b. Inadequate risk assessment for the operation of the mixer machine. This includes not learning the lessons from, or adequately addressing, the numerous warning signs and incidents. Many of these signs and incidents were clear indications that there was something wrong with how the mixer machine was being used;

c. Lack of a comprehensive emergency response plan which should indicate the escape route and response procedures in case of an incident such as a fire; and

d. Not providing or ensuring the donning of suitable personal protective equipment such as fire-retardant clothing.

Recommendations

12. The existing Workplace Safety and Health Act ("WSHA") and its subsidiary legislation already provide comprehensive general duties on various stakeholders to ensure the safety and health of workers. These duty holders include occupiers, employers and principals, suppliers, and manufacturers. In addition, there are also risk-based regimes in place to govern safe use of machineries at workplaces as well as use of combustible powders under the WSHA and the Fire Safety Act.

13. The IC also notes that the mixer machine involved in the accident is generally not a high-risk equipment when properly used, and there is a wide range of combustible powders commonly used in the industry as well as in households, such as flour and sugar. Hence, the IC is minded not to recommend knee-jerk reactions that could result in over-regulation and impose excessive regulatory burden on the economy.

14. However, this accident has shown that more could be done to enhance the existing regimes in order to prevent the recurrence of another similar accident. In summary, the IC recommends the following enhancements:

a. <u>Safe use of machineries:</u>
   i. Encourage buyers of industrial equipment to certify their purchased equipment to SS 537-1: Code of Practice for the Safe Use of Machinery – General Requirements; and
   ii. Review and expand the Fifth Schedule of the WSHA to include higher-risk machineries such as those powered by mechanical, electrical, hydraulic, or pneumatic energy.

b. Safe use of combustible dusts:
   i. Suppliers of materials that pose a defined level of combustible dust hazard to include a label explicitly informing on the hazard before selling or redistributing;
   ii. Companies that handle prescribed amounts of specified combustible powders to register or notify the authorities; and
   iii. Occupiers to inform building owners or landlords on the use of combustible powders, so that they will be made aware and can deconflict incompatible work amongst tenants, if any.

c. More outreach and guidance efforts be conducted, specifically directed towards Small and Medium Enterprises ("SME"), as well as workers who may be at risk.

CHAPTER 3 INTRODUCTION

Background and Preface

15. Singapore has come a long way in our collective workplace safety and health performance. The workplace fatal injury rate declined by more than 80% from 4.9 per 100,000 workers in 2004 to 0.9 per 100,000 workers in 2020, the lowest on record since 2004. However, there is still much work to be done as we continue to see workplace fatalities and injuries every year.

16. In particular, three workers lost their lives and five more were severely injured in a large explosion at Stars Engrg's premises located at 32E Tuas Ave 11 Singapore 636854 on 24 February 2021. Their unfortunate and avoidable deaths had irreparably changed the lives of their families and friends.

17. Stars Engrg's core business is the installation of fire protection systems. Stars Engrg also uses a fire-rated insulation wrap under the brand name "Shield+" to wrap piping and ducting systems in building construction for its clients. The commercial arrangement between Stars Engrg and Shield+ was that Shield+ engaged Stars Engrg to produce the fire wrap. Mr. Chua Xing Da ("Chua") is the sole director of both Stars Engrg and Shield+ Pte Ltd ("Shield+"). On 24 February 2021 at about 0830hrs, two workers were preparing a mixer machine to mix potato starch powder with heated water, to produce a compound that would be used to manufacture fire retardant sheets. Six other workers were at the worksite performing other works. A flange connected to one of the mixer machine's heating elements was noticed to be glowing. It is understood that the workers shut down the machine to allow it to cool down in consideration of replacing the faulty heating element.

18. At about 1122hrs, an explosion occurred. All eight workers from Stars Engrg suffered varying degrees of burn and were conveyed to the Singapore General Hospital. Two workers from P3 Project Pte Ltd ("P3 Project"), who were working at the unit opposite of Stars Engrg, also sustained injuries. Both were conveyed by their employer to Ng Teng Fong General Hospital. The fire was extinguished at 1146hrs on the same day. Officers from the Ministry of Manpower ("MOM") responded promptly at the scene and a Stop Work Order was issued for the worksite (see Annex A).

19. It cannot be emphasised enough that workplace deaths and injuries can and must be prevented. While we examine the causes of this unfortunate accident, it is timely that we send a clear and cogent message that a callous and cavalier attitude towards the safety of workers will not be condoned and all stakeholders must do their parts. In line with Singapore's aim to have one of the best workplace safety records in the world, a concerted effort is required from all stakeholders – workplace occupiers, contractors, employers, employees, and also suppliers and manufacturers.

Appointment and Terms of Reference of the Inquiry Committee

20. In view of the multiple fatalities and injuries, extensive damages, and to facilitate a comprehensive review of the regulatory and institutional governance for industrial machineries and combustible dusts, the Minister for Manpower appointed an IC on 2 March 2021 under Section 26 of the WSHA to hold an inquiry and ascertain the causes and circumstances of the explosion at Stars Engrg.

21. The IC comprised Senior District Judge Ong Hian Sun as the Chairman, and two assessors, Er. Lucas Ng Hong Kiang, General Manager of Plant, Petrochemical Corporation of Singapore (Private) Limited (PCS), and Dr. Peter Nagler, Chief Innovation Officer of Agency for Science, Technology and Research (A*STAR). The brief biographies and appointment letters of the IC members are appended at Annexes B and C, respectively.

22. The Terms of Reference ("TOR") for the IC is appended at Annex D and reproduced as follows:

    a. Inquire into and ascertain the causes and circumstances of the accident that led to an explosion at the premises of Stars Engrg Pte Ltd located at 32E Tuas Ave 11 on 24 February 2021.
    b. Make recommendations to prevent the recurrence of such an accident at workplaces.
    c. Consider the evidence put before the IC as led by State Counsel from the Attorney-General's Chambers.
    d. Make and submit a report of the proceedings, findings, recommendations, and any other relevant observations related to the cause of the accident to the Minister of Manpower.
    e. If the District Judge appointed to the IC is of the opinion that criminal proceedings ought to be instituted against any person in connection with the accident, he shall also forward a copy of the report to the Public Prosecutor.

Assistance to the Committee

23. The IC was assisted by a Secretariat team from MOM comprising the Secretary, Ms. Audrina Chua; Assistant Secretary, Mr. Delvinder Singh; as well as Mr. Eric Tan, Ms. Jaslyn Tan, and Mr. Matthew Tay in providing administrative support to the IC.

24. Senior State Counsel Ms. Kristy Tan led the evidence during the two tranches of the IC hearings at State Court No. 8A from September to November 2021. She was assisted by Deputy Senior State Counsel Ms. Ang Feng Qian and Mr. Sivakumar Ramasamy, as well as State Counsel Ms. Amanda Sum.

25. The accident was investigated by Chief Investigation Officer (CIO) Ms. Jaime Lim, MIChemE, PPSE. She was supported by Assistant Chief Investigation Officer Mr. Mohamed Haniffa and Investigation Officer Mr. Lucas Ng, from the Occupational Safety and Health Division (OSHD) of MOM.

Actions Taken by the Committee before the Hearings

26. The IC had three meetings before the public hearings commenced. The following were covered during these meetings:

Date	Agenda
5 Mar 2021	a. The CIO provided preliminary updates on the investigation progress and findings; b. The IC visited the accident site to understand the worksite and survey the extent of the damage; and c. The IC members were updated on its TOR and other administrative matters such as timeline for the IC proceedings.
23 Apr 2021	a. CIO briefed members on the progress of investigation; b. State Counsel updated the IC on the list of witnesses to testify; and c. the IC agreed on an updated timeline and to conduct the public hearing in two tranches.
14 Sep 2021	a. The IC was updated on the progress of the investigations, as well as presented with an updated hearing schedule.

Conduct of the Inquiry Hearings

27. Evidence presented by the State was led by State Counsel. Stars Engrg was represented by Counsel from Rajah & Tann (Singapore) LLP, led by Mr Thong Chee Kun and assisted by Ms Josephine Chee and Ms Zheng Yirong.

28. The IC hearing was conducted in two tranches:

    a. The first tranche held from 20 September to 7 October 2021 focused on the causes and circumstances that led to the fatal explosion and fire. The IC heard from a total of 22 witnesses: 15 fact witnesses, four experts, and two investigation officers called by State Counsel, and one expert called by Stars Engrg. The experts called by the State were (i) Mr. Robert Shandro ("Mr. Shandro") and (ii) Mr. Ashley Ng ("Mr. Ng"), both from Matcor Technology & Services Pte Ltd ("Matcor"), (iii) Dr. Shaik Mohamed Salim ("Dr. Salim"), Principal Specialist A*STAR, ICES, and

(iv) Emeritus Prof. Chew Yong Tian ("Prof. Chew"). The expert called by Stars Engrg was Dr. David Rose ("Dr. Rose") from Hawkins & Associates (Singapore) Pte Ltd ("Hawkins").

b. The second tranche held on 15 and 16 November 2021 focused on recommendations to prevent the recurrence of such an accident at workplaces. The IC invited the relevant government agencies, professional bodies, industry associations and members of public to submit written representations on recommendations to prevent the recurrence of such an accident at workplaces between 13 and 31 October 2021. The following areas were highlighted to be of particular interest to the IC: (a) Measures to ensure the safe commissioning, operation, maintenance, and repair of industrial machines operating in a similar manner as that involved in the incident; and (b) Measures to ensure the safe supply, storage, and handling of combustible dust or powders at workplace settings similar to that involved in the incident. Of the 17 written representations received from organisations and individuals, seven representatives were called to testify during the second tranche of the hearing held.

29. Closing submissions were heard on 15 December 2021 in State Court No. 8A.

30. The opening statement, list of witnesses, list of exhibits, list of witness statements and submissions, expert reports, written representations, and closing submissions are appended at Annexes E to K, respectively.

CHAPTER 4 THE WORKSITE

Key Parties

31. Particulars of the Workplace

Name of Occupier	:	Stars Engrg Pte Ltd
Address	:	32E Tuas Avenue 11 Singapore 636854
Type of Industry	:	Manufacturing
Workplace Number	:	201024323G0004

32. Particulars of the Accident

Type	:	Fatal
Casualties	:	3 deaths, 7 injured
Date and Time	:	24 February 2021 at about 1122hrs

33. Particulars of Deceased:

Name	Anisuzzaman Md	Shohel Md	Subbaiyan Marimuthu
Nationality	Bangladeshi	Bangladeshi	Indian
Age	29	23	38

34. Particulars of Injured:

Stars Engrg

Name	Ahmmed Lizon	Hossain Jitu	Mehedi	Molla Md Yousuf	Rahad Asfaquzzaman
Nationality	Bangladeshi	Bangladeshi	Bangladeshi	Bangladeshi	Bangladeshi
Age	25	32	21	27	30

P3 Project

Name	Miah Md Azam	Zhao Jian Wang
Nationality	Bangladeshi	Chinese
Age	39	44

Stars Engrg

35. Stars Engrg was incorporated in 2010 with an ACRA registered address at 15 Changi North Street 1, #01-24 I-Lofts @ Changi, Singapore 498765. Stars Engrg's principal business activity is "*installation of fire protection and security alarm systems*". This involved installing fire-retardant

wraps[1] on water pipes and ventilation ducts at construction project sites to increase the resistance of such building infrastructure against fire damage. Stars Engrg also carried out general electrical installation works at project sites.

Figure 1: Fire wrap on pipes

Figure 1: Fire wrap on ducting

36. At the Tuas worksite at 32E Tuas Ave 11, the main work process was the manufacture of fire-retardant wraps, commonly referred to by Stars Engrg's workers as "*fire wrap*". The fire wrap manufactured at its Tuas worksite had a "*Shield+*" logo affixed on its exterior.

37. Chua is the sole director of Stars Engrg who oversaw and managed the operations at the worksite. An extract of Stars Engrg's organisation chart is appended below:

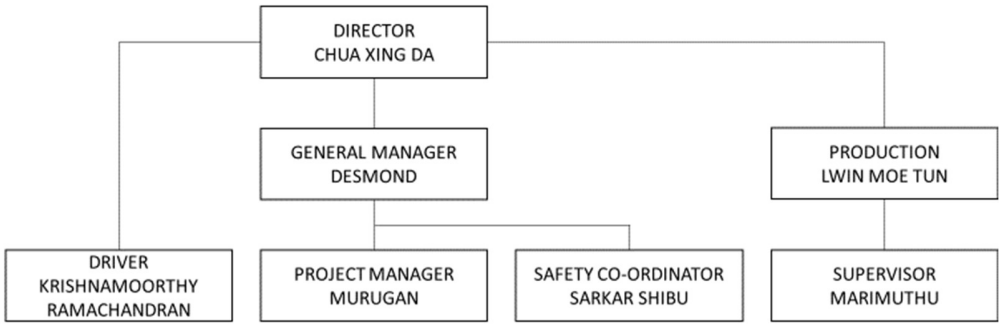


Figure 3: Extract from Stars Engrg organisation chart

Shield+ Pte Ltd

38. Shield+ was incorporated in 2009. Its ACRA registered address is at 32E Tuas Avenue 11, #01-00, Platinum@Pioneer, Singapore 636854. Stars Engrg rented the worksite in June 2019 and allowed

[1] A form of passive fire protection used in buildings, to slow down the spread of heat and fire.

Shield+ to register the worksite as its corporate address. Chua is the sole director of Shield+ and co-owns Shield+ with two other shareholders: Mr. Alvin Loo and Mr. Goh Yong Ping, who are both not involved in the day-to-day operations of Shield+.

39. Shield+ holds the patent for the fire wrap and engaged Stars Engrg to manufacture the fire wrap. Stars Engrg accordingly deployed its workers to produce the fire wrap at the worksite and charged Shield+ for the provision of manpower and rental costs in respect of the worksite. As part of this arrangement, when Stars Engrg had any projects involving the use of the fire wrap, Shield+ would charge Stars Engrg a discounted price for the wrap.

Layout Plan

40. The Stars Engrg worksite measured about 17.55m by 9.90m. There was a raised platform within the premises of the worksite, which the mixer machine and its control panel was placed on. Two assembly tables were placed near the front shutters and two roller machines were located between the assembly tables and the platform. See *Figures 4 and 5* below for the general layout of the worksite:

Figure 4: Photo showing the layout of the Tuas Site before the accident, with labels added

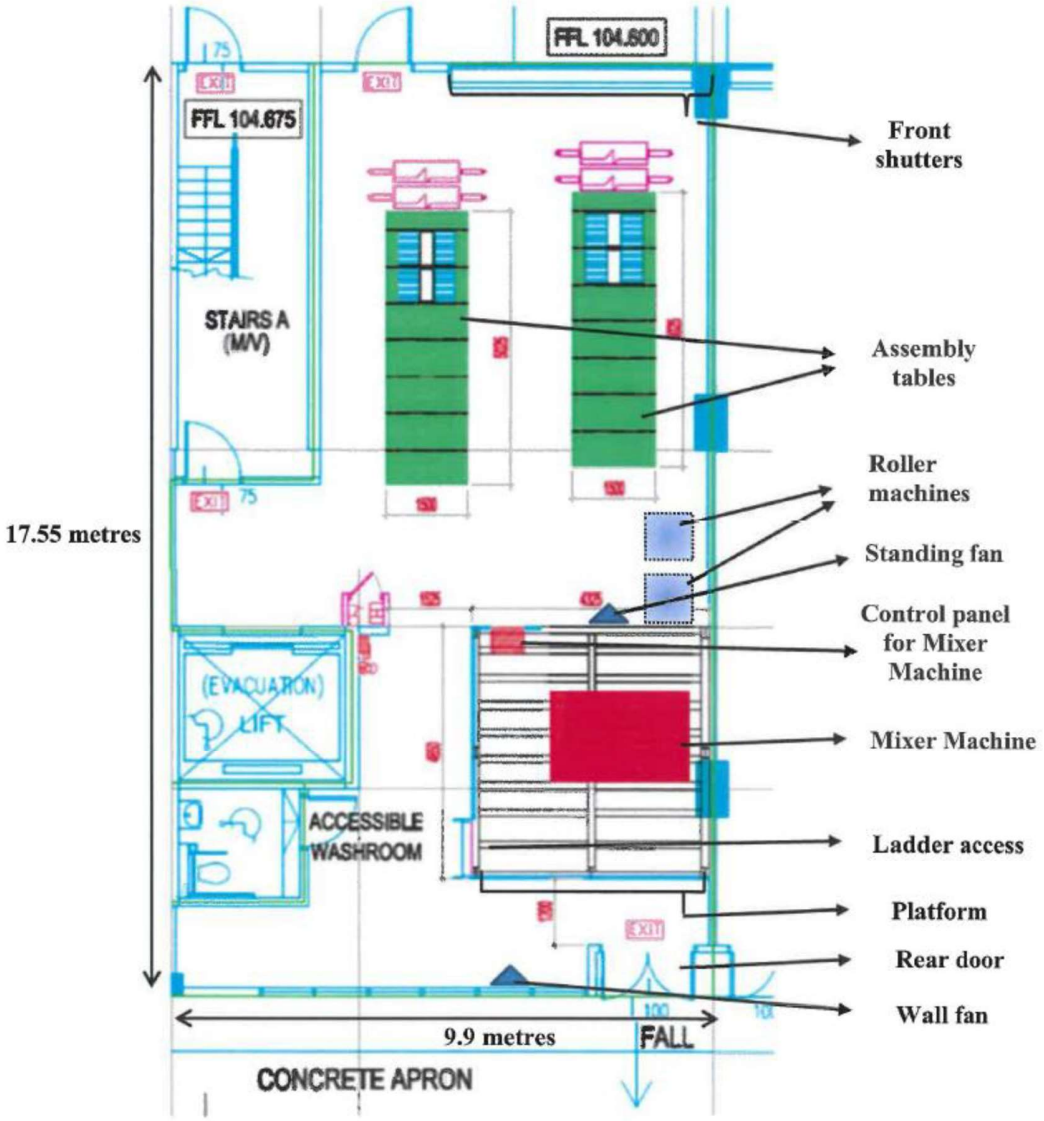


Figure 5: Reproduced layout of the Tuas Site just before the accident, with labels and dimensions added

41. The shutters at the front entrance of the worksite faced a common driveway located within the Platinum@Pioneer compound. The yard just outside of the shutters stored rolls of materials, equipment and work items. Some completed rolls of fire wrap were also placed in the yard.

Fire Wrap Production Process & Equipment

Fire-rated Wrap

42. The fire wrap manufactured by Stars Engrg comprised an aluminium sheet exterior and was made up of layers, including a clay-like lining that Stars Engrg referred to as “fire clay”. The final fire wrap

product measured 5m by 1m and was rolled and packed in a yellow plastic bag for supply to their clients. The fire wrap was fire-rated to up to at least two hours.

Process of making Fire Clay

43. A mixer machine was used to make fire clay. The quantities of raw materials and the mixing times required depended on the quantity of fire clay being produced. At the peak production period between January and February 2021, about 800kg of fire clay were being made. To make this amount of fire clay, about 176 litres of water would first be heated for about 35 to 40 minutes in the mixer machine up to 80°C or 90°C, before about 88kg of potato starch was added to the heated water. The heaters would then be turned off and the rotating blades in the mixing chamber turned on. Other raw materials such as boric acid powder, liquid silicon, aluminium trihydrate, and bentonite clay were then sequentially added based on Stars Engrg's proprietary composition. The mixer machine would continue mixing the materials together to a pasty consistency.

44. The fire clay would then usually be poured out of the mixer machine and laid out on the platform. Subsequently, chunks of the fire clay would be transferred to the ground floor below. Workers at the roller machines would pick up the chunks and flatten to 10mm with one of the roller machines. The 10mm fire clay would then be passed to the next roller machine to be flattened further to 5mm, in preparation for fire wrap assembly.

Fire Wrap Assembly Process

45. From the aluminium roll of 1.2m in width, two sheets were cut at slightly more than 5m in length. Both sheets were taped together lengthwise to create sufficient width to go around as the fire wrap width was about 1.1m.

46. Layers were then placed on the taped aluminium sheet in this order – plastic sheet, ceramic fibre, fibreglass net/mesh, pieces of fire clay placed together to form a layer, and another layer of ceramic fibre. The plastic sheet enfolded the layers within and was shrink wrapped with heat.

47. The shrink-wrapped layers were then enveloped within the taped aluminium sheet and sealed with aluminium tape to complete the fire wrap assembly process. The fire wrap was finally rolled and bagged in preparation for delivery to and installation at project sites.

Mixer Machine

48. The mixer machine was the main equipment used in the production of the fire clay. It was similar to other mixer machines used to mix ingredients, such as flour and water, but came with an external jacket for heat transfer fluid and built-in heaters for heating of the contents. It was purchased by Stars Engrg sometime in August 2019 via the 'Alibaba' online platform.

49. Laizhou Keda Chemical Machinery Co., Ltd ("Laizhou Keda") manufactured the mixer machine sometime in September 2019 and it was delivered to Stars Engrg sometime between October and November 2019.

Figure 6: Label affixed on the mixer machine

50. Accompanying the mixer machine during the delivery was a control panel, one blue funnel, and nine spare heaters. One of the oil jacket's top openings (the front pipe) also came sealed with an end cap. The front of the mixer machine was where the lid opened for access to the mixing chamber. The heaters were connected onto the jacket at the back of the mixer machine.

51. There were three openings on the oil jacket: one was located on the top front of the mixer machine, one was located at the top back of the mixer machine, and one was located at the bottom and operated as an oil drain. As the "NH Sigma Mixer User's Guide" stated "*An oil vapor vent is provided at the highest point behind the machine*", the opening at the top back of the mixer machine with an elbow bend was likely meant to function as the said vapor vent.

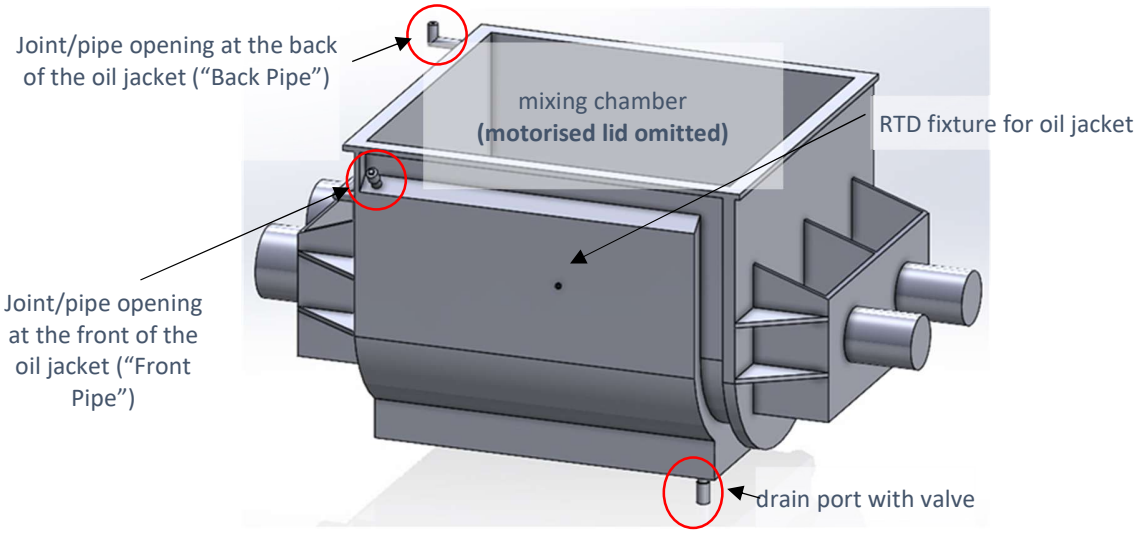


Figure 7: Front view of mixer machine with the three openings on oil jacket circled in red

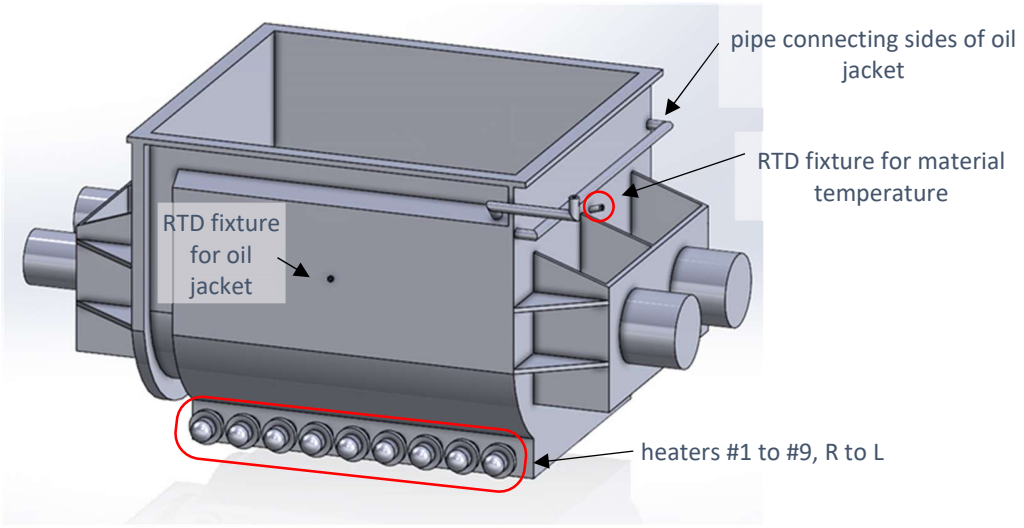


Figure 8: Rear view of mixer machine with nine heaters encircled in red

Control of Operations via Panel

52. The mixer machine had various functions that were controlled via the control panel. This included opening and closing of the lid, tilting the mixer to facilitate loading and unloading of materials into or from the mixer machine, turning on and off the mixer, and turning on and off the heaters.

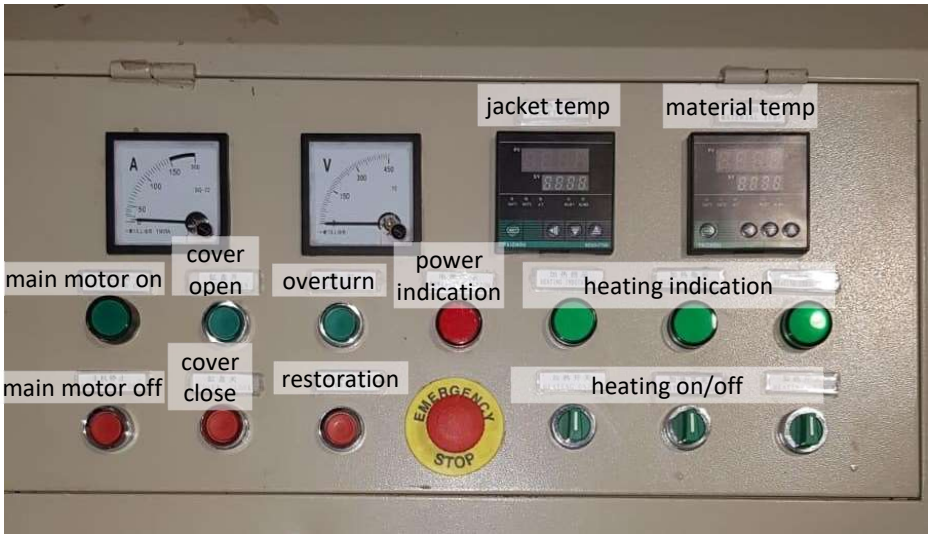


Figure 9: The local control panel for the Mixer machine, labels added

53. The lid was operated via a hydraulic system and 2 sigma blades (or Z-form blades), which sat horizontally at and parallel to the bottom of the mixing trough within the machine. The blades were driven by a motor attached to the mixer machine. The product was discharged by tilting the mixer machine, via the same hydraulic system that operated the lid.

54. The panel also showed two temperature readings connected to two resistance temperature detectors ("RTD"), a type of temperature sensor, via electrical cables. One sensor was intended for measuring the jacket temperature and another for material temperature, which were presented as two sets of readings on the panel – Jacket Temperature and Material Temperature. The temperature setting for each temperature sensor could be entered on the control panel, although only the jacket temperature sensor came with a safety interlock to cut off heat supply when the pre-set temperature was reached.

55. There were three fixtures on the mixer machine that fitted the screw-on attachments for the RTDs – one on each side of the oil jacket and the third one on the side of the mixer machine (see *Figures 7 and 8* for locations of the RTD fixtures).

Thermal Oil Jacket ("Oil Jacket")

56. The mixer machine was built with an oil jacket, which was meant to contain conductive heat transfer fluid to transfer heat from the heaters to the contents of the mixing chamber. The heat transfer fluid used by Stars Engrg was "*Daphne Alpha Thermo 32*[2]" thermic oil. Based on the Safety Data Sheet, the thermic oil had a flash point of around 220°C.

[2] Daphne Alpha Thermo 32 is the same as Daphne Alpha Thermo 32S.

57. Within the oil jacket, nine heaters were electrically connected in parallel to generate heat from electrical power. Each of the heaters was rated 220V and 5kW. When all nine heaters were turned on, the total power rating was 45kW.

58. The User's Guide stated that the oil jacket had a working pressure of ≤0.2 MPa (2 bar). The oil jacket's design temperature was 200°C while the operating temperature was 70°C to 160°C.

Setting up of Worksite and Installation of Mixer Machine

59. From April to early June 2020, Stars Engrg's workers prepared the worksite for the fire wrap manufacturing process. The platform in the worksite was built by Stars Engrg's workers based on the calculations and layout provided by DP Engineers and a Professional Engineer. Related electrical works were also carried out, including the installation of cables to be used on the platform.

60. The mixer machine was installed on the platform on 12 June 2020 and was first operated with water in the jacket. Chua checked the User's Guide and realised that "*The jacket needs to be filled with heat conduction oil. The heat conduction oil is heated by the electric heating tube, and the heat conduction oil transfers the materials inside the mixing cylinder*". He contacted Laizhou Keda's representative, Sherry, and she replied the next day on 13 June 2020 that water could spoil the heaters and recommended heat carrier oil be used instead.

61. Chua then purchased two buckets of thermic oil from Ming Hup Trading Pte Ltd and the oil was delivered to the worksite on 16 June 2020. Each bucket contained 20 litres of thermic oil. Both buckets of thermic oil (total 40 litres) were poured into the oil jacket through a funnel via the vent at the rear of machine. The mixer machine was operated at least once as a trial after the addition of the thermic oil.

62. Between 16 June 2020 and the end of July 2020, the mixer machine was not frequently used as the delivery of raw materials for the fire clay arrived only in late July 2020.

63. Between late July 2020 and October 2020, Stars Engrg started producing small batches of fire clay using the mixer machine. There were at least three times that fire clay was made using the mixer machine. Stars Engrg then continued using the mixer machine and started actual production of fire wraps at the Tuas worksite sometime in October 2020. Throughout this process, Stars Engrg used the two RTDs interchangeably only to measure the temperature within the mixing chamber and did not affix them to the provided fixtures.

Key Events and Warning Signs leading up to Explosion

64. The use of the mixer machine was besieged with red flags since the early stages of its operation leading all the way to the morning of the accident date. A list of the key events leading up to the explosion are summarised in the table below and key events indicated with asterisk are elaborated in the ensuing paragraphs:

Timeline	Event
Apr to early Jun 2020	• Set up worksite for fire wrap manufacturing, including construction of raised platform for Mixer machine
12 Jun 2020	• Installed mixer machine on platform
16 Jun 2020	• 1st purchase of 2 buckets (20 litres each) of Idemitsu Daphne Thermic Oil 32-S ("Thermic Oil"), totalling 40 litres • At this time, there were four workers deployed at the worksite: Imam, Shohel, Molla Md Nasim ("Nasim"), and Mehedi. Imam was in charge at the worksite during this time, with Lwin Moe Tun ("Moe") overseeing the team/fire wrap production.
7 Aug 2020*	• No boiling sounds heard when mixer machine was operated • Low oil level in jacket was found and instructions were issued by Chua to seal all openings on oil jacket
8 Aug 2020*	• Smoke and a spark seen around heater #1 when mixer machine was operated • Oil drained was a darkened hue and heater #1 was replaced • 2nd purchase of 4 buckets of Thermic Oil totalling 80 litres • All openings on oil jacket were sealed
28 Aug 2020*	• Smoke observed around the heaters. • Oil drained was of a darkened hue (about 6 buckets or 120 litres) • Heaters were checked and gaskets replaced
21 Sep 2020*	• Smoke seen around heaters
28 Sep 2020*	• Boiling sounds from inside the oil jacket and oil leaking from a small hole on the surface of the oil jacket
1 Oct 2020*	• Oil drained was darkened in hue (about 5.5 buckets or 110 litres) • Drained oil left to stand so that heavier soot particles settled at the bottom, and oil on top was returned to the jacket • Imam stopped working at the worksite sometime in October 2020 and returned sometime in late December 2020.
2 Oct 2020*	• Chua carried out his monthly maintenance check on the mixer machine

12 Oct 2020*	• Oil leaked again at front left of the mixer machine's jacket, same location as the leak on 28 September 2020 • Hairline crack of about 3mm revealed after grinding off top layers • Welding repairs carried out
8 Jan 2021*	• White smoke seen from three corners of the oil jacket • Imam was asked to leave the worksite again. Anis took over his role for about 10 days before Marimuthu was appointed as the supervisor sometime in January 2021 • From January 2021 to 17 February 2021, the fire wrap production team comprised Marimuthu, Shohel, Anis, and Mehedi.
5 Feb 2021*	• 3rd purchase of four buckets (80 litres) of Thermic Oil
6 Feb 2021*	• New insulation installed around shell of mixer machine
12 Feb 2021*	• Fire broke out at front right of the mixer machine near the drain valve. • Oil stains observed at front right and bottom of the jacket after fire was extinguished. • Boiling sounds could be heard in a video taken of the mixer machine.
13-17 Feb 2021*	• Welding repairs carried out on mixer machine
18 Feb 2021	• Four more workers joined the fire wrap production team at the worksite: Hossain Jitu ("Jitu"), Molla Md Yousuf ("Yousuf"), Rahad Asfaquzzaman ("Rahad"), and Rahman Mohammad Ashikur ("Ashikur"). • Daily production target of 32 fire wraps per day introduced
22 Feb 2021	• Ahmmed Lizon ("Lizon") replaced Ashikur and started working at the worksite. • The respective roles of the eight workers at the worksite became more fixed: ○ Marimuthu in charge of mixer machine with Shohel's assistance; ○ Anis and Lizon cut the fire clay and flattened the pieces using the roller machines, sometimes with Marimuthu's and Shohel's assistance; ○ Jitu, Rahad, Yousuf, and Mehedi assembled the fire wraps at the two assembly tables.
24 Feb 2021 (morning of explosion)	• At about 0830hrs on the morning of the explosion, heater #2 glowed red hot and a small fire occurred at the heater area • At about 1122hrs, a main explosion occurred followed by three flash fires at 1123hrs, 1124hrs, and 1125hrs.

7th August 2020

65. At about 2300hrs on 7 August 2020, Moe instructed Imam to make a batch of fire clay in preparation for making fire wrap the next day. When Imam turned on the heaters, he noticed that

there were no boiling sounds, and suspected that the oil in the oil jacket was running out.

66. As a co-worker, Nasim, was in the vicinity, Imam approached Nasim to help figure out if anything was amiss with the mixer machine. Nasim used an improvised dip stick to determine the amount of oil in the oil jacket. The dip stick showed that the level of oil barely covered the tip of the dip stick, although the depth that the dip stick had reached into the jacket was unclear. After receiving a video of Nasim's dipstick check from Imam at 0030hrs on 8 August 2021, Chua issued instructions to seal all openings on the oil jacket, explaining *"if not all the oil gone already"*. This was not done immediately. Shortly after, at 0037hrs on 8 August 2021, Chua made an order for 4 buckets of thermic oil via WhatsApp.

Figure 10: Screengrab from video sent by Imam to Chua on 7 August 2020

Figure 11: Heater #1 replaced on 8 August 2020

8th August 2020

67. The next day at around 0800hrs, Imam was operating the mixer machine to make a batch of fire clay when he saw a spark and some smoke around the heaters. Imam then activated the emergency-stop button on the control panel which cut off all power supplied to the mixer machine.

68. At around 0930hrs, Imam informed Chua and Stars Engrg's project engineer overseeing production at the worksite, Moe, that a heater was faulty. Chua then guided Imam, via video call, to (i) turn off the mixer machine, (ii) drain the oil from the oil jacket, (iii) remove heater flanges and cables, (iv) replace the spoilt heater, and (iv) check cable connections. Measurements on the electrical connections, including checks for earth leakages, insulation, continuity, and resistance were conducted.

69. Imam said he drained about one and a half buckets of darkened oil that looked reddish black to him. Another co-worker, Mehedi, assisted with the oil draining and recalled that the oil was left to stand and settle before returning the clearer top oil to the oil jacket. The residual dark matter that settled at the bottom was not returned to the oil jacket.

70. Imam then replaced heater #1 with a spare heater that another co-worker, Shohel, retrieved from the level 2 store within the premises. *Figure 11* above shows that the metal surface of the spoilt heater's heating element seemed melted with the interior exposed.

71. Imam carried out Chua's instruction to seal off all the oil jacket openings. He sealed one of the openings with an original end cap that came with the machine and the other with a "Bush" pipe fitting. Following further clarification from Chua, Imam subsequently replaced the "Bush" pipe fitting with another end cap he had sourced himself at a later time. Except for occasions when oil was added to the oil jacket through the back pipe, the front and back pipes remained sealed thenceforth including during the operation of the mixer machine to make fire clay.

72. The four buckets of thermic oil totalling 80 litres ordered earlier by Chua just after midnight in the wee hours of 8 August 2021 were delivered by Stars Engrg's driver to the worksite on the same day. Imam added three buckets of thermic oil in the oil jacket and informed Chua of the top-up at around 1300hrs. Imam also added into the oil jacket the previously drained oil of about one and a half buckets. As there were no instructions on how much oil to be added into the jacket, Imam thought that three buckets of new thermic oil in addition to reusing the drained oil would be sufficient.

73. According to Imam, the remaining bucket of oil was likely to have been added into the oil jacket between 8 and 27 August 2020.

28th August 2020

74. On the morning of 28 August 2020, Imam noticed that the mixer machine took about an hour longer than usual to heat up the water to 90°C and smoke was seen emanating from the area around the heaters. Imam testified that the smoke had an "*oil burning smell*". Imam quickly turned off the mixer machine and opened the yellow caps to check the cables on the heaters.

75. Imam reported the matter to Moe but Moe told him to report to Chua instead. Imam tried to call Chua but was unable to reach him. Imam took a video of the oil being drained and sent it to Moe. About 6 buckets of dark coloured oil were drained out. He also tested the heaters using a megohmmeter[3]. Imam did the draining of the oil and the checks on the heaters with Shohel's and Mehedi's assistance.

[3] A megohmmeter is a special type of ohmmeter used to measure the electrical resistance of insulators.

76. Imam and Mehedi observed that the gaskets on the heater openings of the mixer machine's oil jacket were worn out. Imam said that parts of the gasket were stuck to the heater openings and Mehedi said that some parts of the gaskets had broken and fallen off.

Figure 12: Screengrab from video. The 6th bucket is not shown here as it was under the drain valve

Figure 13: Photo taken on 28 August 2020 after checks and cleaning were carried out

77. Imam called Chua again and managed to update him on the issues involving the mixer machine. Chua told Imam to replace all the worn-out gaskets and instructed Imam to ask Nasim to make new gaskets. Mehedi and Shohel replaced the old gaskets with the new ones made by Nasim and Imam re-installed the heaters. The drained thermic oil, less the black sediments, was then returned to the jacket through the top opening with an elbow via the funnel, and the opening was thereafter resealed with the end cap. Operations of the mixer machine resumed and there were no problems with the heating when he used the machine the next day.

21st September 2020

78. On 21 September 2020 at 0955hrs, Imam sent Moe a video showing smoke around the heaters of the mixer machine. Imam checked with Moe if he and Chua knew about the issue and if there were any concerns. Imam recalled Moe and Chua told him that it was normal for smoke to be produced from the heating.

28th September 2020

79. Imam sent a photo to Moe at 1025hrs showing oil dripping from a hole on the surface of the oil jacket at the front left bottom corner of the mixer machine with the accompanying messages "*hole have small*" and "*need to welding bro*". Imam heard boiling sounds and saw smoke accompanying the oil leak. It was possibly the first time that an oil leak was noticed since the mixer machine was installed at the worksite. Up to that time, Stars Engrg's workload in relation to the production of the fire wrap was not high and the mixer machine had, according to Imam, been used only about 2 to 6 times in a month.

Figure 14: First oil leak on jacket, blue circle inherent in Imam's photograph

80. Moe instructed Imam to ask Nasim or Mehedi to do the welding. Imam agreed and said he would keep Moe updated. However, Moe had not yet checked with Chua when he gave these instructions. According to Moe, he had updated Chua subsequently and Chua agreed with Moe that Nasim should do the welding. Chua admitted during the hearings that he was updated about the leak by late September 2020. However, no welding was performed as Mehedi said he did not know how to weld it and Nasim said he was unable to weld without Chua's express instructions. As such, no welding was performed until the issue resurfaced on 12 October 2020.

1st October 2020

81. Oil was drained for a third time on 1 October 2020. A picture showing five buckets and a smaller container of used oil was taken by Mehedi and sent to Imam. Out of the five buckets, four were the original buckets for the thermic oil. The drained oil once again looked dark in colour.

Figure 15: A total of six containers of darkened used oil were drained from the oil jacket

82. According to Mehedi, Imam had instructed him to drain the oil and remove the residual sooty particles. The drained oil, less the black sediments which settled at the bottom of the buckets, was eventually poured back into the oil jacket later that day.

2nd October 2020

83. Chua carried out his monthly maintenance check on the mixer machine. Although he had been updated about the leak in late September 2020, he did not indicate the leak in the maintenance checklist, which was also inaccurately dated 1 October 2020.

12th October 2020

84. On 12 October 2020, Stars Engrg's workers operated the mixer machine although the oil jacket leak of 28 September 2020 had not been repaired. Mehedi sent a video of the leaking oil jacket and smoke around the machine to Moe at 0855hrs. In the video, white smoke could be seen spurting from the leak at the front left bottom corner of the mixer machine, the same location as the first oil leak on 28 September 2020. A hissing and crackling sound could also be heard. Moe thought that the white smoke seen in the video was oil vapour coming out of the crack in the oil jacket. Based on the WhatsApp chat log between Mehedi and Moe, the temperature for the oil jacket was pre-set to 200°C and all the heaters were turned on. However, the RTD with the safety interlock feature that was meant to measure the oil jacket temperature was not affixed and the oil jacket temperature could not be monitored.

Figure 16: Screengrab from video of 12 October 2020 showing oil leak and smoke, green circle inherent in video

Figure 17: Safety interlock temperature setting at 200°C on 12 October 2020, green digits within red circle

85. Chua instructed Nasim to weld the area to repair the leak although he did not personally visit the worksite to physically inspect the leak. Chua said welding was needed as the leak was at the seam of the oil jacket's original manufacturer's weld. Chua was of the view that it was not possible to use metal epoxy, for example, to seal the leak. Chua did not think of contacting the manufacturer about the leak.

86. This was the first time that Nasim did welding on the mixer machine. According to Nasim's statement, he had ground off the paint coating on the oil jacket so that the crack could be seen more clearly. He estimated the crack to be about a 3mm hairline crack. Nasim then ground a groove of around 50mm length and 7-8mm width along the crack and welded three to four layers. However, Nasim later testified orally at the hearings that all he did was to remove the paint before welding directly onto the old weldment. The latter was consistent with Matcor's observations on the lack of preparation and that the repair welds were done over the existing weld.

8th January 2021

87. On 8 January 2021, Moe forwarded a video to Chua showing the oil jacket leaking again, with white smoke emitting from three corners of the oil jacket – front left and right of the mixer machine, rear of the machine, and the base under the front left of the machine. Moe observed that the white smoke was heavier than on previous occasions and lasted about ten minutes before it was time to switch off the heater. Moe said he felt that something was not safe about the mixer machine.

88. Chua replied that Moe should ask Nasim to weld, and also asked Moe to check if the smoke was leaking from the heater flanges. Moe reported to Chua that the smoke was coming from the three corners of the oil jacket and not from the heater flanges. Ultimately, no further welding was done to the oil jacket on this day. In the meantime and until 12 February 2021, each time the mixer machine's heaters were turned on to heat the water, the workers would observe white smoke from the bottom corners of the mixer machine's oil jacket in the last ten minutes before it was time to switch off the heaters.

89. Chua claimed that he thought that the white smoke was a result of escaping steam from loose gland packing at the sides of the mixer machine[4]. Chua also claimed that the issue was resolved after he tightened the gland packing, and "the worker didn't complain anymore smoke". However, this was contrary to Moe's witness statement where he explained that the white smoke continued to be observed until after the fire on 12 February 2021 when welding repairs were done to the mixer machine.

5th February 2021

90. A final purchase for thermic oil was made on 5 February 2021. Four buckets of thermic oil were purchased, bringing Stars Engrg's total purchase to 10 buckets (or 200 litres) between June 2020 and February 2021.

6th February 2021

91. On 6 February 2021, on Chua's instructions, new insulation of ceramic fibre covered with aluminium sheet was installed around the shell of the mixer machine to prevent workers coming into contact with the hot oil jacket surface. The insulation was affixed onto welding pins which were tag-welded to the oil jacket without penetrating the surface.

Figure 18: Photographs of the insulation on the oil jacket taken by Marimuthu on 6 February 2021

[4] This refers to the seal that is at the outside of the rotating arms of the machine.

12th February 2021

92. On 12 February 2021, which was the first day of Chinese New Year, at about 1650hrs, a fire occurred at the mixer machine near the drain valve at the bottom of the oil jacket. According to Mehedi, Marimuthu, who was operating on the platform, was the first to notice the fire, and said he observed a red-orange flame measuring about 250-300mm high, and 150-250mm wide. Mehedi and Marimuthu then put out the fire with a hose reel, before Marimuthu activated the emergency stop button to turn off the mixer machine. After the fire was extinguished, Mehedi saw beads of black oil leaking from the oil jacket and noticed a lot of smoke from the drain area, where the fire was.

Figure 19: Photograph of the fire taken by Marimuthu on 12 February 2021

93. Chua was not at the worksite that day and was updated via phone call and photos and videos sent over WhatsApp. Chua then instructed the workers to turn off all power and lighting, clear the smoke with the ventilation fan, clean the area of water, remove insulation on the oil jacket, drain out oil from the oil jacket, assess which part of the mixer machine was leaking, and to weld the leaking area after the oil jacket was cooled. Chua separately told Moe to ask Nasim to do the welding and Moe in turn passed on the message to Marimuthu.

94. Around this time, Chua also privately contacted another of Stars Engrg's workers, Pandi Muruganantham ("Murugan"), to go to the worksite to resolve issues in the wake of the fire. Specifically, Chua wanted Murugan to check whether the exhaust vent was working as the smoke was not being vented out of the worksite. Murugan arrived at the worksite at about 1745hrs and noticed the entire worksite filled with smoke. The smoke from the fire was not effectively exhausted as the general ventilation fan in the worksite was not working. The shutters and back

door were then opened fully, and ventilation was further aided by an industrial stand fan and a wall-mounted fan.

95. Chua also instructed Murugan to check on the condition of the mixer machine. Murugan took a photo of the front right bottom corner of the mixer machine where the fire originated. Murugan observed that there were oil stains around the corner and observed that the mixer machine and oil inside the jacket were very hot, because he could feel the heat and hear oil boiling sounds from inside the jacket. Murugan sent a video with "boiling" sounds to Chua. Chua replied that boiling sounds were common as the oil was heated up, similar to heating water over a stove. Chua then sent instructions to Murugan via WhatsApp to check the mixer, and to weld an additional layer of metal plate overlapping the bottom corners of the oil jacket "as they were leaking". Murugan then conveyed Chua's instructions to Nasim and said that Marimuthu would show him the leak areas. Chua conveyed the welding instructions to Murugan via the following marked photographs and accompanying instructions *"All the corner here leaking, so we overlap slightly to cover the leak. Weld dead".*

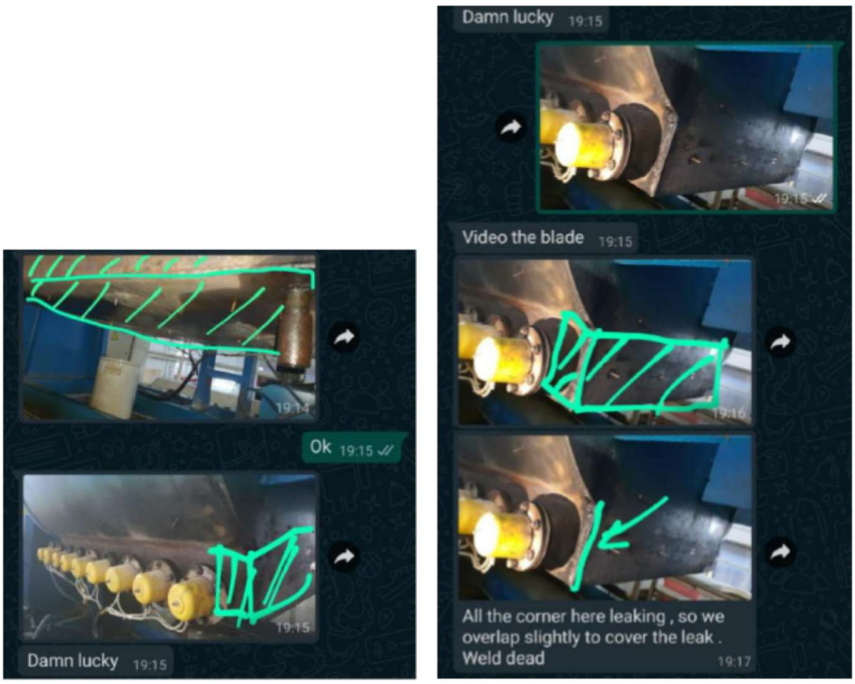


Figure 20: Screenshots from Murugan's mobile phone of his WhatsApp messages with Chua on 12 February 2021

96. In his WhatsApp chat with Moe, Chua said, "*we need high thermal flashpoint oil grade…*" and "*the heat we use is too high for the oil*". He said that it was a possibility that the oil overheated and leaked out, causing the fire. However, after receiving photographs from Marimuthu showing that the edges of the insulation installed on 6 February 2021 were burned off, Chua alleged that he subsequently thought it was the adhesive on the insulation tape that caught fire as the fire was

not "dripping". Chua was of the view that the aluminium tape was unable to withstand the high heat of the oil jacket and thus caught fire.

97. Chua then called and told Laizhou Keda's representative that the mixer machine was not meeting his expectations. The representative replied that the warranty had lapsed and there was little that could be done. In any event, by performing in-house welding repairs, Chua had voided the terms of the warranty provided by Laizhou Keda. Despite being well aware of this, Chua expressed disappointment with the after-sales support as he had expected some support from the manufacturer or be allowed to return the machine. He said the manufacturer was previously unwilling to share detailed design drawings and specifications with him and took time to reply his messages. Nevertheless, Chua still requested for a fresh quotation from Laizhou Keda for a new stainless-steel machine as he wanted to explore the use of water instead of heat transfer oil so that he would not need to keep buying oil. Chua explained to the IC during his testimony:

> *"I have at that point of time ….. I'm actually having the ultimatum of this existing mixer, that means, I have, I had enough of this mixer."*

98. Marimuthu developed concerns about the safety of the mixer machine after witnessing the fire and sent a series of concerned messages via WhatsApp to Moe as reproduced below. Chua heard from Moe about Marimuthu's concerns and tried to call Marimuthu but was unable to reach him. Chua then sent several text messages to Marimuthu claiming that the fire was not actually from the mixer machine, the mixer machine was not dangerous, and it was not the oil that caught fire.

"this one finish I talk to you"
"better I no work"
"I very sect [scared]"
"still I no see my baby"

13th to 17th February 2021

99. On 13 February 2021, Nasim prepared the welding tools and equipment and Marimuthu indicated the welding locations on four corners of the oil jacket with a marker. Oil was drained from the oil jacket before the grinding started. On Nasim's instructions, Mehedi sent a picture of the old weld to Chua with the message "old welding crack ready". The grinding revealed two cracks, one on each edge on the front of the mixer machine. To this, Chua replied between 1449hrs-1450hrs, "*Ya la*" and "*Good, we will repair and the machine is good to go again*".

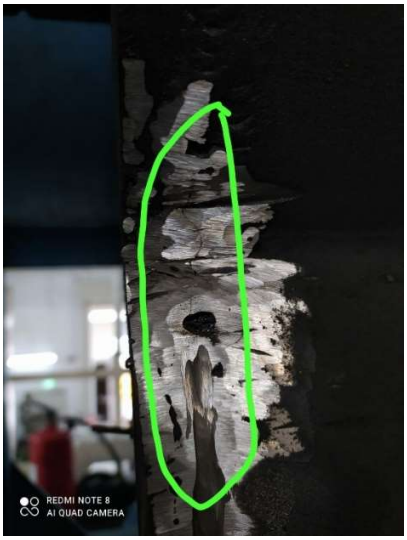


Figure 21: Grinding revealed a hairline crack on front left of machine, green circle inherent in picture

100. Nasim estimated that the front left had a hairline crack of about 50mm while the front right had a hairline crack of 20mm. Both cracks seemed to have propagated from the seams, i.e. the original connection between the 2 plates that made up the shell of the mixer machine.

101. Assisted by Marimuthu, Nasim welded four layers of welding at each of the four corners of the mixer machine on 15 February 2021. On Chua's instruction, the driver Ramachandran delivered a 120cm x 120cm carbon steel plate to the worksite. Nasim cut out a 90cm x 100cm piece from the carbon steel plate and welded the extra base plate to the mixer machine with two layers of welding. The leftover carbon steel was used to make two smaller plates for reinforcing the front lower corners of the jacket where the leaks were seen. Each of the two smaller plates were approximately 16.4cm x 13.2cm[5], and were added after the additional base plate was welded to the bottom of the oil jacket. Nasim then folded up the base plate by 10mm, overlapping slightly onto the two smaller pieces. The front-facing portion of the smaller pieces were about 10cm in length, with the remaining 6.4cm on the other side. The welding was completed on 16 February 2021 at about 1900hrs. According to Nasim, Marimuthu did a visual inspection that evening and had no comments.

102. On 17 February 2021, Chua visited the worksite and checked and did a run through with the mixer machine to make a batch of fire clay. This was the first time that Chua was back at the worksite since the fire on 12 February 2021. Oil was poured into the oil jacket to check for leaks. Chua found the welding acceptable and intended to resume operations. A new set of ceramic fibre insulation was installed on the machine without any aluminium sheet or tape. Chua ran through the fire wrap operations with his workers and said that he would purchase fire blankets. He also advised

[5] With reference to the measurements made post-accident, in Matcor's report.

Marimuthu to don fire-retardant clothing.

CHAPTER 5 THE EXPLOSION

Brief Description of Accident

103. On 24 February 2021, at about 0830hrs, eight workers from Stars Engrg started their workday to manufacture fire wraps. One of the work processes included using the mixer machine to mix potato starch powder and other ingredients with heated water to produce the fire clay. At about 1122hrs, an explosion occurred. All eight workers from Stars Engrg suffered burn injuries and were conveyed to the Burns Centre of the Singapore General Hospital. Two workers of another company, P3 Project, who were working at the unit located opposite Stars Engrg also sustained injuries. Both were conveyed by their employer to Ng Teng Fong General Hospital.

104. The fire was extinguished at 1146hrs on the same day.

Detailed Events

105. On 24 February 2021 at around 0839hrs, a glowing flange and a small flame was observed at heater #2. *Figure 22* below shows a picture of the incident sent by another worker, Anis, to the Shield+Daily WhatsApp chat group at 0839hrs the same day. At about 0921hrs, Moe forwarded to Chua all the photographs that Marimuthu had sent to Moe that morning and Marimuthu's earlier WhatsApp messages. After not receiving any reply from Moe, Marimuthu then forwarded this picture to Chua at 1012hrs on the same day.

Figure 22: Photo of the glowing flange taken by Anis and sent at 0839hrs on 24 February 2021.

106. Marimuthu shouted "Mehedi, fire". While putting out the fire with an extinguisher, Mehedi noticed that the isolator had been turned off; i.e. no power supply to the mixer machine.

107. At 0840hrs, Marimuthu sent Moe through WhatsApp three close-up photos of the heater, showing that it was damaged. Moe queried if the mixer machine could be turned on, to which Marimuthu replied in the affirmative, but that he would change the heater first. At 0856hrs, Marimuthu told Moe in their WhatsApp chat that he had taken a new heating rod and would change it with Shohel. He went on to tell Moe via WhatsApp chat at 0858hrs that "*now oil heat after 10 o clock can change*". Marimuthu then messaged Chua at 0909hrs asking whether Chua could speak over the phone. Chua did not respond. A short while later at 0921hrs, Moe forwarded to Chua all the photographs that Marimuthu had sent to Moe that morning. Moe followed up with the following three messages to Chua: "*I thinl we should go tuas*", "*Heater now muthu changing*", and "*Wire joint may be fire*". Chua did not reply to these messages.

Figure 23: One of the cables on heater #2 had snapped, likely due to the earlier fire

108. Chua gave Marimuthu a missed call at 0958 hrs. At 0959hrs, Marimuthu returned the call and told Chua that there was a fire and one of the heaters was faulty. Between 1006hrs and 1012hrs, Marimuthu sent the following pictures to Chua, including the earlier picture taken by Anis of the glowing flange on heater #2 in *Figure 22*.

Figure 24: Pictures sent by Marimuthu to Chua between 1006hrs and 1012hrs

109. Marimuthu and Chua spoke again at 1010hrs. According to Chua, on this call, he had asked Marimuthu whether Marimuthu knew how to change the heater. Marimuthu replied in the negative. Marimuthu texted Moe contemporaneously at 1010hrs on WhatsApp that Marimuthu was "now online" with Chua and "boss [i.e. Chua] say heater change". According to Chua, the steps conveyed to Marimithu were to stop the machine, drain the oil from jacket, unscrew heater from its flange, and wait for Chua to arrive at the worksite. Chua estimated that it would take an hour to drain the oil, which would give him enough time to get to the worksite. He claimed that he did not know at the time that the workers had already retrieved a replacement heater from the level two store, even though at 0922hrs Moe had sent a message to Chua over WhatsApp saying, "heater now Muthu changing". The accident occurred before Chua managed to reach the worksite.

110. Marimuthu and Shohel were last seen on the platform squatting at the heater area just before the explosion occurred. As the others were looking up from the ground floor, they were not able to see clearly what Marimuthu and Shohel were doing with the heaters. About half an hour before the explosion, Mehedi heard the mixer machine's motor running, indicating that it was in the process of mixing and a few seconds later it stopped. Jitu heard the sound of the mixer machine operating at about 1100hrs, whereas Lizon and Yousuf both heard the mixer machine running before the explosion.

111. At 1110hrs, Moe sent Marimuthu a message asking "*How Muthu? Heater ok?*", which Moe admitted meant that he wanted an update from Marimuthu on the status of the damaged heater. In response, Marimuthu sent Moe the following photograph showing the heaters on the mixer machine at 1113hrs. Moe then replied to Marimuthu at 1132hrs saying "*Ok let me know ASAP*". Post-accident, Moe deleted, from his and Marimuthu's mobile phones, the photograph received from Marimuthu at 1113hrs as well as his message to Marimuthu at 1132hrs. The damaged heater #2 with green taped wiring was found still in the oil jacket after the accident.

Figure 25: Photograph taken by Marimuthu on 24 February 2021 at 1113hrs showing that the wiring of the damaged heater #2 had been taped together with green tape

112. Two other workers, Rahad and Yousuf, were at the packing machine about to set aside a packed fire wrap product for delivery. Anis was at one of the roller machines further away from the platform while another worker, Lizon, was under the platform picking up some fire clay pieces. Another two workers, Jitu and Mehedi, were at the other assembly table when the explosion occurred at 1122hrs. Jitu felt hot oil splashing onto his face and the top part of his chest, and heard some oil splashing on the wall behind him. He felt oil that was splashed on the wall also landed on his back. In a split second, he saw that flames had filled the workplace. He jumped over the table and escaped via the front shutters. The Stars Engrg workers ran out of the worksite to the open field at the back of the industrial estate and other workers from neighbouring units helped to spray water on the injured workers using a hose. Two workers from P3 Project who were working in the area outside and opposite Stars Engrg's worksite also felt the effects of the explosion.

113. At about 1123hrs, SCDF received multiple calls from members of public and the Police Operations Command Centre informing of the explosion and fire. The SCDF first responders arrived at about 1130hrs and the fire was extinguished at about 1146hrs.

Aftermath of Explosion

General Damages

114. The worksite sustained severe damages as shown in *Figures 26 to 28* below.

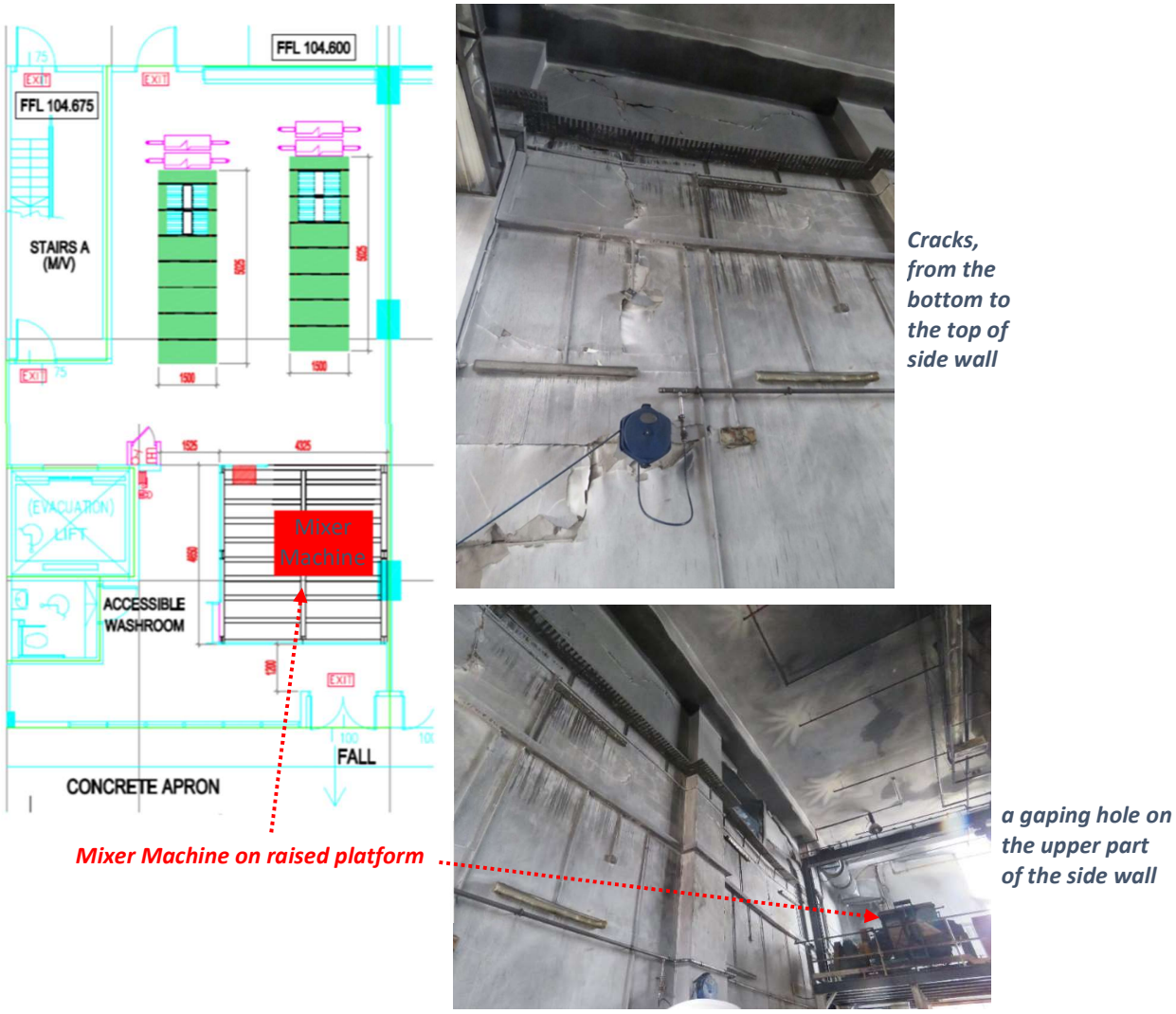
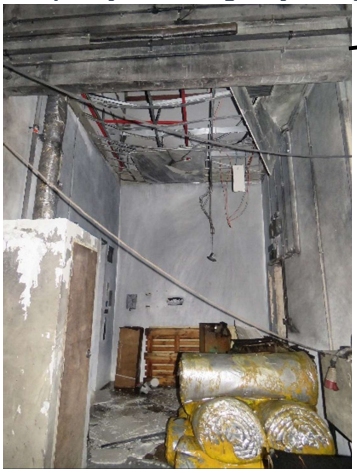
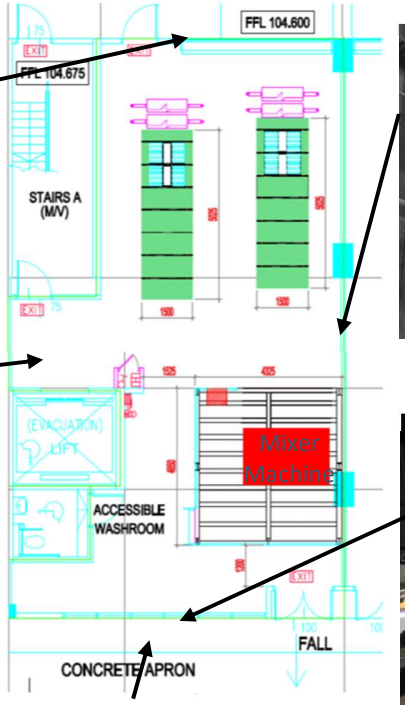


Figure 26: Side wall damage, at front and rear of the worksite

damaged front shutters

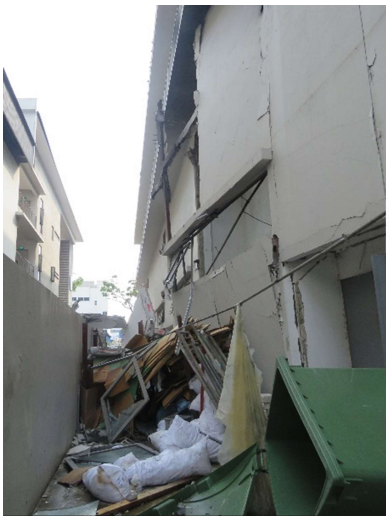
collapsed false ceiling in lift lobby





hole blasted out on side wall

rear wall blasted outwards



debris outside rear wall

Figure 27: General damage within the worksite

Figure 28: Damaged front shutters of the worksite

Damage to Back Wall of Worksite

115. The back wall had partially collapsed, and debris was scattered around the back alley of the premises. The back wall also showed two different shades – the upper part had a blackish hue while the lower part largely retained its original colour.

Figure 29: *Photos showing dual tones on the rear back wall of the worksite*

Damage to Side Walls of Worksite

116. Light fixtures near the platform appeared more damaged compared to the ones near the front shutters. The two lights at the upper part of the side wall beside the platform (*Figure 30*, encircled in red) were more damaged than the one at the lower part of the side wall.

117. Splatter marks were observed on the side wall in the vicinity of the platform (*Figure 30*, dotted triangle in red). Based on the pattern of the splatter marks, the source appeared to be from the platform.

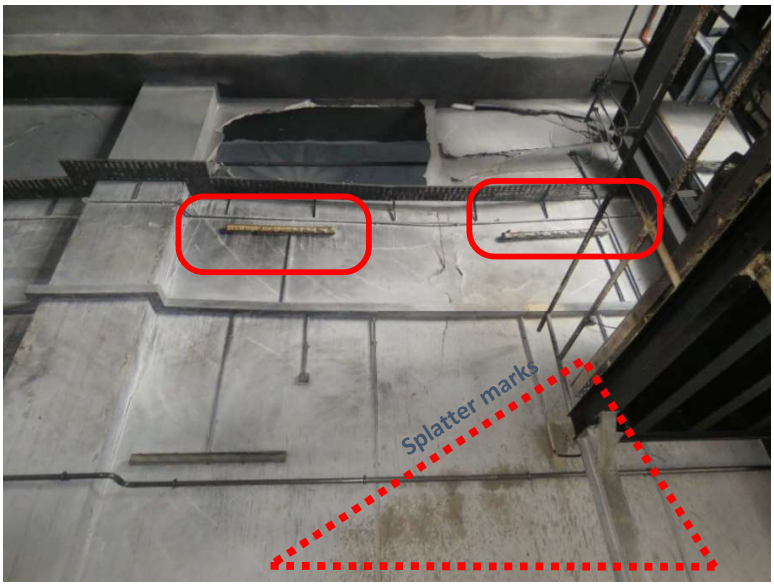


Figure 30: Photo showing the damaged light fixtures and splatter marks from platform

118. Splatter marks, as dotted in red in *Figure 31*, were also observed on the opposite side wall.

Figure 31: Photo showing splatter marks on the opposite side wall from platform

119. A portion of the wall adjoining the next unit was also blown outwards, with the debris found in the adjacent unit occupied by Alif-Engineering Pte Ltd ("Alif"). This side wall was closest to the platform

where the mixer machine was placed on.

Figure 32: Hole at the top of side wall

120. The damages observed suggested that the explosion initiated from the rear of the mixer machine, which was facing the front shutters.

External Damages to Worksite

121. Four louvre panels were dislodged from the exterior façade of the building directly above the worksite. One of the dislodged panels was found dangling from its frame, and one of the panels was found some distance away close to the grass patch.

Figure 33: Photos showing the dislodged louvre panels

122. P3 Project, which leased units opposite the worksite, had four out of its five rear windows shattered because of the accident. These windows were about 58m from the mixer machine. A picture of the shattered rear windows was obtained by MOM from P3 Project and is shown in *Figure 34*.

123. From the damages pieced together on the layout diagrams in *Figures 34 and 35* below, the accident was likely an explosion from the mixer machine that generated blast overpressures sufficient to shatter glass at 58m away, dislodged panels, and destroyed walls.

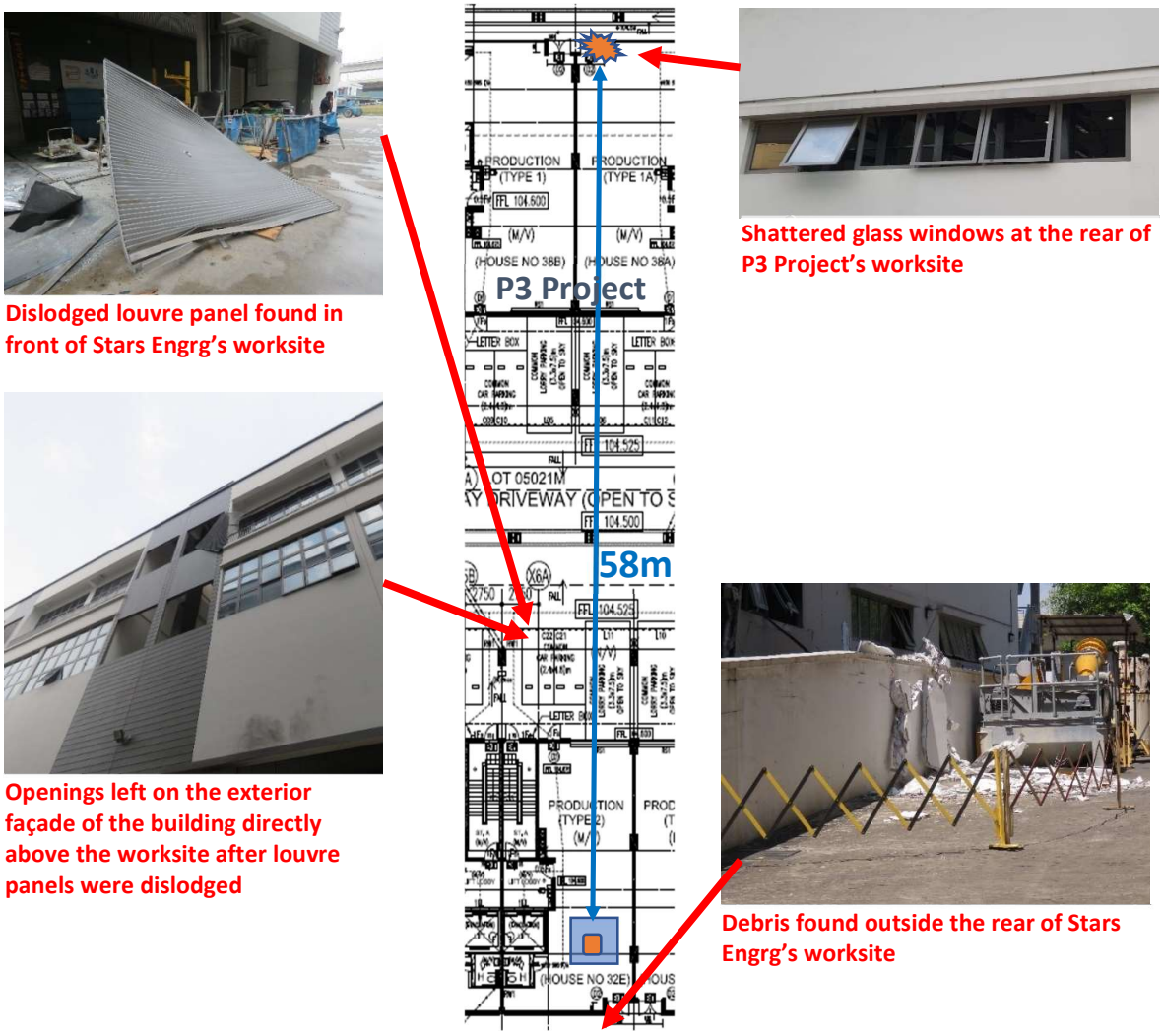


Figure 34: Damage overlaid on layout plan, from the Tuas Site to P3 Project's rear windows

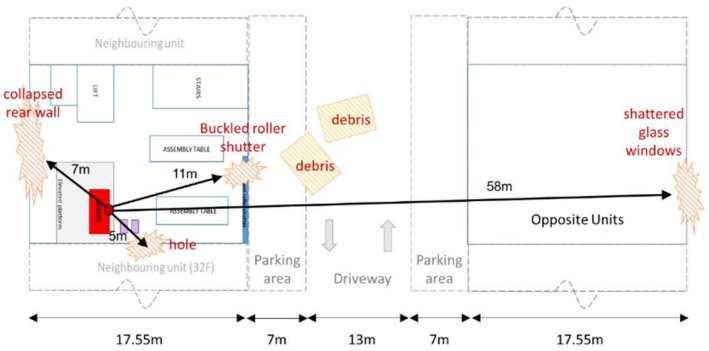


Figure 35: Schematic diagram with measured distances from the mixer machine

Mixer Machine

124. Some remains of the insulation that was originally placed around the oil jacket were found below the mixer machine. The control panel that was located close to the machine reeked a strong smell of remnant oil when opened. A replacement heater was found next to the mixer machine along with some tools (encircled in *Figure 36* below).

Figure 36: Heater found next to Mixer Machine, encircled in red

125. The oil jacket ruptured widest at the seam closest to where the replacement heater was placed. From the rupture's opening, the heating elements inside the jacket were observed to be bent and deformed as shown in *Figure 37*. The other end of the oil jacket had a darkened stain around the seam as shown in *Figure 38*. The stain was likely caused by leaked oil, so the seam at this end likely fractured as well, albeit to a smaller extent.

Figure 37: Deformed heating elements seen through the rupture on the oil jacket, rear of machine

Figure 38: Dark stain on oil jacket, circled in red

126. A cable from the control panel was found connected to a RTD which was placed inside the mixing chamber of the mixer machine (*Figure 39*). Remnants of the insulation on the mixer machine were found with some soot on the exterior. All three openings on the oil jacket were found closed post-accident. Both openings at the top of the jacket had end caps that rendered them sealed, while the drain valve was found in a closed position (*Figure 40*).

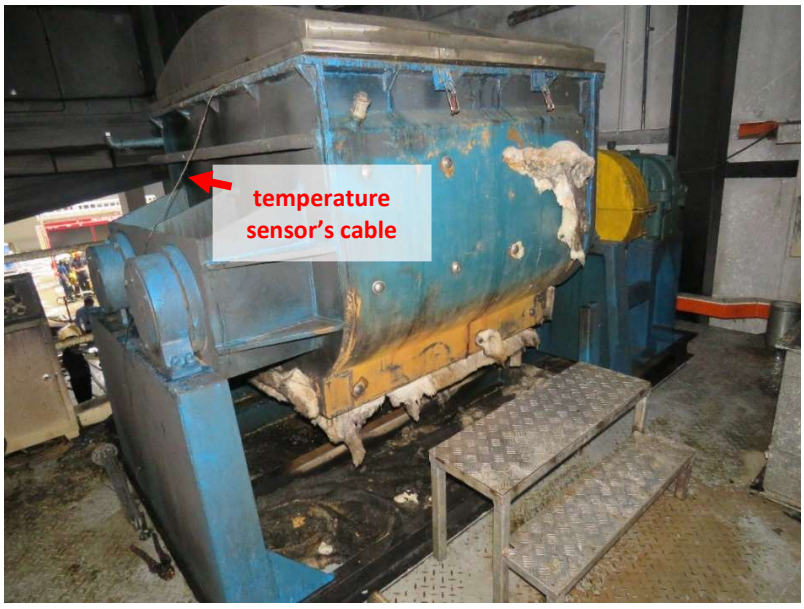


Figure 39: Temperature sensor in mixing chamber

Figure 40: All three openings on the oil jacket circled in red were found closed

127. A welding set was found on the platform as shown below in *Figure 41*, along with an Intermediate Bulk Container, some bags of powder, buckets, and tools.

Figure 41: Welding set on platform, encircled in red

128. Three buckets were found on the platform, one of which was covered (*Figure 42*, circled in red). The isolator located nearby which powered the mixer machine was found in the "ON" position (*Figure 42*, dotted circle in red).

129. Two spanners and a black slipper, likely belonging to one of the workers working on the platform at the time of the accident, were found close to the replacement heater. The spanners are circled in red in *Figure 43* below[6]. The three heater switches on the control panel were found in the "ON" position, boxed up in blue in *Figure 43* below.

[6] The two spanners appear to have been subsequently moved and placed on the mixer machine, as shown in Photograph 30 of Hawkins' report dated 15 September 2021 ("Hawkins' Report").

Figure 42: Covered bucket (circled in red) and mixer machine's isolator in the "ON" position (dotted circle in red)

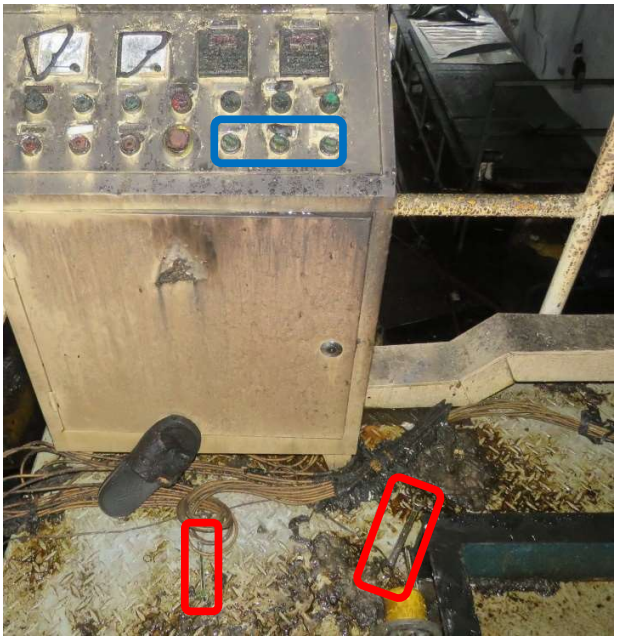


Figure 43: Spanners found close to the additional replacement heater (with yellow cap), encircled in red; heater switches on the control panel found in the "ON" position, encircled in blue

130. The mixer machine's mixing chamber was found upright (i.e. not tilted) with the lid closed, as shown in *Figure 44* below. The inside of the mixer machine's mixing chamber was observed to be filled with water at the bottom as shown in *Figure 45* below.

Figure 44: Upright mixing chamber with lid closed

Figure 45: Inside of the mixing chamber

131. Upon closer inspection, some green tape was found on the wires connected to the terminals of heater #2, as shown in *Figure 46*.

Figure 46: Green tape found on wires connected to two terminal connections of heater #2

Terms of Reference A - Causes and Circumstances Leading to the Explosion

132. The experts called by the State postulated that the explosion occurred across two steps:

a. First, the over-pressure in the oil jacket caused mechanical failure and fracture of the welds. This over-pressure was a result of over-heating of the oil and use of the oil jacket as a closed system.

b. Second, when the welds fractured from over-pressure within the oil jacket, liquid thermic oil was forced out and aerosolised into an oil mist / fine droplets. The aerosols were ignited, leading to the explosion. This eventually ignited the accumulated potato starch powder that was suspended in the air, resulting in the subsequent flash fires.

133. Stars Engrg's expert witness, Hawkins, put forth a different theory. It was suggested that the oil jacket's heaters were exposed following an oil leak. As the heaters continued heating, the exposed part of the heaters would glow red hot. Any of the exposed heaters would have ignited the oil mist in the oil jacket. This started a chemical explosion from within the oil jacket, which fractured the weld seams and led to blast overpressures damaging property outside the oil jacket. The subsequent flash fires were a result of the ignition of smoke plumes.

134. The IC deliberated the various hypotheses and theories put forward by the experts for the State and Stars Engrg. Based on eyewitnesses' accounts, post-explosion investigations, physical tests, numerical simulations, and the evidence presented during the hearings, the IC finds State Counsel's propositions to be a more plausible explanation for the explosion, which was rooted in the unsafe use of the mixer machine, as follows:

a. The temperature within the oil jacket was not monitored. One of the temperature sensors that came with the mixer machine to specifically measure and regulate the temperature within the oil jacket was used interchangeably with the other temperature sensor to measure only the temperature within the mixing chamber.

b. Insufficient thermic oil used in the mixer machine's oil jacket caused inefficient heat transfer and overheating of the thermic oil. The temperature of the thermic oil went beyond its safe operating temperature leading to thermal degradation, which significantly reduced its flash point.

c. The mixer machine was used as a closed system with the two vents sealed off, resulting in inevitable over-pressurisation of the oil jacket. Laboratory tests subsequently showed that the pressure within the oil jacket could hit about 50 times the safe working pressure of two bars when temperatures within the oil jacket was about 450^{o}C.

d. The repeated heating and cooling cycle with each operation of the mixer machine also stressed the oil jacket's integrity, resulting in the oil jacket eventually losing its mechanical strength. This was exacerbated by the weakening of the weld seams due to poor quality repair welds done by Stars Engrg's worker. As a result, the oil jacket ruptured outwards at the weak points, fracturing at the weld seams.

Non-utilisation of Resistance Temperature Detector ("RTD") to measure Oil Jacket Temperature

135. There were two RTDs linked to the control panel labelled respectively as "Material Temperature" and "Jacket Temperature". Specific screw-on fixtures for these RTDs were also provided on the mixer machine. From Matcor' review of the electrical circuity within the control panel, only the oil jacket temperature sensor had a safety interlock which would automatically cut off electricity supply to the heaters when the temperature was detected to be at or higher than a set temperature. This temperature setting for activation of the safety interlock could be adjusted using the up and down arrows on the control panel of the mixer machine.

136. Stars Engrg however, used both RTDs interchangeably to measure only the temperature within the mixing chamber and did not affix the RTDs on the designated fixtures. They instead placed either one of the RTDs directly inside the mixing chamber as they claimed that it was more accurate to directly monitor the desired water temperature of 80°C to 90°C.

137. This implied that there was no monitoring of oil temperature while the heaters were turned on, and the safety interlock, which would automatically turn off the heaters when the pre-set jacket

temperature was reached, was not able to function as it should. Monitoring the oil temperature would provide information about whether the oil and the oil jacket were operating within their respective operating temperatures, so that the heaters could be turned off when overheating was detected. This would ensure that the mixer machine and the thermic oil were used within their respective operating temperatures, and avoid conditions that could thermally degrade the oil, or affect the strength and integrity of the heaters and the jacket.

Insufficient Oil in Jacket leading to Overheating

138. A total of ten buckets of thermic oil, equivalent to 200 litres, was purchased by Stars Engrg for use in the oil jacket during the lifetime of the mixer machine. On 27 May 2021 post-accident as part of investigations, two unused buckets of thermic oil were found in the worksite in the vicinity of the platform's access ladder. Less these two buckets (or 40 litres) of oil, the maximum possible amount of oil that could have been added to the jacket in the mixer machine's lifetime was 160 litres. However, the actual maximum quantity of thermic oil in the oil jacket at any one point in time is very likely to have been much lower than 160 litres, as some would have been boiled off or undergone thermal decomposition.

139. From Matcor's 3D renderings in *Figures 47 and 48* below, a 160-litre oil level would only be just enough to immerse the heating coils, but would not be in contact with the lowest internal surface of the mixing chamber, compared to a much higher oil level if the jacket was filled with 240 litres of thermic oil.

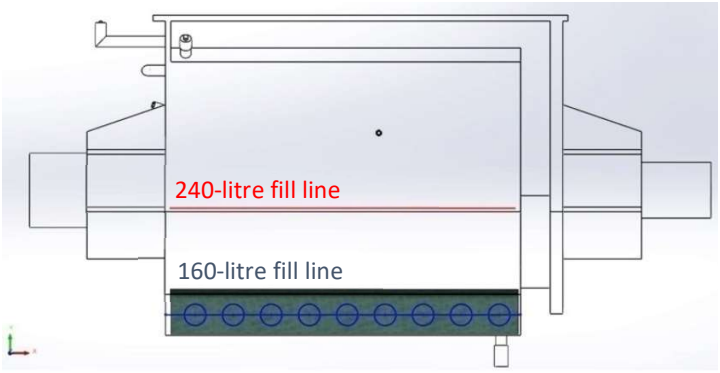


Figure 47: Matcor's 3D rendering showing the fill level corresponding to 160/240 litres in the oil jacket

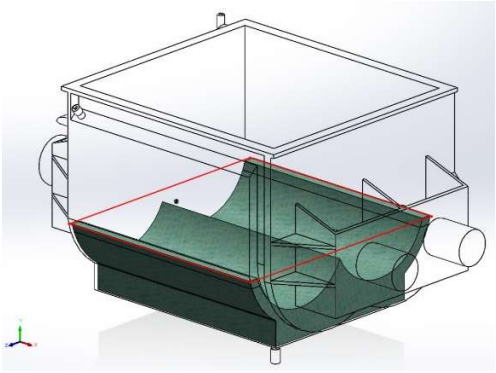


Figure 48: Fill level corresponding to 240 litres in the oil jacket

140. *Figure 49* below shows the fill levels for 245, 160 and 40 litres of oil in the oil jacket.

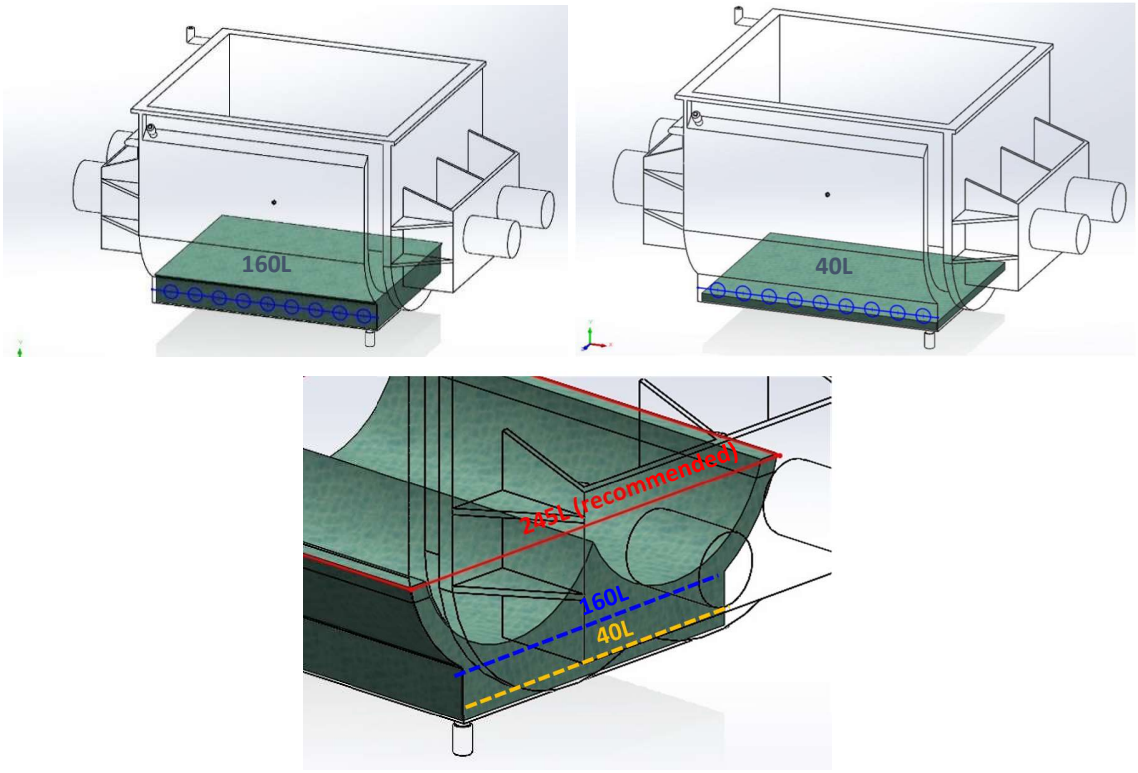


Figure 49: Fill levels corresponding to 40 litres, 160 litres and 245 litres in the oil jacket

141. When Stars Engrg started operating the mixer machine with thermic oil, only two buckets, or 40 litres, of oil were added to the oil jacket. As shown in *Figure 49* above, the heaters were not immersed in the thermic oil and there was a gap between the top of the 40 litres oil level (yellow dotted line) and the lowest point of the mixing chamber. The heaters were immersion type heaters which were meant to be completely immersed in the service medium. This gap created a layer of air insulation between the oil and the mixing chamber, causing inefficient heat transfers between the heated oil in the oil jacket and the water in the mixing chamber. Hence, more heat would need to be supplied by the heaters to the oil, to overcome the air insulation and attain the desired water temperature of 80°C to 90°C in the mixing chamber.

142. As the oil jacket temperature was not monitored and the oil jacket RTD was not properly used for the intended safety interlock to take place, the heaters would continue to provide heat to the oil and the temperatures of the oil would continue to rise until the heaters or the mixer machine were switched off. Over time, the electrical wiring and connections in the heaters hence suffered increased wear and tear.

143. A spark at the heater was seen by workers operating the mixer machine on 8 August 2020, which was no more than 2 months from the date the mixer machine was first installed at the worksite, despite infrequent use of the mixer machine. This implied that the air insulation had created poor

heat transfers from an early stage, causing the heaters to overcompensate to reach the desired water temperature in the mixing chamber. Heater #1 was subsequently replaced.

144. In fact, there was less than 40 litres of oil in the oil jacket at the time, as only about one and a half buckets of oil (about 30 litres) were drained on 8 August 2020. This suggests that a significant amount of the oil had already boiled off or undergone thermal decomposition in those 2 months, further demonstrating that overheating had taken place.

145. Chua was unable to explain why he chose to purchase only 40 litres of thermic oil, despite knowing that at least six buckets of water (20 litres each) had been used in the oil jacket during the commissioning on 12 June 2020. Chua also admitted during the hearings that a simple back-of-the-envelope calculation would have shown that at least 152 litres of oil would have been required to fill even just the vertical section of the oil jacket's base.

146. Typically, heat transfer fluids like the thermic oil are stable over a range of temperatures. Within the operating temperature range, heat transfer fluids remain stable and do not undergo transformation into other substances. However, when subjected to temperatures higher than their operating range, heat transfer fluids would undergo thermal degradation (as hydrocarbons[7] do) and be broken down into smaller molecules.

147. The thermic oil drained on 8 August 2020, 28 August 2020, and 1 October 2020 was observed to be darker in colour compared to fresh thermic oil, which was more translucent and lighter coloured. This implied that the thermic oil was subjected to temperatures beyond its recommended operating range and had undergone thermal degradation. This finding was supported by the decreased flash point of the darkened oil, taken as a post-accident sample by SCDF and tested by the Health Sciences Authority. The darkened oil had a reduced flash point of 135±4°C, compared to the published 220°C flash point in the thermic oil's Safety Data Sheet.

148. One of the spoilt heaters examined by Matcor showed melted carbon steel sheath, as shown in *Figure 50* below. This heater was retrieved by MOM post-accident during its investigation on 27 May 2021, and was likely heater #1 that was replaced on 8 August 2020 (see *Figure 51*). For the carbon steel sheath to have melted, the temperature was likely to have been at the melting point

[7] The Daphne Thermic Oil 32 Safety Data Sheet indicated that the components were a majority of "distillates (petroleum), hydrotreated heavy paraffinic" and "distillates (petroleum), solvent-refined heavy paraffinic". Both majority components are hydrocarbons.

of around 1400°C, indicating that excessive heating had already occurred by 8 August 2020.

Figure 50: Photo showing replaced heater #1 (taken from Chua's phone pre-explosion)

Figure 51: Post-explosion view of spoilt heater, likely to be heater #1, that was replaced on 8 August 2020

149. From A*STAR's Finite Element Analysis (FEA) modelling, under moderate conditions where the mixing chamber is filled with pasty, clay-like material without agitation, the simulated temperatures for the thermic oil in the oil jacket and the inner surface of the mixing cylinder was 427°C to 714°C, above temperatures where thermal degradation sets in for both the used and fresh thermic oil. The dark residual matter that settled at the bottom of the drained oil at various occasions was most likely a by-product of decomposition of oil to the combination of lighter and heavier components from the original substances. This simulated temperature range of 427°C to 714°C was also consistent with the effect of poor heat transfer, due to the air insulation layer within the oil jacket.

150. FEA modelling with a 45kW heat source (*Figure 52*, extracted from A*STAR's report) showed that the temperature of the oil jacket reached around 700°C to 1800°C when the effective thermal conductivity between the heat transfer fluid and the mixer contents was low. This was the operating condition of the mixer machine due to the large air insulation layer that existed within the jacket based on the low amounts of thermic oil used by Stars Engrg.

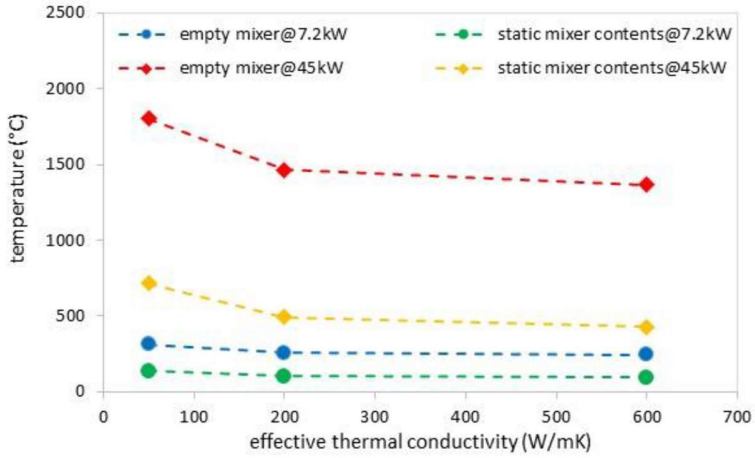


Figure 52: FEA modelling showing how low thermal conductivity of the heat transfer fluid affected jacket temperatures

151. From Matcor's metallurgical structure examinations, the heater's metal sheath was made of carbon steel. A loss of toughness in carbon steel can occur when subjected to temperatures above 427°C[8]. This form of metallurgical damage will have significant impact on the structural integrity, with possible localised corrosion or groove-like flaws. Matcor's metallurgical examinations of the heating coils showed that the heaters were subjected to temperatures of 830°C to 1100°C over time, from the increase in grain size.

152. Stars Engrg contended that the low level of oil in the oil jacket could not have caused the accident because the explosion had not occurred earlier despite the multiple occasions it had used low levels of oil. In its closing submissions, it stated:

> *"… Stars Engrg had always operated the mixer machine with low levels of oil, and in some cases, as little as 40 litres of oil. Yet, up until February 2021, the operation of the mixer machine with low levels of oil neither caused a fire nor an explosion."*

153. Stars Engrg's position is untenable as the low levels of oil used over the course of the mixer machine's lifespan had indeed led to several red flags and near misses as highlighted in the earlier sections of this report. The repeated unsafe operation of the mixer machine despite these warning signs had resulted in the gradual degradation of the oil jacket's integrity and strength, leading to its catastrophic failure on 24 February 2021. Stars Engrg's proposition that the low levels of oil

[8] API 579-1/ASME FFS-1 2016 Fitness-For-Service, extracted from "2B.4.6 Metallurgical Changes".

could not have caused the accident is indefensible in light of the multiple demonstrated red flags of the mixer machine prior to the eventual explosion.

154. In summary, the IC finds that the thermic oil was subjected to high temperatures beyond its operating temperature, leading to thermal degradation. This was evidenced by:

a. The darkened hue and sooty residue seen in the drained oil;
b. A reduction in flash point of the used oil, from a published 220°C to 135±4°C;
c. Melted sheath of the heater that was known to be replaced on 8 August 2020;
d. Simulated temperatures from FEA modelling that the thermic oil in the jacket and the inner surface of the mixing cylinder was 427°C to 714°C based on Dr Salim's conservative assumptions;
e. High temperatures of about 700°C to 1800°C for 45kW of heating power and low effectiveness of thermal conductivity; and
f. Increased metallurgical grain sizes of heaters, due to temperatures of 830°C to 1095°C over time.

Using the Mixer Machine as a Closed System

155. It is undisputed that the oil jacket of the mixer machine operated as a closed system at the material time. Stars Engrg contended that (i) the mixer machine was designed to operate as a closed system, (ii) the low level of oil in the oil jacket could not have caused the accident, and (iii) there is no proof that the welding repairs by its worker, Nasim, had contributed to the explosion.

156. Hawkins' expert Dr. Rose opined that the operation of the oil jacket as a closed system made no difference to the outcome of the explosion. Stars Engrg also claimed that the machine was designed to be operated as a closed system because it indicated an operating pressure of ≤0.2 MPa (2 bar). The IC disagrees with these contentions as they stood in stark contrast with the views of all the other experts presented by the State. Matcor's expert Mr. Shandro had testified that the closed vents, as elaborated in the section "Key Events and Warning Signs leading up to Explosion" of this report, had resulted in the accumulation of pressure. Scientific analysis by Dr. Salim suggested that, when the mixer machine operated in the condition that it did, with low oil levels in a closed system, the pressure within the oil jacket could significantly exceed that of the 2 bar limit of the oil jacket. Dr. Salim reiterated that the pressure build up would have been avoided if there had been an open vent (as per the design) and added that the vaporization process in an open system would also have lowered the temperature of the oil jacket. Prof. Chew was also unequivocal when he said that the mixer machine was not meant to be used as a closed system and that doing so was dangerous.

157. Stars Engrg did not submit any evidence to support its contention that the mixer machine was meant to operate in a closed system. Chua's assertion that the user guide's indication of a working pressure of ≤0.2 MPa suggested that the mixer machine could operate under pressure as a closed system was baseless as it merely indicated the upper limit of pressure that the oil jacket could withstand, and was not an instruction to operate the oil jacket as a closed system. Conversely, there was evidence that it was designed to be operated as an open system as the mixer machine only came with one end cap for the front pipe and the user guide states that there is "*an oil vapor vent … provided at the highest point behind the machine*". There was also neither any pressure release valve nor any pressure monitoring gauge which should be present if the machine was meant to be operated as a closed system. Stars Engrg did not take any steps to ensure that the pressure within the oil jacket could be monitored when the machine was operated.

High Pressures in Oil Jacket

158. Chua had instructed Stars Engrg's workers to seal off all openings on the oil jacket since 8 August 2020, which effectively meant the oil jacket was operated as a pressure vessel. As the temperature of the oil increased, the liquid oil would start to boil with hydrocarbon vapours entering the headspace[9] and raising the pressure within the oil jacket.

159. From the pressure-temperature runs on the thermic oil by A*STAR, the pressures generated started to shoot up exponentially, around 103 bar, once the oil temperature reached 450°C or more. This corroborated with the occurrence of the oil's thermal degradation, as more volatile vapours of lighter molecules were released into the headspace of the jacket as temperatures climbed.

Repeated Heating and Cooling Cycle

160. With each batch of fire clay, the oil was heated up and then cooled to ambient temperatures. The heating caused liquid expansion and increased vapour pressures, while the converse occurred during cooling. Over time, the repeated heating and cooling loop caused cyclic stress on the oil jacket and the oil jacket's mechanical strength gradually weakened. This was demonstrated in Matcor's fractographic examination of the weld fracture surfaces, which showed (i) equiaxed[10] dimples on the surfaces closer to the inside of the jacket indicating that the welding was slowly being pushed apart by internal pressure in the jacket, and (ii) elongated dimples on the surfaces adjacent to the external side of the jacket indicating the final failure of the weakened weld when it catastrophically gave way. This meant that the mechanical rupture of the oil jacket had been built up over time and could have occurred at any time given the unsafe operation conditions it was under.

[9] The volume above the thermic oil within the jacket.

[10] Having approximately equal dimensions in all directions.

161. Post-accident analysis of the mixer machine showed that damage to the oil jacket was in an outward direction, with significant outward bulging on the bottom of the oil jacket as shown in Figure 53.

Figure 53: Bulging deformation, indicative of overpressure release from inside out

State of Heaters Just Prior to Explosion

162. There was no direct evidence whether the heaters were turned on or off just prior to the explosion at around 1122hrs. There were some signs that they were likely turned on: (i) the isolator switch was found in the "on" position, (ii) the Moulded Case Circuit Breaker ("MCCB") of the mixer machine's control panel was in the "on" position, (iii) the heater switches were found in the "on position", and (iv) three of the workers – Jitu, Lizon, and Yousuf – heard the machine in operation prior to the explosion. Mehedi said he heard the machine running about 30 minutes before the explosion. However, what remained unknown was whether, and, if so, when, the emergency stop button was depressed around the time of the explosion. If depressed, all power supply to the mixer machine would have been cut and the heaters would not have been operating. However, due to the heat of the explosion which had melted the button, SCDF's first responders were unable to conclude whether the emergency stop button was depressed at the time of explosion. Matcor's licensed electrical worker who examined the wiring about two months after the accident said the button was depressed but it was inconclusive whether it was depressed during the two intervening months or was already depressed at or immediately after the time of the accident.

163. State Counsel had submitted that the mechanical rupture of the oil jacket on 24 February 2021 could have occurred even if the heaters had been switched off from around 0840hrs, after the initial small fire in the same morning. This was because (i) welds had already been weakened, and (ii) pressure within the oil jacket could continue to be maintained or not ramp down drastically even if the heaters were turned off. On (ii), Dr. Salim had testified that decomposition reactions of the thermic oil could continue to occur as long as the temperature remained above 320°C thereby increasing pressure, and the high temperature could be sustained as the oil jacket was wrapped with insulation. There was also objective evidence of boiling sounds heard on 12 February 2021 about 1.5hours after the mixer machine was turned off.

164. Nonetheless, the IC is of the view that the heaters were more likely turned on, rather than off, at the point of the explosion. This was because of the evidence cited in paragraph 162 above, as well as the more likely cause of the explosion due to continued supply of heat and pressure build up within the oil jacket, contributing to the catastrophic explosion.

How the Explosion Occurred

165. Due to the closed vents and overheating of the thermic oil, pressures within the jacket increased and ebbed, causing cyclic stress and compromising the mechanical integrity of the oil jacket and eventually rupturing it. The sudden rupture released aerosols and hot liquid from an enclosed jacket almost instantaneously, creating a highly flammable mixture in the air when the released oil aerosols met a sudden increase of oxygen in atmospheric air.

166. There were several possible ignition sources in the vicinity of the mixer machine; including electrical switches, electrical boxes, electrical cables, hot surfaces on the mixer machine, hazardous-area unrated fans and lighting, thermic oil heated past its auto ignition temperature[11], and evidence of arcing on heater #2 from Matcor's examinations. Upon contact with any ignition source, the flammables-in-air mixture would combust and lead to a chemical explosion. Based on the overpressure calculations in A*STAR's report, the overpressures from a chemical explosion were consistent with the damages observed post-accident, including the shattered glass on P3 Project's windows 58 m from the mixer machine.

167. On the contrary, Stars Engrg submitted, based on Hawkin's theory, that the explosion was initiated by the combustion of oil vapours within the oil jacket, which was caused by exposed heaters glowing red hot as a result of oil leakage. The combustion led to a chemical explosion from within the oil jacket and fractured the weld seams, leading to blast overpressures damaging property outside the oil jacket.

168. Hawkins's hypothesis that the explosion was caused by the combustion of oil vapours fracturing the weld seams from within the oil jacket was unsubstantiated and highly improbable. This is because it would require (i) at least 40-80 litres of oil to be leaked from the oil jacket in the morning of the explosion in order to expose the heating coils as a source of ignition within the oil jacket, and (ii) sufficient oxygen within the oil jacket to support combustion that would result in the overpressures and damages observed in the aftermath of the explosion. On (i), there was no evidence of oil leakage of the required amount that could cause the heating coils to be exposed.

[11] A temperature above which a flammable material is capable of extracting enough energy from the environment to self-ignite. AITs of hydrocarbons are typically in the region of 300-500°C.

On (ii), Dr. Salim's calculations had shown that there was insufficient oxygen in the oil jacket that would allow for an explosion/combustion of the magnitude seen in the accident. This was also confirmed by Major Huang qualitatively that oxygen would have been a limited factor for combustion to occur within the oil jacket under normal conditions where everything was sealed and intact. There were however no figures, calculations, or evidence submitted by Hawkins to substantiate its theory.

169. The IC therefore concludes that the explosion occurred more likely because the mixer machine was used in overheated conditions as a closed system. This had resulted in the accumulation of pressure within the oil jacket, leading to the mechanical rupture of the oil jacket. Oil vapours were expelled and ignited, which led to the primary explosion and the subsequent secondary flash fires.

170. The IC reached this conclusion following the evidence heard from the other expert witnesses which were consistent with the above. This was also corroborated with several objective pieces of evidence tendered during the hearings, including:

a. The deteriorated gaskets found on 28 August 2020;
b. Blackened oil drained from the oil jacket over several occasions;
c. Boiling sounds heard during operation of the mixer machine;
d. White smoke coming out of the oil jacket;
e. Visible cracks seen on the oil jacket on 28 September 2020, 12 October 2020, and 12 February 2021;
f. Matcor's findings of grain growth in the metal of the heaters which occurs over a long time at temperatures above 700°C; and
g. Matcor's fractographic examination showing signs of overpressure fatigue on the oil jacket's weld seams.

Other Disagreements with the Causes of the Accident

In-house welding

171. State Counsel submitted that Nasim's poor weld repairs, as evidenced in Matcor's report, had further compromised the strength of the original welds thereby contributing to the cause of the explosion. Stars Engrg contended that there was no proof that the welding repairs by its worker, Nasim, had contributed to the explosion. While the IC notes Mr. Shandro's findings regarding the poor quality of the repair welds, the catastrophic mechanical rupture of the oil jacket would have occurred regardless of the quality of the original weld or the subsequent weld repairs, due to the excessive overpressures in the oil jacket that was way above its designed operating pressure. With regard to the repair welds, its contribution to the explosion was not so much the quality of the

weld, but that it was an inappropriate response to the warning signs and red flags: the underlying cause, which was the unsafe operation of the mixer machine, was not addressed.

Workers stopping work on 24 February 2021

172. The IC is particularly concerned with Stars Engrg's conclusion in its closing submissions, which appeared to be an attempt to shift the blame focus away from Chua and Stars Engrg to its workers:

> *"What is indisputable and amply clear is that the Accident would have been avoided if the workers had followed Mr Chua's instructions to stop work and wait for him at the Workplace after the initial fire in the morning of 24 February 2021."*

173. The IC is unable to condone Chua's callous and cavalier attitude to press on with the work, on more than one occasion, to fulfil orders instead of calling a halt to the work process to examine the underlying cause of the problems with the use of the mixer machine, raised by the red flags. The red flags observed on the days and weeks leading to the accident on 24 February 2021 were clear signs of an accident waiting to happen. Even if the workers had indeed stopped work on the day of the explosion, this explosion could have occurred any time before or after 24 February 2021 as it was an accumulation of several events and failures to address red flags, as highlighted earlier in this report, that had caused the continued degradation of the mixer machine. The fact remains that several glaring red flags and concerns raised by the workers were either shrugged off or left unattended with improper ad-hoc "repairs" that did not address the underlying cause of the issues with the mixer machine.

Poor Control of Combustible Powders leading to Secondary Flash Fires

174. The initial rupture of the oil jacket from the unsafe use of the mixer machine had resulted in the primary catastrophic explosion. It was clear from experts' analyses that the primary explosion from the mixer machine caused the most significant damage and injuries. However, witness accounts and CCTV footage also revealed the presence of subsequent secondary smaller flash fires, which were most likely due to the combustion of the potato starch powders. This was corroborated by both Dr. Salim and SCDF's Major Huang, which were consistent with (i) the lack of proper practices for dealing with combustible dusts at the worksite, (ii) the detection of potato starch (a known combustible dust) in the samples analysed by ICES, A*STAR, and (iii) the flash fires observed in the CCTV footages from the neighbouring unit.

175. Stars Engrg used potato starch powders as a raw material to produce the fire clay used in the fire wrap. As part of the production of the fire clay, the workers poured bags of the potato starch into the mixing chamber. As there was neither local exhaust ventilation system to capture residual powders nor adequate housekeeping to keep the workplace dust-free, the combustible potato

starch powder could disperse and accumulate within the worksite, such as on ducting, beams, and floor. A fan mounted on the rear wall just behind the mixer machine further facilitated the dispersion of the powders. Workers testified during the hearing that the working areas at the workshop were generally dusty with powders on the floor. Residual powder samples collected from various locations within the worksite were also found to contain the potato starch.

176. Combustible dust explosions can occur if the following 5 elements are present: (i) fuel (combustible dust), (ii) air, (iii) dispersion, (iv) confinement, and (v) ignition source. Without (iv) confinement, combustible dust flash fires can also occur. The dispersed dusts must be at or above the minimum explosive concentration (MEC)[12] as well as in contact with an ignition source, to trigger a dust flash fires. Based on CCTV footages from a neighbouring unit, there were at least 3 secondary flash fires following the initial chemical explosion, at 1123hrs, 1124hrs, and 1125hrs.

177. When the mixer machine ruptured and the subsequent explosion occurred, the resultant overpressure lifted and suspended the combustible potato starch powders into the environment and was subsequently ignited, causing multiple subsequent combustible dust flash fires. This was evidenced by the flashes observed from the neighbouring unit Alif's CCTV footages. Although the first two flashes were captured only by Camera 8 and not Camera 7, and the third flash was captured only by Camera 7 and not Camera 8, Major Huang explained that this was possible as the captures depended on where the right fuel/air mixture was located and ignited vis-à-vis the location and line of sight of the relevant camera, as well as whether there were any visual obstructions such as thick smoke. It was hence possible that the flash fires captured on Cameras 7 and 8 were the result of potato starch travelling from the worksite into Alif's unit and igniting at different locations close to Camera 7 or Camera 8; and it was equally possible that there were other flash fires inside the worksite that were not captured by either cameras.

178. Stars Engrg submitted that the secondary flash fires which were observed were due to the burning of dense smoke plumes and were not due to combustible dusts. Hawkins's theory on the "auto-ignition" of smoke plumes was unsubstantiated by material facts and there was no information given on the composition, amount, and duration of materials in the smoke plumes to validate this theory. The IC also noted SCDF's Major Huang Weikang's testimony that he had never seen smoke from a fire separately combusting in his years of experience in the SCDF, and his view that it would be harder for smoke plumes to re-ignite as smoke would usually disperse from the affected premises.

[12] The smallest concentration below which a combustible dust explosion would not occur. Based on literature, the MEC of potato starch powder is 60g/m^3.

Other Gaps

179. Through the findings and evidence given by witnesses, other gaps were identified that have contributed to the accident or worsened the injuries sustained by the workers affected by the explosion. Though not exhaustive, some of the more glaring gaps are discussed in the following sections.

180. It is noteworthy to highlight the several red flag events that served as warnings of an impending failure early into the operation of the mixer machine. The insidious warning signs were not adequately understood and dealt with, which could have prevented the accident. Some gaps observed which contributed to or worsened the impact of the accident are:

a. Lack of competent personnel to commission and operate the mixer machine, identify the problems with it, and to understand and remedy the issues appropriately;

b. Inadequate risk assessment for the operation of the mixer machine. This includes not learning the right lessons from, nor adequately addressing, the numerous warning signs and incidents, many of which were clear indications that there was something wrong with the mixer machine or how it was being used;

c. Lack of a comprehensive emergency response plan which should indicate the escape route and response procedures in case of an incident such as a fire; and

d. Not providing or ensuring the donning of suitable personal protective equipment such as fire-retardant clothing.

181. Some of these factors as well as other additional contributory factors are elaborated in the remaining portion of this chapter and elsewhere in the report.

Competency Gaps

182. The workers testified during the hearings that they were not given any specific safety training or briefings for their work relating to the production of fire wrap at the worksite. While they underwent monthly general safety briefings for all Stars Engrg's workers, these safety briefings covered safety measures to be adopted at clients' project sites (i.e. construction sites) rather than specific safety concerns at the fire wrap production worksite.

183. During the IC hearings, Chua testified that "*specific matters relating to operations at the Tuas Site would be covered by Moe, Imam, Marimuthu or me when training".* Chua's testimony of what he considers as adequate training is reproduced below:

> "*When workers joined the Tuas Site, rather than having them attend fixed monthly briefings, we would do a run through of the relevant processes with them. I expected the workers to ask if they had any questions during the run through…….*
>
> *I would also require the workers to show me how they operated the machinery at least once, to ensure that they had internalised what was taught.*
>
> *We may have done a few run throughs with the workers, and asked them if they had any questions. There were no specific times when these trainings took place."*

184. There was inadequate instruction and training for the workers in charge of other aspects of the production process. Moe claimed that he had trained the workers personally when they first started work at the worksite, and had referred to the RA and SWP documents when doing so. This was not supported by the evidence of the Stars Engrg's workers, who informed that they were shown what to do by the other workers already working at the worksite. There was also no safety supervisor appointed at the worksite.

185. In respect of the maintenance of the mixer machine, Chua testified that he did this himself by referring to the user manual.

> "*I personally carried out the maintenance of the Mixer Machine monthly, using a maintenance checklist which I prepared based on the User Guide for the Mixer Machine."*

186. Based on the findings shared above on the red flags and operational issues leading to the accident, Chua clearly showed a lack of understanding on how to operate or maintain the machine so that it could be safely used. That was a major contribution to the continued unsafe use of the machine, exacerbated by the workers' apparent fear of approaching him or seeking guidance or clarifications.

Inadequate Risk Assessment and Incident Investigation

187. Despite the various operational issues and red flag incidents while using the mixer machine, there was no stoppage of work to critically examine and uncover the root cause of the problems. There were two leaks or losses of containment, i.e. smoke emanating from the oil jacket on 28 September and 12 October 2020. On 12 February 2021, there was also a fire from loss of containment.

However, no detailed investigations into the underlying cause of these incidents or near misses were carried out, to prevent similar recurrences in the future.

188. Even Chua's regular maintenance checklists appeared to have been completed in a slipshod manner, as evidenced, for example, by his omission to indicate certain issues with the mixer machine that he was aware of and the indication of a wrong date (cf. paragraph 83 above).

189. The various events of aerosolised thermic oil (smoke emitting from mixer machine) or its thermal degradation products (dark and sooty drained thermic oil) were also warning signs, as well as the glowing flange on the morning of the accident. Again, there were no active steps taken to understand the underlying cause and seek professional help or to replace the machine with a safer alternative.

190. These events were near misses and opportunities for intervention. However, they were not thoroughly investigated because the occurrences were not adequately understood, and no further risk assessments were conducted. Had the red flags been properly addressed, the unfortunate explosion could have been avoided.

Emergency Escape Route

191. Jitu was working at one of the assembly tables which was near an emergency exit just before the explosion. However, access to the emergency exit was obstructed with a drilling machine, aluminium rolls, and a gas cylinder etc, as depicted in *Figures 54 and 55* below. Jitu thus had to jump over the table to escape.

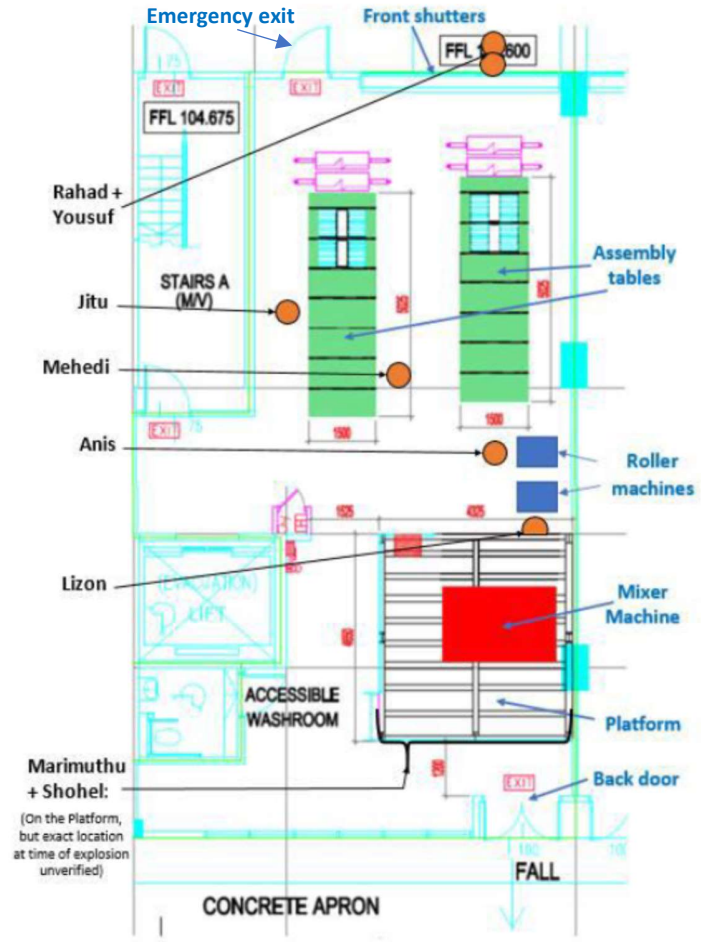


Figure 54: Layout showing where the workers were positioned before the accident

Figure 55: The assembly table that Jitu worked at, with obstructions at the emergency exit

192. Fires and explosions can result in advancing flame fronts and high levels of thermal radiation within a short period of time. It is imperative that the shortest possible emergency escape routes are provided to minimise the exposure times which in turn would lead to less severe burns.

Personal Protective Equipment

193. Although lowest in the hierarchy of risk control measures, personal protective equipment is still a useful last resort to minimise injuries to workers in the event of accidents. The workers testified that they were not given specific instructions for personal protective equipment to be worn at the worksite. While Imam, Anis, Shohel, Mehedi, and Marimuthu were issued respirators for their work, the additional workers who joined the team in February 2021 were not given respirators and wore cloth face masks instead. Although Chua had apparently instructed and reminded the workers to wear their safety shoes when making fire wrap, many of the workers wore slippers. None of the workers wore fire retardant clothing ("FRC") during work.

194. All three deceased workers suffered about 90% full thickness burns. As Marimuthu and Shohel were last seen on the platform and Lizon witnessed Anis being splashed by oil, it was likely that the hot thermic oil landed on much of their bodies. The subsequent chemical explosion of the aerosolised oil further caused severe thermal and fatal injury due to the oil already present on their bodies.

195. From accounts of the five injured Stars Engrg workers, they were thrown off their feet due to the force of the explosion. Jitu recalled being splashed by hot oil just before the explosion occurred. P3 Project's injured workers also stated a flame front coming towards them while they were in the yard near the driveway. Zhao Jian Wang ("Zhao") saw the flame front first, followed by Stars Engrg's workers escaping from the Tuas Site.

196. All ten victims suffered burns from the thermic oil. Although we recognise that FRC, as a personal protective equipment, should not be the first means of protection of workers, and that FRC might not have reduced burn injuries due specifically to the hot oil, it might have lessened injuries caused by the flame front and should have been provided to workers who are working with flammable substances. As Zhao was wearing an FRC jacket and pants but had taken the FRC top off before the accident, his face, neck and arms were burnt but the bottom half of his body was spared.

CHAPTER 6 RELEVANT REGULATORY REGIMES AND DUTY-HOLDERS

General Workplace Safety and Health Regimes

197. The central focus of WSH is to assess and manage occupational risks through the application of preventive and protective measures. Following a series of serious workplace incidents in Singapore, including the collapse of Nicoll Highway in 2004, the Government undertook a fundamental reform of its occupational safety and health framework to improve workplace safety and health standards. The WSHA, which replaced the Factories Act (Cap 104, 1998 Rev Ed) in 2006, was enacted primarily to put in place a legislative framework to help achieve these objectives. Three cardinal principles were established under this new framework, *i.e.* reducing risks at source, engendering a greater industry ownership over workplace safety outcomes, and stipulating higher penalties for poor safety management. The legislative intent of the WSHA is amply clear from the speech of then-Minister for Manpower, Dr Ng Eng Hen, at the second reading of the Workplace Safety and Health Bill[13]:

> *"Three fundamental reforms in this Bill will improve safety at the workplace. First, the Bill will strengthen proactive measures. Instead of reacting to accidents after they have occurred, which is often too little too late, we should reduce risks to prevent accidents. To achieve this, all employers will be required to conduct comprehensive risk assessments for all work processes and provide detailed plans to minimise or eliminate risks.*
>
> *Second, industry must take ownership of occupational safety and health standards and outcomes to effect a cultural change of respect for life and livelihoods at the workplace. ...*
>
> *Third, this Bill will better define persons who are accountable, their responsibilities and institute penalties which reflect the true economic and social cost of risks and accidents. Penalties should be sufficient to deter risk-taking behaviour and ensure that companies are proactive in preventing accidents. Appropriately, companies and persons that show poor safety management should be penalised even if no accident has occurred."*

13 *Singapore Parliamentary Debates, Official Report* (17 January 2006) vol 80 at cols 2206

Duty holders

198. Stakeholders such as occupiers, employers, and principals, as well as duty holders such as suppliers and manufacturers are best positioned to put in place the necessary safeguards and inculcate a culture of ensuring workplace safety standards. When errant stakeholders and duty holders fail to do what is reasonably expected of them and accidents occur, robust enforcement and tough judicial sanctions must necessarily follow to reflect our society's stand that callous attitudes to the health and safety of workers will not be tolerated.

199. Stars Engrg is an employer to a group of workers and had a duty under section 12 of the WSHA to ensure the safety and health of its workers at work. It was also an occupier of the worksite and had concurrent duties under section 11 of the WSHA. For ease of reference, the duties incumbent upon employers and occupiers are reproduced in full at Annex L.

Risk Management

Risk Assessment

200. A risk assessment ("RA") is one of the most fundamental aspects of good WSH practice. As part of managing the health and safety of workers, employers must assess and control the risks at its workplace. To do this, employers need to think about what might cause harm to its workers and decide whether it is taking reasonable steps to prevent that harm. It is therefore mandated by regulation 3 of the Workplace Safety and Health (Risk Management) Regulations that employers, self-employed persons, and principals shall conduct a RA in relation to the safety and health risks posed to any person who may be affected by his undertaking in the workplace (see Annex M).

Safe Work Procedures

201. A safe work procedure ("SWP") is another integral part of the risk management process. After risks have been identified, regulation 4 of the Workplace Safety and Health (Risk Management) Regulations requires employers, self-employed persons, and principals to take all reasonably practicable measures to eliminate foreseeable risks at the workplace. If this cannot be done, then they should implement such reasonably practicable measures to minimise the risk and such SWP to control the risk. A SWP is therefore a sequence of plan of actions established for the purpose of carrying out work safely, consistent with generally accepted safe and sound practice. Such SWP should be made readily available at the worksite. Employers, self-employed persons, and principals should also take all reasonably practicable measures to inform persons at the workplace of the risks involved and any SWP implemented (see Annex M).

Method Statement

202. One manner of informing the relevant persons of the SWP for the activities at the worksite would be the use of a method statement ("MS"), which is a document that details the way a work task or

process is to be completed. The MS outlines the hazards involved and include a step-by-step guide on how to do the job safely.

Safe Use of Machineries

203. Singapore currently has a 3-tier risk-based approach to regulate safe use of machineries at workplaces, as summarised in *Figure 56* below.

Tier	Description	Regulatory Requirements
1 (Low risk)	All machinery used at work *[including the mixer machine used by Stars Engrg]*	Duty on **Owners, Occupiers, Principals, and Employers** to ensure that the machinery is safe.
2 (Medium risk)	11 classes of machinery specified in the Fifth Schedule of the WSHA *[E.g. forklifts, power presses, scaffolds]*	Additional duties are imposed on **Manufacturers, Suppliers, Installers and Persons who modifies** to ensure that: a) the machinery is safe when properly used; b) Information about the safe use of the machinery is available/adhered to; and c) The installation or modification is in accordance with the information supplied by the designer, manufacturer or supplier of the machinery.
3 (High risk)	2 classes of statutory equipment under the Workplace Safety and Health (General Provisions) Regulations: a) Lifting Equipment (e.g. Cranes) b) Pressure vessels (e.g. Steam Boilers)	These equipment are individually registered, tested and examined by a MOM Authorised Examiner, before use and at regular intervals thereafter.
Note: There is a parallel safety regime for 33 categories of general consumer products, where they are to be tested to specified safety standards and affixed with the "SAFETY Mark" before they can be sold in Singapore. This is governed under the Consumer Protection (Trade Descriptions and Safety Requirements) Act. These products are for personal, domestic consumption; hence, this regime is not applicable for industrial purposes.		

Figure 56: Regulatory Regime on Safe Use of Industrial Machinery under WSHA

Tier 1 (Low Risk) – All Machinery used at work

204. As discussed in the preceding section, the general duties of employers and occupiers applies for Tier 1 machineries, which covers all machinery used at work including the mixer machine used by Stars Engrg. In the event that the operators are non-workers, the owners of machinery also have

duties as principals to make available the precautions to be taken for the safe use of the machinery to persons using the machinery and ensure that the machinery is maintained in a safe condition.

Tier 2 (Medium Risk) – 11 Classes of Machinery and Equipment

205. 11 classes of machinery and equipment under Tier 2 are specified in the Fifth Schedule of the WSHA (Annex L). Due to their higher risks, there are additional duties imposed on manufacturers, suppliers and persons who erect, install, or modify these machineries.

206. Under section 16 and section 17 of the WSHA, suppliers and manufacturers are respectively required to make available information about the safe use of the machinery to persons to whom the machinery is supplied for use at work. This is to ensure that the machinery is safe when properly used and that the machinery is examined and tested. In addition, any person who erects, installs, or modifies these machineries is to ensure that the machinery is erected, installed or modified in such a manner that it is safe when properly used, and in accordance with the information supplied by the designer, manufacturer, or supplier of the machinery (see extracts at Annex L).

Tier 3 (High Risk) – 2 Classes of Statutory Equipment

207. Tier 3 refers to the highest risk category of industrial machinery and is deemed as Statutory Equipment. There are 2 classes of machinery under this category, namely lifting equipment and pressure vessel. Under the WSH (General Provisions) Regulations, these equipment are to be individually registered, tested, and examined by a MOM Authorised Examiner before use and at regular intervals thereafter. An extract of the relevant regulations under the WSH (General Provisions) Regulations is appended at Annex N. The key features of the regulatory regime under Tier 3 are summarised as follows:

a. *Registration Requirements:* As part of the conditions for registration, the owner of the statutory equipment shall ensure that the equipment is designed, constructed, and tested in accordance with MOM-approved design standards or codes relevant to the equipment concerned. This includes the provision of the required safety devices to ensure the safe use of the equipment. The owner shall ensure that the equipment is examined, tested, and registered by an Authorised Examiner to certify that the equipment is safe for intended use before it is put into operation. The owner shall de-register the statutory equipment once it is no longer in use.

b. *Requirements for periodic test and examination by Authorised Examiners:* Following the registration, the owner of the statutory equipment shall ensure that the equipment is periodically examined and tested by an Authorised Examiner at intervals stipulated under the WSH (General Provisions) Regulations and that a Certificate of Registration has been issued by

the Authorised Examiner after each examination to certify that the equipment continues to be in good working condition and safe for intended use.

c. *Requirements for approval for repairs or modification:* The owner of the statutory equipment shall notify and seek approval from MOM before carrying out any repair or modification to any statutory equipment. In addition, these repairs and modification shall be supervised by an Authorised Examiner and that a new Certificate of Registration shall be issued by the Authorised Examiner to certify that the equipment is in good working condition and safe for intended use after each repair or modification.

d. *Requirements for Training and Competency of Operator:* To ensure that no danger should arise due to improper or unsafe operation of the statutory equipment, the operator of the statutory equipment must be properly trained or competent to operate the equipment. For example, the operator of a mobile or tower crane must be the holder of a certificate of registration issued by MOM (MOM licensed crane operator) while an operator of a steam boiler must have successfully completed a training course acceptable to the Commissioner on the safe operation of the steam boiler.

Approved Codes of Practice, Singapore Standards, International Standards

208. In addition to the regulatory requirements, Approved Codes of Practice ("ACOP") provide practical guidance on safety and health to the industry. They are intended to be used as a yardstick to assess whether reasonably practicable measures have been taken to upkeep safety and health standards at a workplace. A notice of the issue of ACOPs is generally published annually in the Government Gazette. Under section 40C of the WSHA, regard shall be had to the relevant ACOPs in determining whether the relevant obligations under the WSHA have been discharged.

209. Singapore Standards are a set of specifications, guidelines, codes of practice, test methods or management systems that are designed to enhance the safety and health, market acceptance, innovation, quality or sustainability of the materials, products and services that companies and public use every day. Many organisations in Singapore are involved in the development and promotion of standards.

210. The relevant Singapore Standard in respect of the safe use of machinery is the Singapore Standard SS 537-1: Code of Practice for the Safe Use of Machinery – General Requirements. It had already been adopted as an ACOP under the WSHA and provides for the following:

a. Requirements on the design and manufacture of machinery to ensure that the machinery incorporates basic safety features;

b. Guidance on the safety and health issues relating to the installation, testing, maintenance, and servicing of machinery; and
c. Guidance on the methods for safeguarding the dangerous parts of machinery and enhancing safety in the use of machinery.

211. International standards are technical standards developed by one or more international standard organisations. They are available for consideration and use worldwide. They are also documents that had been developed through consensus of experts from many countries and are approved and published by globally recognised bodies. They comprise rules, guidelines, processes, or characteristics that allows users to achieve the same outcome time and time again.

Competency of Operators

212. There is currently no specific guidance for the use of a mixer machine for mixing activities. The IC has also not heard any evidence of specific training or certification courses for the use of a mixer machine before competency can be successfully established. However, there are general duties that exists for employers under section 12(3)(e) of the WSHA to ensure *that those persons at work have adequate instruction, information, training, and supervision as is necessary for them to perform their work*.

Combustible Powders – Supply, Storage, and Handling

213. Singapore currently has no single authority regulating combustible dust due to the wide variety of combustible dusts. Instead, different agencies regulate different materials or substances (some of which are combustible dust) under their respective legislation. *Figure 57* below summarises the various agencies' involvement. The details of the Regulations for respective agencies are compiled at Annex O.

Agencies	Import	Distribution	Storage	Use	Disposal
Singapore Customs (SC)	Import declarations are submitted through TradeNet platform				
Singapore Food Agency (SFA)	Trader needs to be registered to import processed food. Labelling requirements for food safety are imposed. *[Examples of processed food include potato starch, flour, etc., which are combustible powders]*				

Agencies	Import	Distribution	Storage	Use	Disposal
			License to manufacture and process of animal feed. *[Animal feed is an organic matter which are combustible powders]*		
Singapore Civil Defence Force (SCDF)	Petroleum and Flammable Materials (P&FM) license is required for import, storage and use of P&FM at any premises. *[List of P&FM Include metal powders such as aluminium, magnesium, zinc and iron carbonyl which are combustible powders]*				
			The building plan approval for fire safety works will also apply to premises that store and use flammable substances.		
Ministry of Manpower (MOM)			Protection of persons at work under WSHA and its subsidiary legislation. Precautions and measures to be taken at workplaces with regards to explosive or flammable dust, gas, vapour or substance.		
National Environment Agency (NEA)			The development control and building plan approvals may apply to premises that store and use combustible dust to ensure compliance with environmental health and pollution control requirements.		License Toxic Industrial Waste (TIW) collectors to ensure proper disposal of TIW. *[TIW include polyvinylchloride waste which is combustible dust]*

Figure 57: Regulatory agencies' roles based on the life cycle stages of combustible powders

Workplace Safety and Health

214. As with the above for safe use of machineries, the general duties for employers, occupiers, and principals under the WSHA similarly applies for combustible dust hazards. The WSH (General Provision) Regulations also focuses on the general provisions of safety, health, and welfare, on areas such as ventilation, lighting, lifting gears, storage of goods, prevention of fire, as well as

permissible exposure levels of toxic substances. Regulation 26 in particular focuses on precautions with regard to explosive or flammable dust, gas, vapour or substance, and is useful for the current case.

215. Arising from a 2013 combustible dust fire where 2 workers suffered burn injuries, MOM conducted an operation to assess and engage the process industry on combustible dust. Following the operation, MOM issued a circular to industry in 2015 to raise awareness of the hazards and controls of combustible dusts in workplaces. A non-exhaustive list of combustible dust examples was included in the circular (refer to *Figure 58*).

Category	Examples
Metals	Aluminium, Bronze, Magnesium, Zinc, Iron Carbonyl.
Chemicals	Adipic Acid, Ascorbic Acid, Sodium Ascorbate, Calcium Acetate, Calcium Stearate, Sodium Stearate, Lead Stearate, Dextrin, Lactose, Methylcellulose, Paraformaldehyde, Sulphur.
Plastics	Polymers e.g. Polymethylmethacrylate, Polyacrylamide, Polyacrylonitrile, Polyethylene, Polyvinylchloride, Resins, Melamine.
Organic Matter	Sugars, Corn Starch, Flour, Charcoal, Coal, Peat, Soot, Cellulose Pulp, Tobacco, Wood Dust

Figure 58: Examples of combustible dust listed in MOM 2015 Circular

216. Companies were advised to implement proper control measures such as dust control, ignition control, explosive relief and venting, training, and awareness, as well as personal protective equipment to mitigate the risk and prevent any possible combustible dust fires.

Fire Safety Act

217. The Fire Safety Act ("FSA"), which falls under the purview of the Singapore Civil Defence Force (SCDF), regulates substances that pose flammability hazards through a licensing regime under Part IV of the FSA. Part IV of the FSA covers areas such as appointment and duties of qualified persons, supervision for fire safety works as well as the prohibition of fire safety works without approval of plans.

218. The Fourth Schedule to the Fire Safety (Petroleum and Flammable Materials) Regulations contains a full list of regulated chemicals, including four combustible metal powders (i.e. aluminium, iron carbonyl, magnesium, and zinc) which are also classified under the UN Hazard Classification system as flammable solids. As other combustible powders such as milk powder, sugar, flour, and epoxy resin are not classified as flammable solids under international standards, it is not regulated under the FSA.

Singapore Standards, International Standards

219. The Singapore Standard SS 667: Code of Practice for Handling, Storage and Processing of combustible dust was launched in May 2021 and gazetted as an ACOP in November 2021. It includes:

a. Specific control measures to prevent combustible dust fire;
b. New risk assessment approach for combustible dust. It is a systematic review to identify and evaluate the potential fire, flash fire, and explosion hazards associated with the presence of one or more combustible dusts; and
c. Recommendation on electrical equipment zoning for the design of facilities with dust explosion hazard which makes reference to international standard IEC 60079-10: Classification of Hazardous Areas.

220. In respect of international standards, the American National Fire Protection Association (NFPA) is one of the internationally recognised authorities on fire protection. The NFPA standard 652 provides a listing of the *Kst* values[14] of over 100 materials.

221. The Institute for Occupational Safety and Health of the German Social Accident Insurance (GESTIS-DUST-EX) has a more comprehensive database, with combustion and explosion characteristics of close to 7,000 materials. Under this listing, there were several *Kst* values listed for potato starch, which was the combustible dust used by Stars Engrg.

[14] *K*st is defined as the deflagration index of a dust cloud. It is a generalized number used to estimate the anticipated behaviour of dust deflagration or explosion, allowing an approximation of a dust's explosive power compared to other dusts.

CHAPTER 7 POSSIBLE CRIMINAL LIABILITIES

Terms of Reference E – Possible Criminal Liabilities

222. Pursuant to section 26(6) of the WSHA, the District Judge appointed to the IC is required to consider whether criminal proceedings ought to be instituted and, if he is of such opinion, forward a copy of the IC's report to the Public Prosecutor. This statutory requirement is mirrored in TOR E.

223. Having considered the evidence, the Chairman of the IC is of the opinion that criminal offences have been disclosed in respect of acts and/or omissions by Stars Engrg, Chua Xing Da, and Lwin Moe Tun. The potential offences considered relate to issues that are closely connected to the accident. They are not intended to be definitive or exhaustive or fetter the Public Prosecutor's discretion in instituting criminal proceedings as he deems fit.

Stars Engrg

224. Stars Engrg had failed in its duty as an occupier under section 11(c) of the WSHA by not ensuring that the mixer machine used for the manufacturing of fire clay was safe and without risks to the health of everyone within the premises. Despite multiple instances where the mixer machine showed possible signs of failure and risk to safety and health (e.g., oil leaks and instances of fire), the causes were not properly investigated before operations of the mixer machine continued.

225. Under section 12(1) of the WSHA, Stars Engrg has a legal duty to ensure the safety and health of all its employees. Stars Engrg had failed in its duty as an Employer under section 12(1) of the WSHA for the following reasons:

a. Stars Engrg did not ensure that there was a RA and SWP for the mixing activities within the worksite.
b. No proper training was provided to the workers for the safe use of the mixer machine.
c. The mixer machine was not commissioned by a competent person, resulting in the improper and unsafe operation of the mixer machine.
d. An emergency evacuation plan was not developed for the foreseeable risk of a fire breaking out within the worksite.
e. No toolbox meeting was conducted to discuss the general work activities or highlight the hazards that workers were exposed to during the work activities at the worksite.

f. No RA or SWP was developed or communicated for the use and storage of combustible dust such as potato starch powder, and foreseeable risks such as fire and explosion were not addressed and mitigated.
g. Stars Engrg instructed unsafe in-house remodification works, such as welding works, to be done on the mixer machine.
h. Stars Engrg failed to review RA and investigate causes of the multiple near misses and red flags.
i. Stars Engrg failed to provide a local exhaust ventilation system to prevent the accumulation of the combustible starch powders in the workplace and improper housekeeping methods by dry sweeping.

Chua Xing Da

226. While Stars Engrg is potentially liable as an occupier and employer, the officers of Stars Engrg, a body corporate, can also be held liable under section 48(1) of the WSHA. As the sole director who was overall in charge of Stars Engrg and its workers, Chua falls within the definition of a corporate officer as defined in section 48(1) of the WSHA. Chua was also the one who procured the mixer machine. Despite having insufficient knowledge on how the mixer machine was to be safely used for its intended design, Chua had installed and commissioned the mixer machine by himself. Chua had made ill-founded assumptions when dealing with the operation, modifications, and failures of the mixer machine, and had been the person responsible for instructing Stars Engrg's workers on dealing with the mixer machine. The failure in Stars Engrg's duties, whether as occupier or employer, can be attributable directly to Chua's acts and/or omissions.

227. For the above reasons, Chua is potentially liable as the sole director of Stars Engrg for offences committed by Stars Engrg.

228. Chua is also potentially liable under section 204A of the Penal Code (Cap. 224, 2008 Rev Ed) ("Penal Code") for obstructing the course of justice when he lied to MOM's investigators and omitted to mention Moe's deletions of WhatsApp messages between Moe and Marimuthu. Prior to his deletions, Moe had shown Chua the messages and photographs on 25 February 2021 and asked whether he could delete them from his mobile phone, and Chua had said "ok". Moe then deleted the same messages and photographs from Marimuthu's mobile phone the next day on 26 February 2021 after asking Chua if he could likewise delete those messages and photograph. At the time, Chua had just dropped Moe off at a canteen near Stars Engrg's Changi site while Chua went back to meet MOM's investigators regarding the accident. Chua allegedly told Moe to wait for him to return and not to delete the messages and photographs in the meantime. However, when Chua met MOM's investigators and was asked to hand over Marimuthu's phone, Chua lied to the investigators that he was checking on the whereabouts of Marimuthu's phone despite knowing

that it was with Moe and that Moe was considering making deletions. When Chua handed over Marimuthu's phone to the Singapore Police Force on 1 March 2021, he also failed to mention that Moe had already made deletions from the mobile phone. Chua had lied and omitted to mention about the deletions from Marimuthu's phone knowing that his lie and omission were likely to do so by impeding investigations.

Lwin Moe Tun

229. A person at work in Singapore has a duty to ensure that he does not endanger, whether wilfully, recklessly, or negligently, the safety and health of himself as well as that of others under sections 15(3) and 15(3A) of the WSHA. The evidence revealed that Moe had, at the very least, been negligent and endangered the safety and health of others, and breached his duty under section 15(3A) of the WSHA when, as the Production Manager overseeing production at the Tuas worksite, he failed to stop Marimuthu and Shohel from attempting to use the same heater on 24 February 2021 despite the glowing hot heater and small fire that occurred the same morning.

230. Moe was aware that Marimuthu had attempted to fix heater #2 with green tape around the damaged heater's wires, after receiving a photograph of the fix from Marimuthu. There would have been no reason for the workers to tape up the damaged heater and/or to test its cables unless they were intending to use the damaged heater, and Moe must have clearly understood this. Moe was ambivalent to the workers' safety and left them to their own devices despite understanding the safety risks involved, especially after the fire in the morning of 24 February 2021.

231. This explains why Moe chose to delete the WhatsApp messages containing the photograph that Marimuthu sent him and his request to Marimuthu for an update. Following the accident, Moe must have realised that he should not have allowed Marimuthu and Shohel to attempt to use the damaged heater when it was unsafe to do so, and therefore felt compelled to get rid of the evidence that implicated him.

232. Moe is also therefore potentially liable under section 204A of the Penal Code for obstructing the course of justice when he deleted items from his mobile phone and Marimuthu's mobile phone. During the recording of his first statement by MOM officers, Moe omitted to mention that he had made deletions from his WhatsApp chat with Marimuthu, and only came clean during his second interview on 13 April 2021. The circumstances surrounding Moe's deletion of the messages and photographs and his failure to inform MOM of the same indicate an intention by Moe to impede investigations and obstruct the course of justice. Even if Moe did not intend to so impede investigations, he would have known that his actions would likely do so.

CHAPTER 8 LESSONS, RECOMMENDATIONS & OBSERVATIONS

Lessons

233. Amidst painful and catastrophic results, every accident produces lessons which we can learn from to prevent future recurrence. The current tragedy arising from the explosion is no different. It is thus imperative that we must learn from these fundamental lessons, summarised as follows:

a. The operation, maintenance, and/or modification of any industrial machinery need to follow sound engineering principles and practices. Where in doubt, proper guidance should be sought from the manufacturer, supplier, or a qualified person; and

b. The hazards of combustible dust and all other hazards should be properly communicated to all stakeholders involved and be properly managed.

Terms of Reference B - Recommendations

234. In summary, the IC recommends the following, which are elaborated in the later parts of this chapter:

a. Safe use of machineries:
   i. Encourage buyers of industrial equipment to certify their purchased equipment to SS 537-1; and
   ii. Review and expand the Fifth Schedule of the WSHA to include higher-risk machineries such as those powered by mechanical, electrical, hydraulic or pneumatic energy.

b. Safe use of combustible dusts:
   i. Suppliers of materials that pose a defined level of combustible dust hazard to include a label explicitly informing on the hazard before selling or redistributing;
   ii. Companies that handle prescribed amounts of specified combustible powders to register or notify the authorities; and
   iii. Occupiers to inform building owners or landlords on the use of combustible powders, so that they will be made aware and can deconflict incompatible work amongst tenants, if any.

c. More outreach and guidance efforts be conducted, specifically directed towards Small and Medium Enterprises (“SME”), as well as workers who may be at risk.

Safe Use of Machineries

(i) Encourage Certification to SS 537-1

235. It is clear that the range of industrial machines available for purchase is extensive, and to control each and every one of them would not only be impractical and costly for the industry, but and also create an unrealistic and tedious task for regulators. Therefore, the concern is that there should not be over-regulation of every industrial machine, but rather to ensure that buyers of industrial machines exercise the necessary due diligence before and after the purchase to ensure their safety during use.

236. This problem is compounded by the pervasiveness of online marketplaces where companies are now able to easily procure industrial machineries from overseas manufacturers and suppliers. Such machineries might not be manufactured according to established standards or subjected to certification or rigorous testing. Therefore, encouraging buyers of industrial equipment to certify their purchased equipment to SS 537-1, and to ensure it conforms to relevant safety standards on machineries, would serve the interest of owners of such machines. MOM had proposed encouraging the adoption of certification to SS 537-1 through a multi-prong approach:

a. Work with accreditation bodies and trade associations to develop voluntary accreditation schemes for SS 537-1 certification of high-risk industrial machines within the supply chain;
b. Promote and raise awareness on the use of SS 537-1 through outreach and engagement programs such as workshops, seminars, and conferences; and
c. Require owners of machines whose integrity may be questionable to undertake the certification. This can be done via MOM's inspection or investigation.

237. Representatives from Singapore Manufacturing Federation (SMF) and Institution of Engineers Singapore (IES) concurred with MOM's proposal to adopt certification to SS 537-1, which would give more assurance especially to buyers purchasing machineries from overseas. It was also a common consensus during the Inquiry that SS 537-1: 2008 is quite dated and ought to be revised, incorporating the findings from this tragic accident.

238. The IC hence supports encouraging buyers of industrial equipment to certify their purchased equipment to SS 537-1, and further recommends that SS 537-1 be reviewed so as to incorporate findings from this Inquiry as well as be updated for other developments that might have occurred since its launch in 2008.

(ii) To Review and Expand the Fifth Schedule of the WSHA

239. The evidence presented at the hearings showed an alarming failure to understand how to safely operate the mixer machine. Without much aftersales support from the overseas manufacturer of the mixer machine, Chua had directed much of the commissioning, operation, and subsequent modification of the mixer machine in a trial-and-error approach.

240. It was in evidence that the mixer machine had not been commissioned as intended by the manufacturer and that the mixer machine had also been operated without proper use of the safety features provided by the manufacturer. The following were clear instances:

a. Insufficient thermic oil was used;
b. The vent port of the mixer machine was sealed; and
c. The temperature sensors, in particular the one with built-in safety interlock meant to measure and regulate the temperature within the oil jacket, were not installed.

241. The mixer machine showed multiple signs of failure, but Stars Engrg had proceeded to modify the machine on their own without any instructions from the manufacturer. This fateful accident serves as a solemn reminder that even an inherently safe machinery has the potential to cause a catastrophe if improperly used.

242. MOM's and Singapore National Employers Federation's (SNEF) experts recognised the importance of commissioning and modification of equipment, and the following was suggested by MOM:

> *"… MOM recommends expanding the Fifth Schedule of the WSHA to cover a broader range of industrial equipment such as those powered by mechanical, electrical, hydraulic or pneumatic energy… By doing so, it will automatically impose duties on the manufacturers, suppliers, installers and persons who modify the machine to ensure they are safe to use when operated properly and that relevant information about their installation, commissioning, use, repair and modification are supplied to the buyer."*

243. The IC notes that the mixer machine is generally not a high-risk equipment if properly used, and the primary cause of the accident was largely due to operational failures rather than the adequacy of the design of the mixer machine for its intended use. The IC is also minded not to propose a knee-jerk reaction to regulate all industrial machineries as "controlled item" or statutory equipment (Tier 3 regime in para 207), as this will impose excessive regulatory burden on the economy. Having considered the recommendations and written submissions put forward, the IC agrees that an expansion of the Fifth Schedule of the WSHA is a balanced approach that would bring similar higher risk equipment – such as those powered by mechanical, electrical, hydraulic,

or pneumatic energy – under the ambit of the existing Tier 2 regime for workplace machineries, thereby subjecting similar higher risk equipment to a more rigorous regime involving (i) the manufacture and supply; and (ii) the installation, commissioning, repair, and modification. By doing so, duties will be imposed on the manufacturers, suppliers, installers, and persons who modify these machines to ensure they are safe to use when operated properly and that relevant information about their installation, commissioning, use, repair, and modification is supplied to the buyer and eventual user of the machine. This would be a timely update to the Fifth Schedule which has not been expanded since the WSHA was enacted in 2006.

244. Dr. Salim had recommended a review of regulation 26 of the WSH (General Provisions) Regulations, and if necessary, for it to be amended such that the terms "combustible liquid aerosols" and "flammable gases and vapours arising from material decomposition" be included and made explicit. The IC recommends that MOM reviews the actual text to ascertain if the current language already covers these substances and include them if they are not already covered.

Safe Use of Combustible Dusts

245. While it is clear that the underlying cause of this accident was the unsafe use of the mixer machine, and the mechanical rupture and primary explosion from the machine caused most of the damages and injuries sustained, the occurrence of secondary combustible dust flash fires showed that the hazards of combustible dust were not fully understood or made aware to the parties involved in this accident. This was evident from the lack of control measures to manage combustible dust hazard properly at the worksite such as inadequate housekeeping done as well as the lack of a local exhaust ventilation system installed at the worksite. Although the flash fires in this particular accident were not as severe when compared to the primary explosion, the situation could have been reversed and exacerbated many folds had there been larger quantities of combustible dust present in the premises. The IC is thus minded to make recommendations that would ensure that all parties – including regulators, occupiers, employers, workers, and property owners – involved in the use of combustible dust are made fully aware of and can properly manage the hazard.

Gazetting SS 667 as an ACOP

246. The recommendations shared during the hearing, in particular the evidence heard from Dr. Salim, IES, and SMF, included calls for SS 667 to be gazetted as an ACOP. The aim is to provide practical guidance to the industry on safe use and storage of combustible dusts. However, the IC noted that MOM and WSHC has already gazetted SS 667 as an ACOP on 19 November 2021.

247. Following the adoption of SS 667 as an ACOP, the standard sets out a framework to safely manage combustible dust hazard arising at a workplace. It begins with hazard identification and incorporates a dust hazard analysis, specific to combustible dust. After identification, adequate

control measures are to be implemented to eliminate or reduce the risk to an appropriate level. It is also worth noting that SCDF has already incorporated SS 667 into its processes, though the issuance of a circular on 1 June 2021 stating that SS 667 would apply to all new buildings and buildings undergoing fire safety works that store flammable powders.

WSHC's Role in Education and Outreach

248. It is crucial that any form of legislative change or adoption of an ACOP reaches its intended target for the intent to be satisfied. The IC notes that the WSHC already has an extensive outreach programme focusing on the education of both employers and workers; through industry events, promotional material, accreditation of WSH courses, and WSH resources such as guidelines, circulars, bulletins, and direct messages to workers in their native languages through the FWMOMCare app. This should continue as education and re-education plays a pivotal role in the prevention of accidents through knowledge gathering and sharing.

Impact of Combustible Dust Risks to Neighbouring Units

249. The Stars Engrg explosion and flash fires resulted in significant damage to the building. Not only was Stars Engrg's premises affected, but the blast also affected neighbouring units. It is therefore in the interest of the building owners to know if their tenants are using or handling combustible dusts. SCDF's expert also said that:

> *"… it is important to make sure that the building owner … in the case of a tenancy arrangement, is being kept informed of what's going to take place within their property."*

250. This view was also proposed by a member of public in his written submission stating:

> *"Business owners should declare their business operations/ products / by-products taking into consideration the type of risks and generation of hazards during the process. The information needs to be evaluated by the landlord (if applicable) and landlord (if applicable) shall evaluate if the business operations are suited to be carried out in the leased office/workshop. Landlords (if applicable) need to consider the adjacent/ neighbouring business operations compatibility. There could be a risk of incompatible operations between 2 or 3 neighbouring businesses and could result in a catastrophe if there is a chain of failures. This is specifically valid for businesses located in compacted factories with multi tenant developments."*

Summary of Recommendations

251. In view of MOM's recommendations, SCDF's views, and submissions by members of public, the IC recommends that relevant agencies adopt the following with regard to the import and supply, bulk storage, and usage of combustible dusts:

    a. Suppliers of materials that pose a defined level of combustible dust hazard to include a label explicitly informing on the hazard before sale or redistribution;
    b. Companies that handle prescribed amounts of specified combustible powders to register or notify the authorities; and
    c. Occupiers to inform building owners or landlords on the use of combustible powders, so that they will be made aware and can deconflict incompatible work amongst tenants, if any.

Competency and Knowledge

252. Awareness and competency are important factors in workplace safety and health. As described in Chapter 6 of this report, there are existing regulatory regimes governing general workplace safety and health duty holders, risk management requirements, and rules and standards covering safe use of machineries and combustible dusts. However, this inquiry showed non-compliance to these regimes, underscoring that awareness and competency relating to industrial machineries and combustible dust hazard were lacking, especially in the SMEs. The cornerstone of risk management is to first identify. There lies the issue that one would not know how to identify a hazard that they do not know is a hazard. Additionally, SMEs do not have the same resources in terms of knowledge or expertise compared to MNCs and might have also different priorities and views towards safety.

253. While it cannot be ascertained why the red flags that occurred at Stars Engrg were not reported to the authorities, one thing that stood clear was the possibility that the workers were swayed by Chua's assurance and were not able to appreciate the magnitude of the imminent dangers presented by the multiple near misses.

254. It is apparent that more outreach and guidance, be it in the form of additional guidelines or engagement sessions with the authorities or associations, need to be provided for the SMEs to upgrade their technical competencies in the areas such as machine safety and combustible dust hazards. Only then would SMEs be made aware of available standards and be equipped with the expertise to properly execute and comply with these standards.

255. The IC hence recommends that more outreach and guidance efforts be conducted, specifically directed towards SMEs, as well as bring in unions to have targeted outreach and education to workers who may be at risk.

CHAPTER 9 CONCLUDING REMARKS

256. One of the strategic outcomes of WSH 2028 is to strengthen Singapore's reputation for integrity, quality, trust, and competency. To achieve our aims, every company and its management must be intrinsically motivated to care for their workers' safety and health, and there must be mutual trust between employers and workers.

257. There is an urgent need to address any lack of attention to WSH risks in a supply chain, especially in SMEs where the resources and know-how are more limited, as seen in the present case.

258. While we mourn the loss of three valuable lives and how the lives of seven others had changed forever after the explosion at Stars Engrg, we must remember and learn how decisions entrusted to and made by company management can prevent such regrettable accidents. The life of every worker matters, and every decision made plays a role in ensuring that workers return home to their family safe and sound. No decision made in respect of WSH matters is ever small, unimportant or should be taken lightly. Directors, middle management, and even supervisors play pivotal roles and make life-changing decisions every day when they lead their workers, who in turn, place a high level of trust in them.

259. The IC hopes that this report helps to bring some closure to the tragic explosion on 24 February 2021 and offers useful recommendations to prevent the recurrence of this regrettable accident. Singapore had learnt many lessons in our history, including several WSH-related incidents that had shaken the nation. The IC trusts that Singapore's employers and workers will learn from this tragic accident, and Singapore's WSH standards and performance will reach greater heights, towards the shared vision of being amongst the world's best.