Summary: Interim Report by the Accident Investigation Committee

Accident Investigation Committee

1. Introduction
In response to an accident (1 person killed and 4 persons injured) at an arc furnace (Furnace B) of the head office plant of Komatsu Castex Ltd. in Himi City, Toyama Prefecture on April 25, 2014, Komatsu created the Accident Investigation Committee with members from three outside specialists and supported by the secretariat, consisting of three Komatsu employees on May 2, 2014.

The objectives of the Committee were to first uncover the conditions which had led to the accident, then investigate the cause(s) of the accident, and propose preventive measures based on identified cause(s). The Committee has met three times, made progress in investigation, and has disclosed an interim report concerning the mechanism which had triggered the accident and other pertinent matters uncovered as of June 10, 2014. This paper is a summary of the interim report.

2. Outline of the accident
Around 18:04 on April 25, 2014, during the process of oxygen steelmaking (to remove slag) as part of the melting process in an arc furnace* (Furnace B) at the head office plant of Komatsu Castex, a fire started in the furnace soon after using the automatic oxygen blower designed to increase temperature and mix molten steel, scattering heated air and slag covered with molten steel, and injuring five workers near the furnace.

* Melting Process in Arc Furnace
- Loading scrap metal
- Melting process
- Oxidation and reduction processes
- Tapping

1) Loading scrap metal: Loading materials (scraps, etc.) and lowering three artificial graphite electrodes which are connected to the three-phase AC source
2) Melting process: Turning on electricity → Forming an arc between main materials to melt them
3) Oxidation process: Injecting oxygen to generate a chemical reaction (O₂ + 2C → 2CO +
4,400Mcal/t), thereby removing impurities
Reduction process: Desulfurizing and adjusting chemistry, and then controlling molten steel at
designated temperature
4) Tapping: Tapping molten steel into the vessel

3. Assumption of causes
We have evaluated probable causes, such as 1) phreatic explosion, 2) dust explosion, 3) explosive
boiling of molten bath and 4) explosion of fuel, etc. With respect to 1) phreatic explosion, we found
no evidence of water leaks in this accident. With respect to 2) dust explosion, there is no dust near
the furnace, which is easy to catch fire. With respect to 3) explosive boiling of molten bath, we
found no damages on the hearth, which should have been caused if there had been explosive boiling.
With respect to gas explosion caused by fuel leaks, the concerned arc furnace uses only a small
amount of kerosene and we found no evidence of fuel leaks. Based on all these findings above, we
believe the possibility is extremely low for any of the probable scenarios above to be valid causes.

Therefore, the remaining conceivable cause as of today is 5) sudden combustion of carbon
monoxide, that is, when a large amount of carbon monoxide generated inside the furnace rapidly
reacted with oxygen, a chemical reaction into carbon dioxide dynamically advanced, gushing out a
large amount of heated air together with slag. We believe this is a possibility.

In the course of our investigation, we looked for other accidents resembling this one, but
found none.

Based on the knowledge gained in the investigation to date, we can assume the following processes
in case of 5).
- Oxygen was supplied into the furnace by the automatic oxygen injector (automatic lance) as
  well as oxygen generated from a kind of slag, which was formed into iron oxide and deposited
  on the refractory lining. When the molten steel was dispersed, the deposit of iron oxide dropped
  into the molten bath, reacted with carbon in the molten bath, generated a large amount of carbon
  monoxide gas, and might have unexpectedly caused super-scale boiling.
- Due to this unexpected development of super-scale boiling, the slag closed the slag removal
  spout, etc., lowered the performance of the dust collector and resulted in excessive lack of
  oxygen in the furnace.
- When the slag, which had closed the slag removal spout, flowed out, an opening developed in
  the spout and simultaneously the dust collector recovered its performance, allowing a large
  amount of air to flow into the furnace.
- Oxygen in the air flowed into the furnace and a large amount of carbon monoxide triggered
  rapid combustion in the furnace, generating and gushing out heated air together with the slag
and causing the accident.

4. Preventive measures
With respect to preventive and additional safety measures based on what we can assume today, please refer to “Interim Report 10. Preventive measures” (attached below). We will validate each item listed in the section above and continue to investigate further.

5. Future efforts
As this Report complies what has been identified as of now, we will continue a further investigation in more detail concerning the direct cause(s). We will also identify other important matters which are directly and indirectly related to the accident, such as facilities, machine operations and business management, as well as organizations and corporate climate, develop more preventive measures and propose them.

(end)
Appendix: Interim Report 10. Preventive measures

We have identified the following preventive measures based on the assumption of causes. We will study the effectiveness thereof into the future.

1) Assumed causes and possible measures

<table>
<thead>
<tr>
<th>Assumed causes</th>
<th>Possible measures</th>
<th>Description of possible measures</th>
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</thead>
<tbody>
<tr>
<td>1. Breakout of a massive amount of CO</td>
<td>1) The decarburization rate was fast.</td>
<td>1) Use the correct rate of decarburization.</td>
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<td>(1) Never use automatic lance.</td>
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<td>(2) Determine the optimal rate of decarburization for manual lance.</td>
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<td>(3) Never inject oxygen and turn on power for the electrodes at the same time.</td>
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<td>(4) Monitor CO concentration and stop when it goes over the limitation.</td>
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<td>2) Danger detection (installation of sensors)</td>
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<td>2) Installation of sensors for boiling (measurement of CO concentration, etc.)</td>
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<td>(1) “Visualization” of operational conditions inside of the furnace (melting temperature, % of</td>
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<td>carbon, the amount of iron oxide in the slag, etc.)</td>
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<td>(3) “Visualization” of atmospheric conditions inside of the furnace (amount of flow-in air,</td>
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<td>gas temperature, internal pressure of the furnace, etc.)</td>
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<td>2) % of carbon when iron melts was high.</td>
<td>1) Never make any heat with high % of carbon.</td>
<td>1) Reassess the location of scrap yards. (prevention of rusting)</td>
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<td>(2) First-in, first-out of scraps (prevention of rusting)</td>
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<td>(3) Research in stabilization of % of carbon in molten steel</td>
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<td>2) Never hasten decarburization when % of carbon is high.</td>
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<td>(1) Writing down specific work pointers in the work procedure according to the range of % of</td>
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<td>carbon</td>
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</table>
3) Iron oxide (FeO) slag deposited on the refractory lining fell off.

- 1) Establish a method to prevent FeO of large sizes from falling off.
- 2) Establish a method to prevent FeO slags.

4) A large amount of air (O₂) mixed in molten bath.

- 1) Improve the dust collection method.
  - Application of a method not to heap up but direct always toward CO₂ (a method to combust little by little)

Note: *Inhibit the generation of CO by injection of aluminum ingots before oxygen (O) and carbon (C), contained in the FeO slag, are combined, thereby changing it to Al₂O₃.

2) Additional improvements for safer working conditions

* Measures to minimize the damages, should the same accident happen. Etc.

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<tr>
<th>Measures</th>
<th>Description of improvements</th>
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<tbody>
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<td>1) Improvement of facilities (unmanned operation near the furnace)</td>
<td>(1) Study the feasibility of manipulating the oxygen injector. (unmanned operation near the furnace)</td>
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<td>(2) Automate measurement of temperature and sampling (unmanned operation near the furnace)</td>
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2) **Protective gears and heat-insulating panels to protect workers from heated air (important to protect the body from heated air for one to two seconds)**

- **(1)** Change of protective gears (Tested the material of protective gears and produced aprons.)
- **(2)** Use of a heat-insulating panel exclusively for oxygen blowing
- **(3)** Installation of heat-insulating panels at workplaces (control panels, temperature measurement, sampling location, alloy injection area, ladle site)
- **(4)** Authorized persons only for the furnace areas and installation of panels to prevent dispersion of molten iron in the furnace areas
- **(5)** Installation of shower for cooling
- **(6)** Preparation of an emergency manual

3) **Other**

- **(1)** Reinforcement of safety check patrols jointly by management and labor union representatives