Renovation of evacuation facilities in case of leakage of high-temperature molten metal

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Abstract. In this paper, the renovation design of the evacuation facility in the high-temperature molten aluminum casting workshop was designed by the research team of the State Key Laboratory of Fire Science, University of Science and Technology of China to deal with the impact of high-temperature molten metal leakage and diffusion accidents. The field experiment results show that the evacuation path of the mixed furnace eye worker and the crane driver is severely blocked. In response to this problem, the evacuation escalator and evacuation slide were respectively designed during the renovation, and the evacuation path after the renovation was re-planned. According to the numerical simulation results, the new evacuation system has made great progress, and the efficiency of evacuation of people has been significantly improved. The current research provides a model for the reconstruction of the personnel evacuation system in the existing metallurgical workshop accident scene, which has great practical value for ensuring the safety of high-temperature molten metal operations.

1. Introduction

High-temperature molten aluminum leakage is one of the most serious hazards in the aluminum smelting industry. In the process of smelting, transportation, casting and processing, molten aluminum leakage and water explosion accidents often occur, which may easily cause casualties and deaths of operators. Induce other secondary accidents, such as collapse of metal structure, fire, etc. The response to high-temperature molten aluminum leakage accidents mainly focuses on strengthening the preliminary safety management and continuous improvement of the production process, such as strengthening the preparation and drills of accident emergency plans, strengthening the safety production responsibility system, and improving the production process and process parameters. However, the safe evacuation route of people in traditional aluminum production sites has not been planned for liquid aluminum leakage accidents, and there is a shortage of personnel escape facilities in response to extreme accidents. Once liquid aluminum leaks and water explosion accidents occur, the escape route of personnel is blocked and evacuation is difficult. At present, the research on accident escape facilities at home and abroad is progressing slowly. The installations and facilities that have been reported are mainly concentrated in the construction industry, and the layout is mainly designed for fire accidents. The structure of escape slides is mainly divided into two types, namely, outdoor escape slides and indoor escape slides.

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2. Analysis of influence scope of molten aluminum leakage and diffusion
According to the research results of high-temperature molten aluminum diffusion and flow experiments, the scope of influence of molten aluminum leakage and diffusion under the scene of aluminum ladle tipping and mixing furnace mouth leakage is determined. In order to facilitate the analysis, the influence range is simplified to a circular area with the leaking point as the center and the longest diffusion distance as the radius, and the diffusion radius change function can be simplified as shown in the following formula.

\[ R = V^{\frac{1}{2}} n^{\frac{1}{2}} \pi^{\frac{1}{2}} \left[ 2(\cos \theta) \gamma_L \right]^{\frac{1}{2}} \rho^{\frac{1}{2}} g^{\frac{1}{2}} \]  

(1)

Where \( \rho \) is the density of high temperature molten metal, \( V \) is the volume of high-temperature molten metal, \( n \) is the number of molten metal leaking drops, \( \theta \) is the contact angle between the droplet and the ground surface, \( \gamma_L \) is the free energy of solid-liquid interface, \( g \) is the acceleration of gravity.

3. Analysis of the existing escape route in the foundry

3.1 Site layout and personnel distribution
The aluminum casting workshop of Taiyuan Donglv Aluminum Co., Ltd. has a length of 84m and a width of 24m. The workshop plane is divided into two platforms, namely the upper platform and the lower platform, with a height difference of 2.4m. The main equipment in the workshop includes 2 mixing furnaces, 2 continuous casting production lines with a length of 27m, and 2 cooling water tanks with a volume of 9.6m³. The main production activity of the foundry workshop is to pour the high-temperature aluminum liquid in the aluminum ladle sent from the electrolysis workshop into the mixing furnace, and stir, mix and remove the slag in the mixing furnace, and then the high-temperature aluminum liquid is discharged from the furnace mouth of the mixing furnace Flow out to the aluminum liquid channel, and pour into the mold to form. Among them, the high-temperature aluminum liquid is poured into the mixing furnace and the aluminum liquid flows out of the mixing furnace. These two production links are more dangerous, which may easily lead to the overall overturning of the aluminum ladle or the aluminum liquid protrusion accident. Leakage accidents were named as aluminum ladle overturning accident and furnace mouth leakage accident.

The main job positions on the site are set up as crane driver, mixing furnace watcher, mixing furnace eye worker, skinner, foundry worker and packer, etc. Figure 1 shows the distribution of personnel in various positions.

![Figure 1. Distribution of personnel in various positions in the aluminum casting workshop](image)

3.2 Analysis of evacuation routes for people in different positions
In an accident-free state, the evacuation path of each post will pass through the upper platform, stairs (climbing ladder), and lower platform, and evacuate through the exit; in the event of an aluminum ladle overturning accident, the stairs connecting the upper and lower steps will be covered by liquid
aluminum Operators on the upper platform do not have the conditions to directly evacuate from the lower platform. They are evacuated through the upper platform exit via the electrolysis workshop next door. However, due to the special location of the crane driver, the evacuation time is longer, and the on-site molten aluminum is diffused. The high temperature caused the crane driver to be unable to evacuate; in the event of a furnace mouth leakage accident, the workers on the steps up and down were still evacuated according to the evacuation route without accident, but the furnace eye workers were close to the furnace mouth and leaked aluminum liquid It will directly affect its evacuation, and it is impossible to evacuate directly according to the original route. Table 1 shows the specific evacuation routes for workers at various positions.

From the perspective of the evacuation path of each post under different accident scenarios in the foundry, the evacuation path of the foundry, peeler, and packer on the lower steps will not be affected; in the event of an aluminum ladle overturning accident, the molten aluminum will be formed on the upper platform. The liquid injection port is a circular area with a radius of about 3m. Taking into account the influence of the high-temperature heat radiation of the molten aluminum, the upper platform no longer has the evacuation conditions. Affected by this, the evacuation of the crane driver and the furnace eye worker is difficult; when mixing occurs In the event of furnace mouth leakage accident, high-temperature molten aluminum will be sprayed from the furnace mouth of the mixing furnace. The affected area is mainly the area below the furnace mouth. The affected area is about 3m². Affected by this, the furnace eye of the mixing furnace is difficult to survive.

**Table 1 Evacuation routes of workers at various positions in different accident scenarios**

| Accident scene       | Scene 1: No accident | Scene 2: Aluminum ladle tipping | Scene 3: Furnace mouth leakage |
|----------------------|----------------------|---------------------------------|------------------------------|
| Aluminum liquid diffusion area | /                    | Upper platform, with an area of about 30m² | Below the furnace mouth, with an area of about 3m² |
| Crane driver         | Escalator→Upper platform→Stairs→Lower platform→Exit 1 | Evacuation on the platform is blocked | Escalator→Upper Platform→Exit 2 |
| Duty officer         | Stairs→Lower platform→Exit 1 | Stairs→Lower platform→Exit 1 | Escalator→Upper Platform→Exit 2 |
| Furnace on duty      | Step→Upper Platform→Stairs→Down Platform→Exit 1 | Evacuation on the platform is blocked | Evacuation on the platform is blocked |
| Impurities remover   | Upper platform→Exit 1 | Upper platform→Exit 1 | Upper platform→Exit 1 |
| Foundry worker       | Upper platform→Exit 1 | Upper platform→Exit 1 | Upper platform→Exit 1 |
| Packer               | Upper platform→Exit 1 | Upper platform→Exit 1 | Upper platform→Exit 1 |

### 4. Renovation of escape facilities in the foundry and optimization of evacuation routes

Considering the particularity of the aluminum ladle tipping accident and the leakage accident of the furnace mouth of the mixed furnace, and the impact of escape facilities on the daily production activities on the spot, the renovation of the escape facilities for furnace workers and crane drivers needs to consider three requirements:

- The escape facilities need to be exhausted;
- The structure of the escape facility must not be disturbed by the heat radiation of the high-temperature molten aluminum, and will not be damaged by the heat radiation of the high-temperature molten aluminum;
- The escape facility must be set up as a permanent facility. Proceeding from these three requirements, a plan for the modification of the escape facilities for the operators was designed, and the escape facilities for the mixed furnace and the crane driver were modified accordingly.
4.1 Modification of escape facilities for furnace eye workers of mixed furnace

According to the results of the on-site evacuation experiment, when the aluminum ladle leaked, the evacuation time of the furnace eye workers was about 14 seconds. At this time, the aluminum liquid had completely covered the platform area and it was difficult to escape directly. In the design of the transformation plan, an escape escalator can be added to the working platform of the mixed furnace and furnace to directly lead to the lower platform. At the same time, the emergency evacuation plan of the enterprise can be modified to change the escape escalator to the lower platform for escape. The transformation plan is shown in Figure 2.

The furnace eye workers’ escape escalator is cast in one-time reinforced concrete. The platform height is 1.6m, the number of steps is 10, and the horizontal projection length is 2.1m. To the next platform.

4.2 Renovation of escape facilities for crane drivers

According to the results of the on-site evacuation experiment, it takes 22 seconds for the crane driver to escape directly from the stairs. Considering the parking time of the crane, the time will be longer, and the scene can no longer meet the escape conditions. In the design of the renovation plan, the escape route was modified, and escape escalators and escape slides were added to the outer walls, and the crane driver escaped directly from the escape slide to the outside of the factory. The transformation plan is shown in Figure 3.

The crane driver’s escape escalator is equipped with a cantilevered platform, 3 side doors, and 2 outdoor slides, so that it can quickly escape no matter where it is in the event of a high-temperature molten aluminum leakage accident. The structure is divided into two parts: the first part is a cantilever platform set on the outer wall, the center line of the platform is the center line of the wall, and the combined structure of I-steel-thin steel plate is adopted. The length of the platform extending indoors and outdoors is 0.5 m, a safety railing is provided on the edge of the platform. The structural section is shown in Figure 4. The second part is an escape slide connected to the cantilevered platform on the outer wall. The slide is installed on the outer wall and is made of stainless steel. The height of the slide is 4.5m and the inclination angle is 45°. Fences are set around the escape slide to facilitate daily management.
5. **Optimization of evacuation routes for workers based on the reconstruction of escape facilities**

The overturning accident of the aluminum ladle in the aluminum casting workshop and the leakage of the furnace mouth of the mixing furnace will not affect the evacuation of the on-site mixing furnace duty personnel, peelers, foundry workers and packers. Therefore, the evacuation routes of the workers in these four positions will not be modified. Escape according to the original evacuation route. Focus on optimizing the escape routes of crane drivers and hybrid furnace eye workers who may be affected by the leakage and diffusion of molten aluminum.

- In the scene of an aluminum ladle overturning accident, the crane driver will no longer evacuate through the interior of the foundry workshop. The evacuation route is modified to: crane→cantilever platform→escape slide→outdoor.
- In the scene of the aluminum ladle overturning and the leakage of the furnace mouth of the mixed furnace, the furnace eye workers of the mixed furnace will no longer evacuate through the upper platform. The evacuation path is modified to: the working platform of the furnace mouth of the mixed furnace → escape escalator → lower platform → exit 1.

6. **conclusions**

In this paper, a personnel evacuation system in the scene of a high-temperature molten metal leakage accident is designed, including an escalator for evacuation of furnace workers and a slide for evacuation of crane drivers. And considering the use of the evacuation system, the original evacuation strategy for different positions in the workshop was re-planned, so that the efficiency of evacuation was significantly improved. Relevant research results can provide engineering cases for the evacuation and transformation of similar workshops.

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