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DEVELOPMENT OF REFRACTORY THICKNESS METER FOR TORPEDO LADLE CAR

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Abstract – To inspect the refractory of torpedo ladle car at high temperature is effective in expanding its service life and reducing its maintenance cost, preventing metal break out. As to metal impact area, the refractory thickness could not be inspected by thermal analysis of outer steel shell. The refractory thickness meter was installed at torpedo repair shop for evaluating its measurement stability and refractory thickness measurement accuracy. It has two surface profile maters using laser rangefinder equipped with two tilt stages, facing each other. It measures the inner refractory profile and the outer steel shell profile at one time to calculate the accurate refractory thickness without influence of the outer shell deformation. After 90 minutes from discharging molten iron, it could achieve stable measurement without the influence of fume and heat haze, and could measure the refractory thickness with a good accuracy of 7.3mm (1 sigma).

Keywords: Torpedo ladle, laser surface profiler, refractory thickness

1. INTRODUCTION

Torpedo ladle car is a horizontal cylinder shape container transferring molten iron taped from blast furnace to steel making plant. It is lined with refractory constructed the insulating bricks on the inside of steel shell. This refractory must be repaired or relined when the refractory is thinned down or worn away by erosion. For torpedo ladle car, the service life is determined by the refractory thickness in the two critical areas with high erosion rate. One is slag line area, at the torpedo side wall, eroded by slag floating on the molten iron. Another is metal impact area at the bottom of torpedo ladle. Fig. 1 shows cause of refractory erosion in this area. The refractory is eroded by thermo-mechanical shock when the molten pig iron taped from blast furnace.

To inspect the refractory accurately at high temperature is effective in extending its service life by efficient refractory use and reducing its maintenance cost. Conventionally as to the refractory of containers used to transport and pour out molten metals like ladles, two inspection methods have been reported. One method was measuring the inner brick surface profile by laser rangefinder with laser scanner [1], [2]. Another method was estimating the refractory thickness from temperature distribution monitoring of container shell by the infrared camera [3], [4].

The measuring the inner refractory surface profile, by laser rangefinder, has the problem that thickness measuring accuracy was limited by thermal deformation of outer steel shell and its positioning accuracy. This method has not been applied for torpedo ladle. On the other hand, temperature distribution monitoring has been widely used for inspection of torpedo ladle refractory. However, this method needs the torpedo filled with the molten iron, and is only applicable to inspect the refractory of slag line area at the side wall.

At the metal impact area, erosion rate is the fastest in the all of torpedo ladle refractory. Therefore, to preventing metal break out from this area, the torpedo ladle is cooled to room temperature and inspected its refractory after a fixed-number of molten metal has been transported. Because it is repaired or relined as necessary by the inspection results, the refractory with usable thickness was often relined.

For improving the refractory thickness maintenance accuracy, the refractory thickness meter for thermal impact zone, which has two surface profilers, was installed at torpedo repair shop for evaluating its measurement stability and refractory thickness measurement accuracy. In this paper, the evaluation result of the developed refractory thickness meter is described.

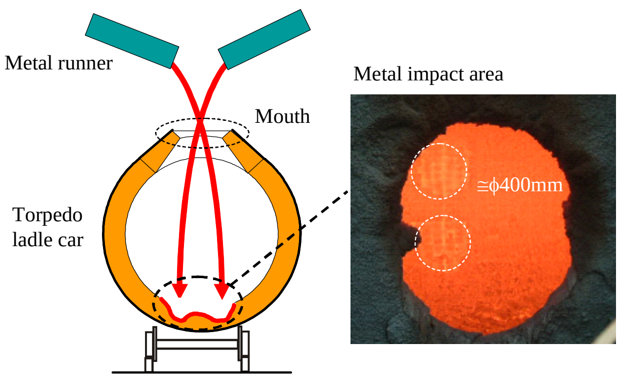

Fig. 1 Cause of refractory erosion in the metal impact

2. REQUIRED SPECIFICATION

Required specification of refractory thickness meter for torpedo ladle is shown in Table 1. A target torpedo capable of holding 400 tons of steel has an outside diameter of approximately 4000mm. It is difficult to obtain the accurate refractory thickness without correcting the influence of the outer shell deformation and its positioning precision.

The refractory must not be cooled down to prevent thermal damage on the bricks. The measurement must be completed within 2 hours after discharging molten iron. Because of inner high temperature, the residual hot slag produces fume and heat haze near the torpedo ladle's mouth. This environment makes it difficult for laser surface profiler to obtain stable measurements.

The challenges to develop the refractory thickness meter are:

(1) To obtain the stable measurements at high temperature right after discharging molten iron.

(2) To measure accurate refractory thickness with accuracy of 10mm (1 sigma) without the influence of outer shell deformation and its positioning precision.

Table 1 Required specification

Item	Specification
Target	400ton torpedo ladle
Outer diameter	Approximately 4000mm
Measurement area	±40 degrees (Central angle) ±500mm (Axial position)
Thickness range	0 - 500mm
Temperature	Max.1100 ºC
Accuracy	10mm (1 sigma)
Measurement time	Within 2 hours after discharge molten iron

3. SYSTEM DESCRIPTION

For removing residual slag from the bottom of the torpedo, the torpedo is tilted 90 degrees right after discharging the molten iron. The residual molten slag flows to side wall of the torpedo. Fig.2 shows the photograph of the laser surface profilers. These equipped with the laser rangefinder and two axis tilt stages. The laser rangefinder is categorized as a class 2 laser product, eye damage couldn't occur, was chosen for outdoor use. It employs a modulated beam "time-of-flight" principle, which measures the time light takes to travel to the target and back. The time delay is indirectly measured by comparing the signal from the laser with the delayed signal returning from the target. This measurement principal could not be influenced by heat haze easily compared to the triangulation one. Its distance measurement accuracy is 1mm (1 sigma) with 4 second response.

For calculation of refractory thickness from inner refractory surface profile, the actual diameter and centre coordinates of outer steel shell are necessary. But these values couldn't be given from the initial design dimension because of thermal deformation and torpedo stop position precision. For considering these values, the developed refractory thickness meter equipped additional laser surface profiler to measure the outer shell profile.

Fig. 3 shows the layout of the refractory thickness meter for torpedo ladle. Two laser surface profilers measure the inner refractory surface profile and the outer steel shell profile. These are facing each other across the torpedo ladle track and positioned at nearly the same height as to the torpedo ladle central axis. The distance between laser surface profiler, measuring inner refractory profile, and torpedo ladle central axis are about 5000mm to get optical path through the required measurement area, central angle ±40 degrees. The distance between laser surface profiler, measuring outer shell profile, and torpedo ladle's central axis are about 9000mm to avoid interfering neighbour hood tracks. The control PC gathers rangefinder's measurements and laser optical path angles of both laser surface profilers. Then it calculates the refractory thickness.

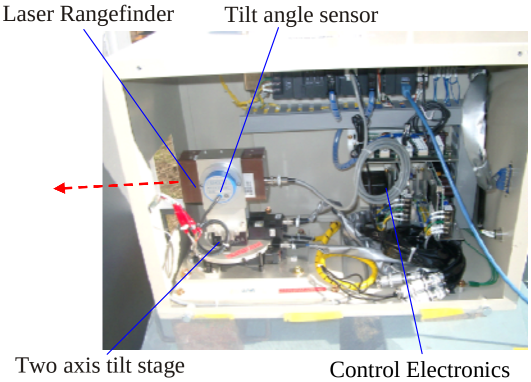

Fig. 2 Photograph of the laser surface profiler

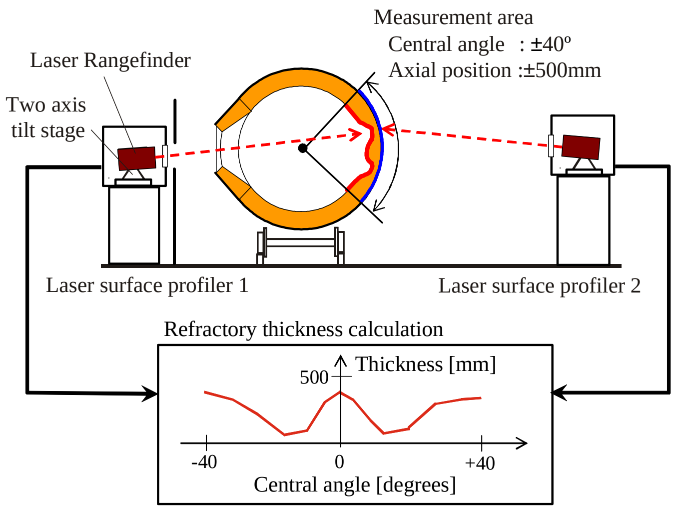

Fig. 3 Arrangement of refractory thickness meter for torpedo ladle

4. THICKNESS CALCULATION

Fig. 4 shows the parameters used for thickness calculation. The profilers output the measured distance L_i and laser incident angle ϕ_i for horizontal, θ_i for vertical. These polar coordinates of measurements translated to orthogonal coordinates by equation (1). Here, the subscript indicates the laser surface profiler, i=1 means the measurement for inner refractory profile, i=2 means the measurement for outer shell profile. D and h_i means relative displacements between two laser surface profilers. D means horizontal distance between them. h_i means vertical displacements from a reference height equal to torpedo ladle central axis occurred by height difference between ground levels.

$$\begin{cases} x_1 = L_1 \cos\theta_1 \sin\phi_1 \\ y_1 = L_1 \sin\theta_1 + h_1 \\ z_1 = L_1 \cos\theta_1 \cos\phi_1 \end{cases} \quad \begin{cases} x_2 = D - L_2 \cos\theta_2 \sin\phi_2 \\ y_2 = L_2 \sin\theta_2 + h_2 \\ z_2 = L_2 \cos\theta_2 \cos\phi_2 \end{cases} \tag{1}$$

For calculating equation (1), the relative displacements hi and D are necessary. Fig. 5 shows the method to measure the relative displacement. The target board, on which the cross-hair is drawn, is positioned at the same height as to torpedo central axis between the laser surface profilers. When both lasers of laser surface profilers indicate to the cross-hair intersection, measured distances L_{Ti} and incident vertical angle θ_{Ti} are given. Using target thickness T, relative displacements between two laser surface profilers h_i and D could be calculated by equation (2), (3).

$$D = D_{T1} + D_{T2} = L_{T1}\cos\theta_{T1} + L_{T2}\cos\theta_{T2} + T \tag{2}$$

$$h_i = -L_{Ti}\sin\theta_{Ti} \tag{3}$$

Fig. 6 shows the example of inner refractory profile and outer steel shell profile after translation to orthogonal coordinates. The regression circle to the outer shell profile is calculated. Its central axis coordinates (x_C, y_C) and its diameter R_S are equal to the actual target torpedo's ones. Using these values and outer steel shell thickness T_S, the refractory thickness T_R and central angle α could be calculated by equation (4), (5).

$$T_R = R_S - T_S - \sqrt{(x_1 - x_C)^2 + (y_1 - y_C)^2} \tag{4}$$

$$\alpha = \tan^{-1}\left(\frac{y_1 - y_C}{x_1 - x_C}\right) \tag{5}$$

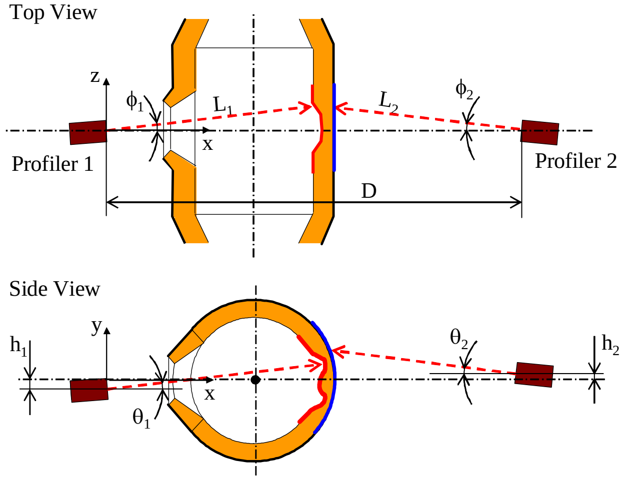

Fig. 4 the parameters used for thickness calculation

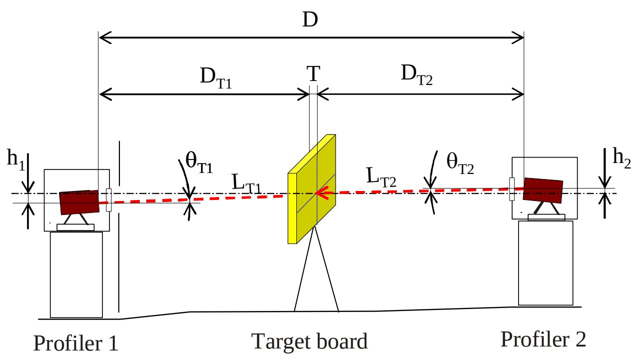

Fig. 5 the method to measure the relative displacement

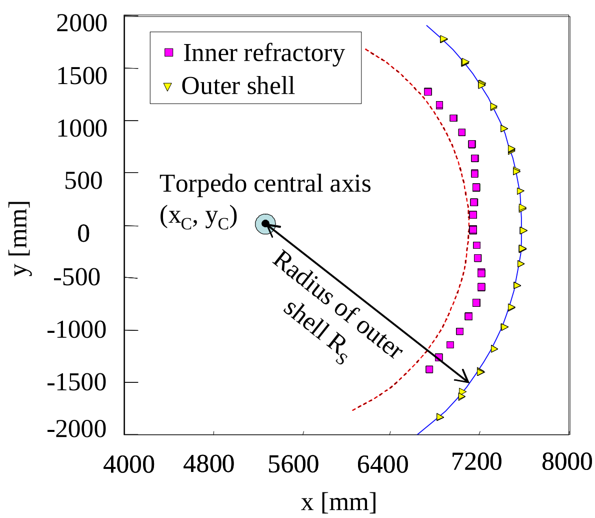

Fig. 6 The example of measured profiles

4. EVALUATION RESULT

The thickness measurement accuracy at room temperature was evaluated by arc-shaped mock-up sample. Its radius of curvature was equal to torpedo ladle's initial one and thickness was 200mm. Fig.7 shows the example of the thickness measurement result for the mock-up sample. It indicated that the refractory thickness meter had thickness measurement accuracy within 4mm, and could achieve the required measurement accuracy at room temperature.

Fig. 8 shows the influence of progress time after discharging molten iron on rangefinder's measurement stability. To evaluate the influence of fume and heat haze near the torpedo ladle mouth at high temperature, intensity and measurement success rate of the rangefinder were monitored continuously after discharging molten pig iron. After 90 minutes from discharging molten pig iron, disappearance of fume and heat haze increased the received intensity and measurement success rate. It indicated that the laser surface profilers could measure the accurate inner refractory profile after 90 minutes from discharging molten iron.

Fig. 9 shows an example of the refractory thickness measurement result for the torpedo ladle at high temperature. The eroded refractory profile at metal impact area could be observed clearly. To evaluate its thickness measurement accuracy, some eroded refractory bricks were sampled from the bottom of the torpedo when its refractory was relined after cooling. Then, these thicknesses were directly measured by ruler. Fig. 10 shows the comparison of the thickness measured by the refractory thickness meter with one of the samples after cooling. The difference of the thickness measured by the developed refractory thickness meter and one of the samples is 7.3mm (1 sigma). It indicated that the developed refractory thickness meter had good measurement accuracy.

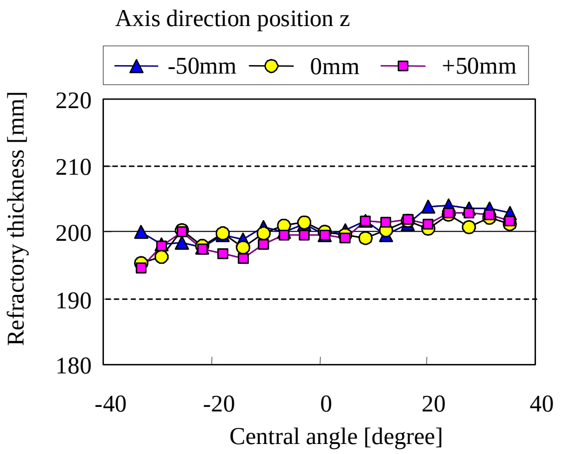

Fig. 7 Measurement accuracy of mock-up sample

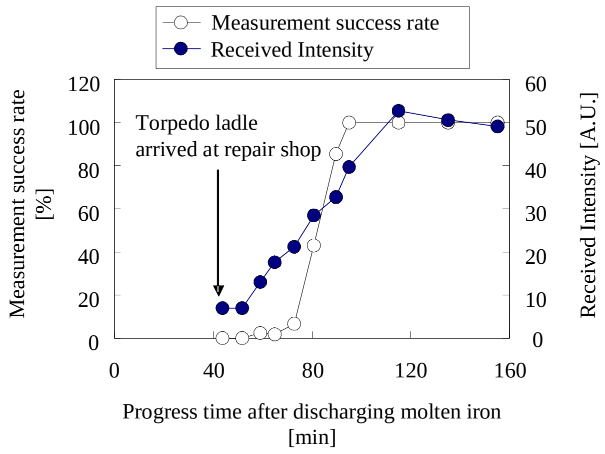

Fig. 8 Influence of progress time after discharging molten iron on rangefinder's measurement stability

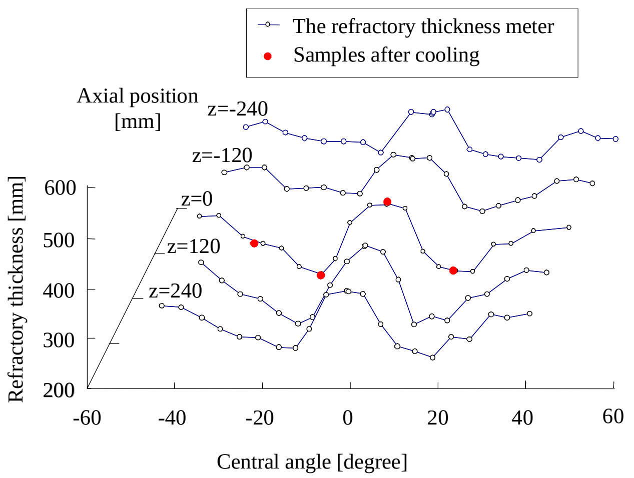

Fig. 9 The example of the refractory thickness measurement result

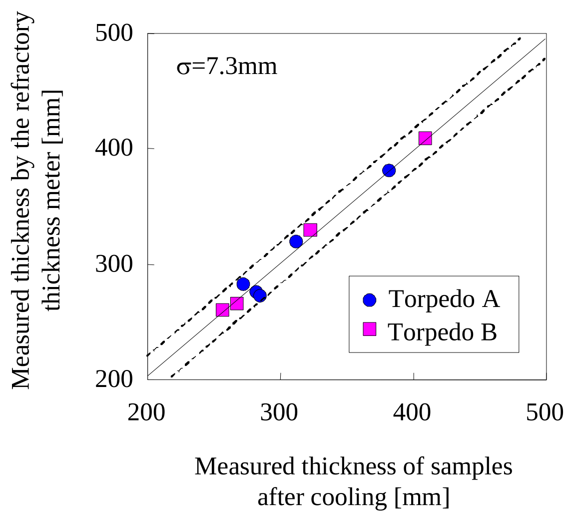

Fig. 10 Comparison of the thickness measured by the refractory thickness meter with one by the sampling after cooling

5. CONCLUSION

For improving the refractory thickness maintenance accuracy, the refractory thickness meter for metal impact area was developed. It was equipped with two surface profilers, and was installed at torpedo repair shop for evaluating its measurement stability and thickness measurement accuracy. The evaluation result is below;

After 90 minutes from discharging molten iron, it could achieve accurate and stable measurements without the influence of fume and heat haze.

It measures the inner refractory and outer steel shell profile at one time to calculate the accurate refractory thickness without influence of outer shell deformation and its positioning precision. It could measure the refractory thickness with a good accuracy of 7.3mm (1 sigma).

The refractory thickness meter would be able to be effective in expanding the service life and reducing maintenance cost of torpedo ladle car.

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