ESTIMATION OF LUBRICITY BY NUMERICAL METHOD ON SURFACE OF NBC-REINFORCED TOOL FOR HOT STEEL ROLLING

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Summary. *Investigation was carried out on the lubrication mechanism of NbC-reinforced tool for hot metal working. Observations on the surface of reinforced tool carried out after use to clarify that the tool surface was covered with a kind of oxide. X-ray analysis showed that the oxide was Nb_2O_5. Laboratory experiment was carried out to grasp the condition of heating in air for the transformation of NbC to Nb_2O_5, and following the condition NbC powder was heated to obtain Nb_2O_5 powder. Hot rolling experiment of steel sheet followed. Prior to rolling Nb_2O_5 powder was placed on one side of the sheet on the inlet side, and the curl of the rolled sheet was measured. Elastic-plastic FEA was carried out to specify the coefficient of friction at high temperature. The numerical result well matched to the experimental result when the value of coefficient of friction of Nb_2O_5 was 0.15. The value is equivalent to the value of graphite which is a well know good lubricant at high temperature.*

1 INTRODUCTION

It is known that the tool life for hot steel rolling extends ten times as long as that of conventional tool when the surface is reinforced by NbC powder using a Plasma-Transferred-Arc (PTA) welding technique [1]. The reinforced tool is also applicable to stainless steel or Titanium [2] but the mechanism operating on the surface for elongating the tool life has not been clarified yet. The authors have made clear the influences of size and fraction of NbC particle in the parent powder mix for PTA on the wear resistant characteristics of the reinforced tool. In the course of the past investigation it has been estimated that NbC grains on the tool surface may reveal lubricity when the tool is used at high temperature. It is important to characterize the surface of NbC grains on tools surface when it is exposed to high temperature. NbC may change to a substance which may show high lubricity [3]. It is also important to know, on the application stage, the value of the coefficient of frction of the substance that cover the NbC grains. Elastic-plastic FEA is powerful to specify the value and only a comparison is necessary between the experimental and numerical results. When no lubricant is applied on both surfaces of sheet the geometry of rolled sheet is flat, but when a lubricant is applied on one side of the sheet the rolled sheet curls exposing the lubricated side toward the outside depending upon the coefficient of friction. The details are as follows.

2 BASIC EXPERIMENT BY PTA-WELDED TOOL

Fig.1 shows an example of PTA-welding machine and an enlarged illustration of the nozzle where a mixture of matrix and reinforcing powders is dispersed. The matrix powder and the reinforcing powder are conveyed by a plasma onto the specimen surface to form a reinforced surface by a hard powder, in the present case NbC particles.

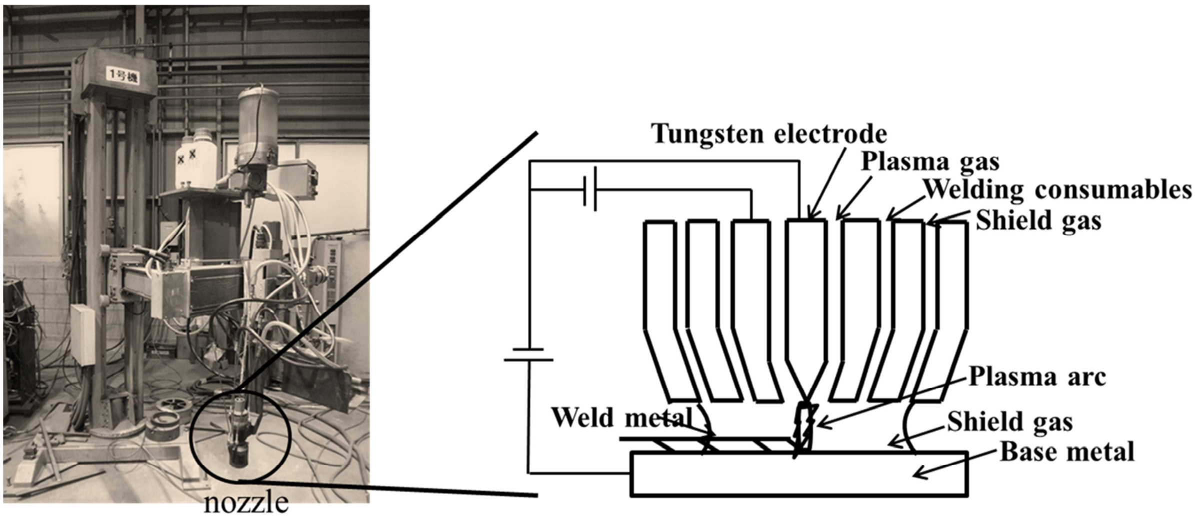

Fig. 1 Example of PTA machine and illustration of nozzle.

Usually powder with diameter from a few ten μm up to about 150μm is chosen to form a stable reinforced layer with thickness of a few mm on the specimen surface. Fig. 2 shows typical examples of welded layer using various sizes of NbC particles. The matrix powder is SUS309L and the base metal is a medium carbon steel. It is shown that according to the mixture ratio of NbC and SUS309L powders before PTA-welding and according to the powder size, the density of dispersed NbC particles in the welded surface layer is different.

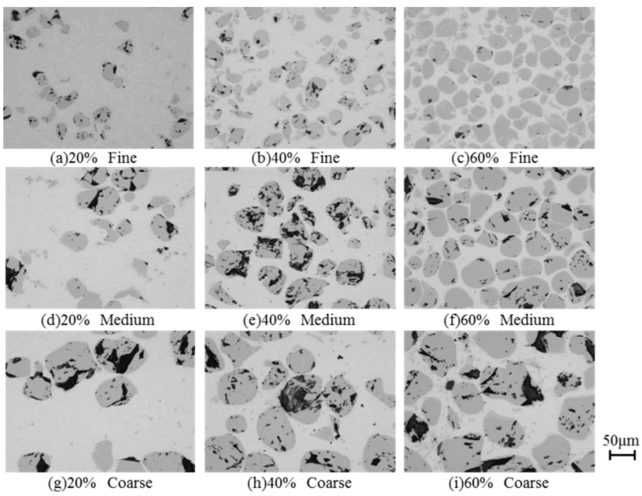

Fig. 2 Examples of dispersed NbC particles in welded layer under different welding conditions.

Observation by FE-SEM and analysis by EDX showed that the particles are NbC as it is shown in Fig. 3.

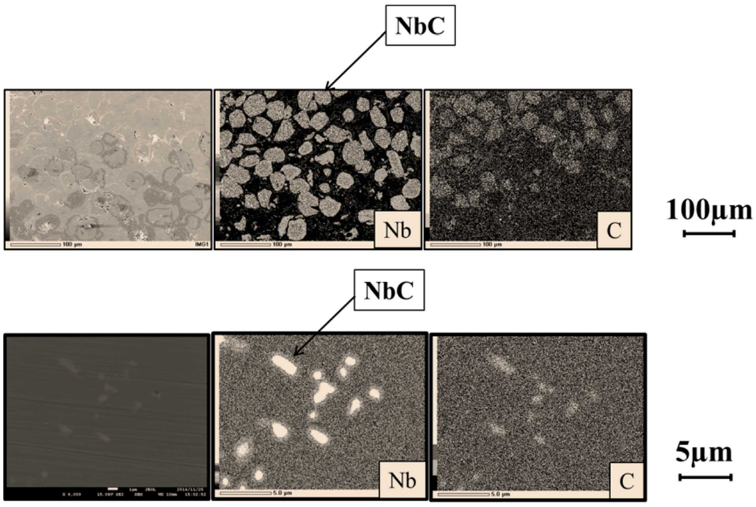

Fig. 3 Example of analytical result of surface layer by FE-SEM and EDX.

Hot sliding test was carried out following the manner indicated in Fig. 4. A disc made of medium carbon steel with 125mm in diameter was rotated in a speed of 33rpm and the surface of the disc was heated by an induction coil. The specimen surface reinforced by NbC particles was pressed on the rotating disc under the force of 980N. As soon as the sliding distance reached 600 mm the test was stopped and the specimen was taken out of the machine in order to observe the wear track. Considerable difference was not observed among the specimens having different fraction and size of parent NbC powder.

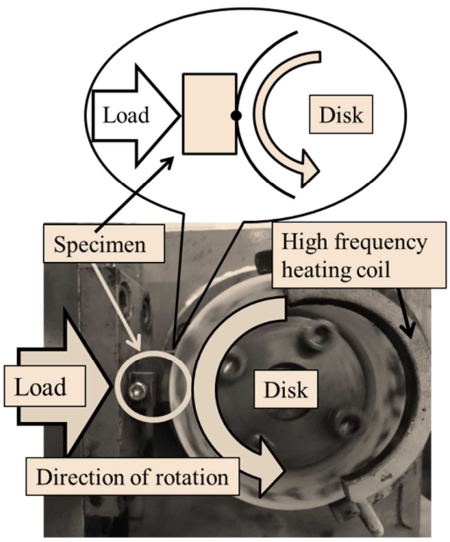

Fig. 4 View of hot sliding test.

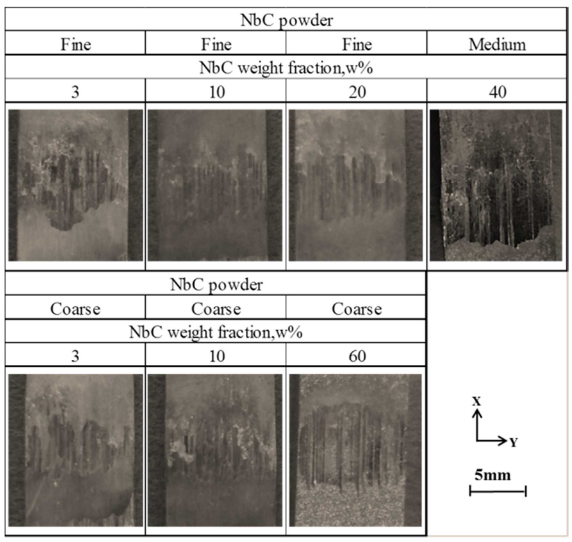

Fig. 5 Comparison of wear tracks.

Fig. 6 shows the result of sliding test. It is clearly indicated that small amount of NbC is enough to reinforce the tool surface.

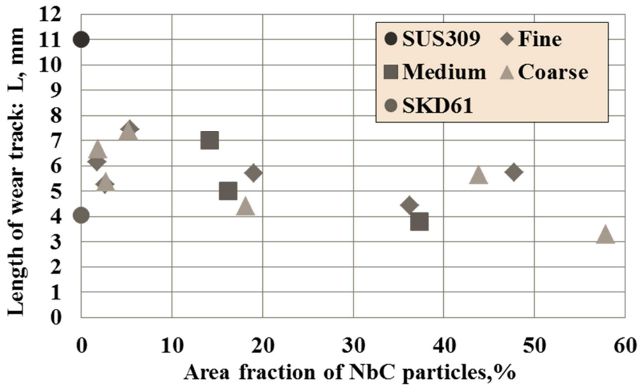

Fig. 6. Influence of size and weight fraction of NbC powder in parent powder on length of wear track

It is curious to note that on the surface of wear track slight amount of whitening was observed and closer investigation on the wear track by FE-SEM-EXD suggested that oxide of Nb might be formed on the wear track. One of the examples is shown in Fig. 7.

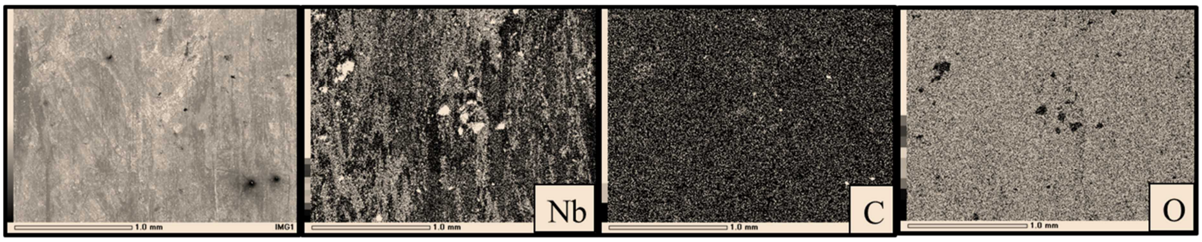

Fig. 7. Indication of oxide formation on wear track after hot sliding test.

3 EXPERIMENT FOR TRANSFORMATION OF OXIDE

Fig.1 shows an example showing the influence of temperature and holding time on transformation of NbC powder to oxide. Heating temperature of 873K is enough for the transformation, and the higher the heating temperature is the shorter the holding time becomes.

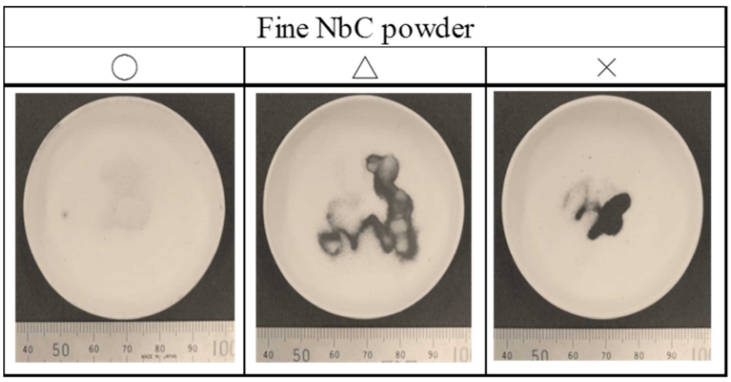

Fig. 8 Comparison of heating condition on oxide formation of Nb.

The transformed white powder was subjected to X-ray analysis. The result is shown in Fig. 9 and it is indicated that the oxide was Nb_2O_5.

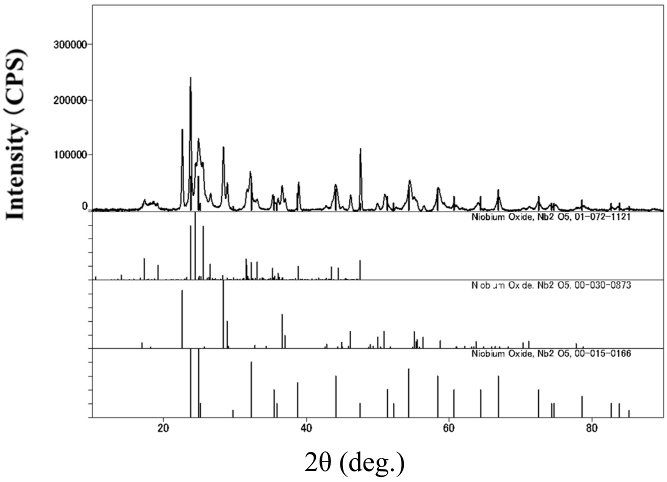

Fig. 9 Result of XRD analysis of powder after whitening. (Courtesy of Technology Research Institute of Osaka Prefecture)

4 HOT ROLLING TEST

In order to evaluate the coefficient of friction of Nb_2O_5 at high temperature hot rolling test was carried out. The specimen prepared for the experiment was a sheet specimen with thickness in 2.9mm and width in 40mm. Only on the upper side of the sheet Nb_2O_5 powder was uniformly placed before the specimen was put in an electric furnace. Two levels of heating temperature was adopted; 1073K and 1273K. For comparison another type of specimen was prepared using a well-known lubricant graphite was placed. If the coefficient of friction reduces on the upper side the sheet would curl downward after rolling. The roll diameter was 70 mm and the barrel length was 117 mm. The result is shown in Table 1. The rolled sheet was flat regardless of the temperature when no graphite or Nb_2O_5 was placed on the upper surface. It means that the coefficients of friction were the same on the upper and lower surfaces of the sheet. When lubricant was placed on the upper surface the sheets curled downward, i.e. the direction of curl was the same for graphite and Nb_2O_5, and the curvatures were nearly the same. This result suggested that Nb_2O_5 shows an excellent lubricity at high temperature. It is important to note that the higher the temperature is the larger the effect is in decreasing the coefficient of friction. The value approaches to that of graphite according to the increase in temperature.

Table 1: Comparison of curvature between rolled specimens

Lubrication condition	Curvature (1073K)	Curvature (1273K)
No lubricant	0	0
Graphite on upper surface	0.015	0.015
Nb_2O_5 on upper surface	0.02	0.017

5 FEA ON HOT ROLLING

Elastic-plastic FEA was carried out on hot sheet rolling. It was a plane strain analysis in the width direction and the code used was ELFEN. The coefficient of friction on the lower side was fixed throughout the analysis to 0.2 or 0.3 that has been used in the conventional analysis as the value of coefficient of friction in hot rolling. One of the results is shown in Fig. 10 which is a plot of calculated curvature by FEA against the change of the value of coefficient of friction on the upper side leaving the value of coefficient of friction on lower side constant. According to the increase in friction coefficient on upper side the rolled sheet becomes flat. Because the measured curvature was 0.02, it is estimated that the coefficient of friction on the upper side was 0.13. It is a considerable decrease. Similar results were obtained when the value of the coefficient of friction on the lower side was changed.

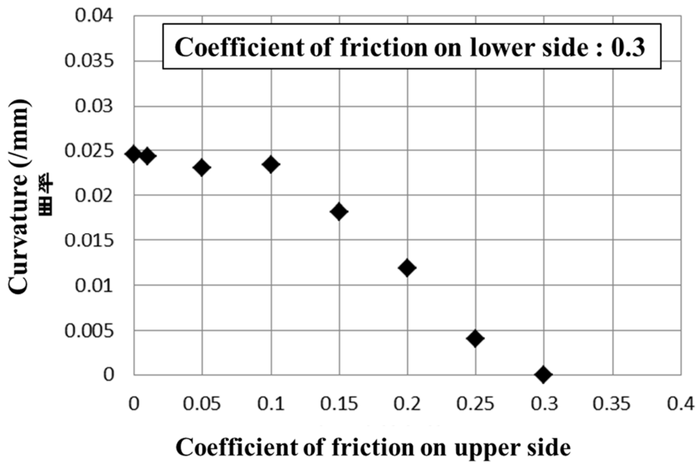

Fig. 10 Estimation of coefficient of friction of Nb_2O_5 at 1073K.

6 CONCLUSIONS

Experiments were carried out to investigate the mechanism of high performance of NbC reinforced surface layer of tool by PTA-welding. The result suggested that not only the reinforcement of matrix by dispersed NbC particles but also lubricity of tool may be the cause of high performance of the reinforced tool. Investigation made it clear that the surface of NbC particle changes to Nb_2O_5 and Nb2O5 might show high lubricity. Hot rolling experiment of steel sheet validated this hypothesis and elastic-plastic FEA suggested that coefficient of friction Nb2O5 may be slightly smaller than 0.15.

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