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Stress Analysis of Shrink Fitting System used for Conveying Rollers

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1. Introduction

Steel conveying rollers used in hot rolling mills (see Fig.1) must be changed very frequently because conveyed strips with high temperature induces wear on the roller surface in short periods. Flame spray coating [1] has been used to repair such damage and effect of material properties of roller has been investigated in previous studies. However, a conventional roller as shown in Fig.2(a) is not suitable for maintenance because we have to change the whole roller.

In this study, we will focus on the roller structure where a sleeve and short shafts are connected by shrink fitting at both ends as shown in Fig.2(b). The new roller is suitable for maintenance and reducing the cost by changing the sleeve only. In addition, the running speed of the steel strip can be changed easily due to the light weight. Moreover, further cost reduction can be realized if ceramics are used as the sleeve material because they offer high temperature resistance and high abrasion resistance.

However, for the hollow rollers, care should be taken for the maximum bending stress at the centre of roller and maximum stress appearing at the edge of the sleeve. Especially, because fracture toughness of ceramics is extremely smaller compared with steel, stress analysis for the roller becomes more important. Therefore, in this study FEM analysis is applied to the structure as shown in Fig.2(b).

2. Method of Analysis

2.1 Boundary Condition Define the shrink fitting ratio as δ/d where δ is the diameter difference with the diameter $d=210\text{mm}$. Assume that the roller is subject to

distributed load $w=100\text{N/mm}$ and simply supported at both ends (see Fig.3). The friction coefficient (between sleeve and shafts) is assumed as 0.3.

2.2 The Material Properties Stainless steel is usually used for conventional rollers but ceramics and cemented carbide rollers may provide a longer maintenance span due to high temperature resistance and high abrasion resistance. However, stress analysis is necessary for ceramics and cemented carbide because of their low fracture toughness and high sensitivity for

Fig.3 Models considered

Fig.4 Finite element mesh

Fig.1 Layout of Conveying Rollers

Fig.2 Roller Structure

Table.1 Material Properties

	Young's Modulus [GPa]	Poisson's Ratio	Fracture Toughness [MPa.(m) ^{1/2}]	Tensile Strength [MPa]
Steel	210	0.3	120	600
Ceramics	300	0.28	7.7	500
Cemented Carbide	500	0.24	20	1,000

(a) $\sigma_{\theta s}$ due to shrink fitting
Fig.5 Stress distribution σ_{θ} when $\delta/d=3.0 \times 10^{-4}$
($\sigma_{\theta s}$: Stress due to shrink fitting, $\sigma_{\theta b}$: Stress due to load distribution)

(a) $\sigma_{\theta \max}(=\sigma_{\theta s}+\sigma_{\theta b})$ vs. δ/d
Fig.6 σ_{θ} vs. δ/d when $L=100, 150, 210$ mm ($\sigma_{\theta s}$: Stress due to shrink fitting, $\sigma_{\theta b}$: Stress due to load distribution)

small defects. Table 1 shows the material properties of steel, ceramics, and tungsten carbide.

2.3 Analysis Model Fig.4 shows the finite element mesh model of the conveying rollers. The number of elements is 23,340 and the number of the nodes 26,751. Only 1/4 of the roller is considered due to symmetry.

3. Results and Discussion

3.1 Maximum Tensile Stress Figure 5 shows stress distributions of the conveying rollers. Figure 5(a) shows stress $\sigma_{\theta s}$ due to shrink fitting and Fig.5(b) shows maximum stress distribution $\sigma_{\theta \max}(=\sigma_{\theta s}+\sigma_{\theta b})$ due to load distribution $w=100$ N/mm after shrink fitting. As shown in Fig.5(a), the maximum tensile stress at point A while shrink fitting is 75.2MPa. It becomes 85.6MPa by applying the distribution load after shrink fitting, which is a 10.4MPa increase.

3.2 Effect of Fitting on Length Figure 6(a) shows $\sigma_{\theta s}$ vs. δ/d relation and $\sigma_{\theta \max}(=\sigma_{\theta s}+\sigma_{\theta b})$ vs. δ/d relation for different fitted length L . As shown in Fig.6(a), $\sigma_{\theta s}$ is proportional to δ/d independent of L . Figure 6(b) shows $\sigma_{\theta b}$ vs. δ/d relation. For shrink fitting ratio $\delta/d=0$ at $L=210$ mm $\sigma_{\theta b}=43.4$ MPa. When the length $L=100$ mm $\sigma_{\theta b}=91.1$ MPa. Stress $\sigma_{\theta b}$ increases with decreasing L .

However, when shrink fitting ratio $\delta/d \geq 2.0 \times 10^{-4}$, $\sigma_{\theta b}$ becomes constant 10.8MPa independent of δ/d . When $\delta/d \geq 2.0 \times 10^{-4}$, the shaft and sleeve can be treated as a unit body independent of δ/d . From Fig.6(a), it is found that $\sigma_{\theta \max}$ has minimum value 60.5MPa at $\delta/d=1.8 \times 10^{-4}$ when $L=100$ mm. Similarly, optimum shrink fitting ratio is $\delta/d=1.2 \times 10^{-4}$ when $L=150$ mm, and also $\delta/d=5.0 \times 10^{-5}$ when $L=210$ mm.

Figure 7 shows $\sigma_{\theta \max}(=\sigma_{\theta s}+\sigma_{\theta b})$ vs. δ/d relation and $\sigma_{\theta b}$ vs. δ/d relation for different material of conveying rollers. Maximum stress $\sigma_{\theta \max}$ of cemented carbide is larger than that of ceramics and steel at the same value of δ/d .

Fig.7 σ_{θ} vs. δ/d of steel, ceramics and tungsten carbide of conveying rollers. ($\sigma_{\theta s}$: Stress due to shrink fitting, $\sigma_{\theta b}$: Stress due to load distribution)

References

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