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Failure analysis for coming out of shaft from shrink-fitted ceramic sleeve

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ABSTRACT

This paper deals with failure analysis for coming out of the steel shaft from ceramic sleeve connected by shrink fitting. Only low shrink fitting ratio can be applied because of the brittleness of the ceramic sleeve. However, the steel shafts may be loosening out from the ceramic sleeve under such low shrink fitting ratio. In this study, the coming out behavior of the shaft during rotation is analyzed by the finite element method. The roller rotation is replaced by shifted load in the circumferential direction on the fixed roller. It is found that the load rotation can be approximated by the discrete load shifting at the interval angle $\theta_0 = 12°$ within 1% error. The effect of the shrink fitting ratio on the coming out of the shaft is discussed as well as several other parameters, such as Young's modulus of the shaft, the friction coefficient, magnitude of the load, and geometry of the shaft. Furthermore, it is found that the shear stress distribution at the shrink-fitted area may be useful for evaluating whether the coming out occurs or not.

1. Introduction

Steel conveying rollers are used in the heating furnace as shown in Fig. 1 to produce high-quality steel plates for automobiles. Fig. 2(a) shows the conventional roller whose inside is cooled by water circulation to reduce the temperature although causing some energy loss and maintenance cost. The steel sleeve and steel shafts are usually connected by shrink fitting and bonded by welding, and the steel sleeve is coated by ceramic on the surface to improve wear resistance. However, the thermal expansion mismatch may induce surface failures such as crack, peeling, wearing resulting in short roller life [1].

Fig. 2(b) shows a new ceramics roller consisting of steel shafts at both ends and ceramic sleeve having high heat resistance, wear resistance [2], and corrosion resistance [3]. All ceramic sleeve may prevent most of the defects observed at coated ceramic, and therefore, the roller life can be extended significantly. Since adhesive bonding and metal bonding have very low strength under high temperature, only shrink fitting can be applied for ceramic sleeve and steel shaft connection used in the heating furnace [4–7]. The thermal expansion coefficient of steel is about four times larger than that of ceramic having low fracture toughness [8,9], attention should be paid to the risk of ceramic sleeve fracture.

In the previous study the authors have considered similar ceramic structures under high temperature environment in continuous galvanizing line [10,11], in the continuous pickling line [12], and in the heating furnace [13]. It should be noted that only low shrink fitting ratio can be applied for those structures because of the ceramic brittleness.

As an example, similar all ceramic rolls have been successfully developed to be used in a molten metal bath in continuous galvanized steel line [9–11]; however, coming out of the shaft was observed several times in prototype rolls. Since sliding bearings for rolls and rollers do not restrict the axial movement of the shaft, the coming out can be problematic. Even when the shaft movement is restricted within a small allowable range, the coming out of the shaft may cause local thrust loading, frictional heat generation, and wear

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Nomenclature

δ	diameter difference [mm]
d	inner diameter of the sleeve [mm]
T	sleeve thickness [mm]
t	shaft thickness [mm]
L	contact length [mm]
w	distributed load on the roller surface [N/mm]
ρ	mass density [kg/m^3]
ν	Poisson's ratio
μ	friction coefficient
δ/d	shrink fitting ratio
a	outer diameter of the sleeve [mm]
b	inner diameter of the sleeve [mm]
N	number of cycle
E_{sl}	Young's modulus of the ceramic sleeve [GPa]
E_{sh}	Young's modulus of the steel shaft [GPa]
θ_0	interval of load shift angle in the simulation
u_{zA}	displacement at point A [mm]
u_{zC}	displacement at center point [mm]
σ_r	radial stress on the contact part [MPa]
τ_{rz}	shear stress at z-direction [MPa]

preventing smooth rotation of the roller. Previously, Truman and Booker investigated micro-slipping between the gear hub and shaft connected by shrink fitting [14]. Antony analyzed contact separation for rotating thermos-elastoplastic shrink fit assembly [15]. However, few failure studies are available for coming out of the shaft from the shrink-fitted ceramics sleeve.

In this paper, therefore, the coming out behavior of the steel shaft from the ceramic sleeve will be considered during operation. The finite element method is applied to simulate the behavior. Then, several mechanical factors will be considered to understand the coming out of the shaft.

2. Analysis conditions

2.1. Shrink fitting connection with roller dimensions

Fig. 3 shows dimensions of the roller considered whose outer diameter D = 300 mm. Here, the roller consists of ceramic sleeve and steel shaft connected by shrink fitting. The shrink fitting ratio is defined as δ/d, where δ is the diameter difference and d is the inner

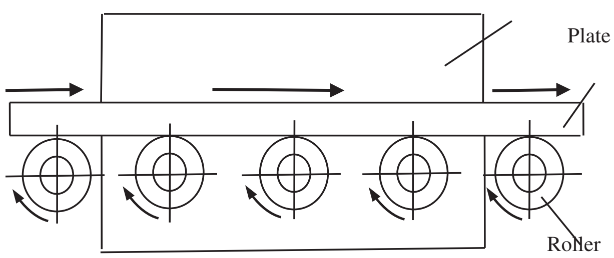

Fig. 1. Layout of rollers in heating furnace.

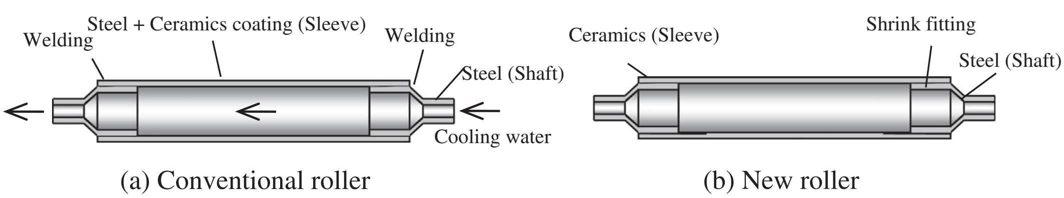

Fig. 2. Roller structure (a) Conventional roller; (b) new roller.