Abstract:

Product design is mostly centered around design of contact pairs. Among contact pairs interference fits pair is widely used. Design of interference fits involves not only dimensional interference but also condition of interface between mating surface. Factors such as texture of interface, hardness of interface material and also physical properties contacting material influence the functional characteristics of interference shrink fitted assemblies. This paper deals with the effect of plating and heat treatment on the strength of the interference fitted assemblies under torque load. The effect of grain size is also assessed. It was observed that there is a considerable improvement in the strength of the interference fitted assemblies when an electroplated layer was introduced between the mating parts and by heating the assemblies. An experimental investigation of the above factors on their assembly strength under torque loading is discussed.

Key words: Torque load, Shrink fitted assembly, Electroplating and Heat treatment

1.1 INTRODUCTION

Interference fitted joints are found to be suitable in mechanical assemblies as they ensure good load carrying capacity as a result of intimate contact between the mating parts [1]. Reliability is attained by form accuracy and good surface finish of mating parts. The load carrying capacity depends on physical dimensions, material characteristics and surface conditions of mating parts.

It also depends on the contact pressure, which is proportional to the magnitude of interference. The coefficient of friction is influenced by many factors such as the roundness and straightness of the shaft and bore and their surface roughness [6]. Earlier studies on
increasing the load carrying capacity of their joints on introducing coatings of different materials, thereby improving the surface finish and area of mating surfaces [1,10]. Such a studies showed that there is scope for considerable improvement on the strength of the assemblies. Sometimes adhesion or mechanical bonding, diffusion between mating parts take place at elevated temperature in case of heat-treated assemblies [5]. Considering some of these aspects into account, the performance of these joints was assessed with an interlayer (coated) between the mating parts. Later, the effect of heat treatment of such assemblies on the torque strength was also found out. The details of experimentation and results are discussed in the following sections.

1.2 EXPERIMENTAL INVESTIGATION

Experiments were conducted to see the strength of interference fitted assemblies using Torque Testing Machine with capacity of 0-2000 Nm (fig.1). The selected grade of fit for investigation was H7u6 with a nominal diameter of 20 mm. The maximum and minimum limits of interference are 54 µm and 20 µm respectively. But, in order to compare the results, it is essential to have a constant interference for all the assemblies to be tested. An interference of 20 µm was selected to facilitate easy assembly using liquid nitrogen. The constant interference was achieved by selective assembly. The photograph, dimensions of the shaft and bush used for investigation are shown in Figs 2. and 3. The material for bush and shaft was mild steel containing 0.23% C and 0.34% C respectively. The bushes and the shafts were finished by cylindrical grinding. In order to see the effect of an interlayer between the mating parts, the shafts were electroplated with chromium and also plated with electroless nickel.

The hardness of the nickel and chromium coating was found to be 450 HV and 1007 HV (Lietz-swiss-micro hardness tester) respectively after this process. The shafts after chrome coating were finished to the required size by cylindrical grinding. This was to achieve uniform finish and also to get similar surface conditions to have a reasonable comparison. The thickness of the coated layer was maintained as 5 µm for all the specimens. In addition to the dimensional measurement (using coordinate measuring machine),
surface finish (Taylor Hobson – surtronics), and roundness (Taylor Hobson - roundness tester) of both the mating parts were checked and only the components with the roundness error within the allowable limits were selected for the assembly and testing as shown figs 5a and 5b. Typical surface finish and roundness profiles are shown in fig 4a and fig 4b. The components were cleaned thoroughly so that they are free from dust and oil. The assembly of the parts used in this experimental investigation was done by shrinking the shaft in liquid nitrogen for few minutes and then pushing it freely into the bore under gravity. These assemblies both coated and uncoated were tested for their strength in a Torque Testing Machine in the static conditions. Some of these nickel coated assembled joints were heat treated by soaking them in a furnace at elevated temperature (500 °C) for specified intervals of time (5 hours), which was followed by furnace cooling. The selection of soaking temperature was based on the results of the previous investigation [6]. The assemblies both coated and heat treated were tested for their strength in a Torque Testing Machine in the static conditions. The maximum torque load required for loosening the joint was noted down for each test, which is the torque load carrying capacity. The results were plotted to the variation of torque load with heat-treated assemblies at elevated temperature and un-heat treated assemblies and are shown in Fig.6, and Tables 1-4.

Three samples were tested in each case and typical results are presented. Based on the results obtained in the load tests some metallurgical investigations were carried out on the heat-treated and un-heat-treated assembled components. The assembled components were separated by electro-discharge machining to avoid the external forces that can induce additional stresses on the specimens. After separating the assembly, the shaft was polished, cleaned and etched with 2% Nital (2% HNO₃ + 98% water). The grain structure of coated and coated with heat treated assemblies were observed under optical microscope at higher magnification. The microphotographs taken at 500X (magnification) were found to be good and so, they were used for grain size measurements. Figure 7a and fig 7b shows the variation of grain size with heat treatment. The maximum torque load required for loosening the joint was noted down and the results are presented.
1.3 RESULTS AND DISCUSSION
The response of coating the shrink fitted assemblies subjected to post assembly heating to the torque carrying capacity was assessed. It was found that the strength increases appreciably by heating the assemblies for a soaking period of 5 hours. The results are shown in table 4. The improvement in strength could be attributed to the formation of fine grain structure due to
Fig.3 General dimensions of the mating parts used in the fit

recrystallization. The grain size was also obtained for these assemblies heat treated at 500 °C and was found to be finer than those of non heat-treated assemblies. Fig 7a shows the microstructure of non heat-treated assemblies with grain size 11.11 µm and Fig 7b that of heat treated at 500 °C, with grain size, 7.14 µm. Another reason for the improvement in strength could be due to strain aging, which occurs in carbon steel. Strain aging is a phenomenon where the metal strength is increased and ductility is decreased on heating at relatively low temperature after cold working [2,3,4]. The effect of plating on the load carrying capacity was assessed by electroless nickel-plating and chrome plating of the shaft to introduce an interlayer between the mating parts. The improvement in the strength was observed in coated assemblies. The increase in strength could be possibly due to the coated layer flowing into the irregularities at the interface thus increasing the contact area. The high shear strength of the hard layer on a
Fig. 4 Typical surface roughness profiles of the mating parts

a) Bush

Ra = 0.173 \( \mu m \), \( R_z = 1.2 \mu m \), \( R_{max} = 1.60 \mu m \), \( R_t = 1.8 \mu m \)

Tracing length: 4.8 mm

Cutoff length = 0.8 mm

b) Bush

Ra = 0.651 \( \mu mm \), \( R_z = 4.64 \mu m \), \( R_{max} = 5.83 \mu m \), \( R_t = 6.23 \mu m \)

Fig. 5 Roundness profiles of the mating parts

Roundness error = 2.16\( \mu m \)

a) Bush

Roundness error = 2.2\( \mu m \)

b) Shaft

Fig. 4 Typical surface roughness profiles of the mating parts
relatively soft substrate could be another reason [8,9]. It was observed that the strength of the assemblies improved further by heat-treating the assemblies with Nickel coated layer of 5 µm thickness at the interface. The improvement could be due to recrystallization and strengthening as a result of improved bonding [7,8,10].

WC = assemblies without coating  
CC = assemblies with Chrome coating  
Nic = assemblies with Nickel coating  
HNiC = assemblies with Electroless coating and heated at 500°C with 5Hrs

Fig.6 Comparison of torque load carrying under Different mating conditions

As coated sample x 500  
Average grain size 11.11 µm

Heat-treated at 500 °C. for 5Hrs x500  
Average grain size 7.14 µm

Fig 7a Structure before heat treatment  
Fig 7.b Structure after heat treatment
### Table 1. Details of torque load tests components without coating

<table>
<thead>
<tr>
<th>Sl.No.</th>
<th>Inside dia of bush mm.</th>
<th>Roundness error µm</th>
<th>Surface roughness Ra µm.</th>
<th>Hardness HV</th>
<th>Outside dia of shaft mm.</th>
<th>Roundness error µm</th>
<th>Hardness HV</th>
<th>Surface roughness Ra µm</th>
<th>Interference µm</th>
<th>Contact length mm</th>
<th>Torque load N-m</th>
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### Table 2. Details of torque load tests with nickel coated assembly

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<th>Roundness error µm</th>
<th>Surface roughness Ra µm.</th>
<th>Hardness HV</th>
<th>Outside dia of shaft mm.</th>
<th>Roundness error µm</th>
<th>Hardness HV</th>
<th>Surface roughness Ra µm</th>
<th>Interference µm</th>
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### Table 3. Details of torque load tests with chrome coated assembly

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<th>Hardness HV</th>
<th>Outside dia of shaft mm.</th>
<th>Roundness error µm</th>
<th>Surface roughness Ra µm</th>
<th>Hardness HV</th>
<th>Interference µm</th>
<th>Contact length mm</th>
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### Table 4. Details of torque load tests with coated and Heat Treated Assembly

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<th>Surface roughness Ra µm</th>
<th>Hardness HV</th>
<th>Outside dia of shaft mm.</th>
<th>Roundness error µm</th>
<th>Surface roughness Ra µm</th>
<th>Hardness HV</th>
<th>Interference µm</th>
<th>Torque load in N-m</th>
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1.4 CONCLUSION

The torque load bearing capacity of interference fitted assemblies has improved due to coating and post heat treatment. The strength improvement depends upon the degree of work hardening and the temperature of soaking which influence the final grain size. As the improvement of strength is due to combined effect of recrystallization and strain aging. The thermal treatment of Nickel coated assemblies gives a much better performance. It is seen that the assemblies with nickel interlayer soaked at 500° C for 5 hours exhibit the highest strength. The variation of strength for the assemblies with different coated layers could be attributed to the characteristics of the coated layer like adhesion of the layer to the base material, hardness of the layers, etc.

REFERENCES


8. Teuvo Juuma, [1999],Torsional fretting fatigue strength of shrink fitted assemblies, Wear 231, pp310-318

