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Analysis of increasing torque with recurrent slip in interference-fits

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ABSTRACT

Previous research associated with interference-fitted assemblies has shown that as recurring slip occurs (i.e. load to total slip, unloading and reload to total slip) there is an observed increase in the holding torque after each loading cycle. The aim of this work was to identify the reasons for this 'torque strengthening' phenomenon. The work also has industrial relevance in the optimum design of interference-fitted rolls used for the hot rolling of steel sections. Previous work has shown that the major contributors to the overall holding torque were the interface pressure, material properties and the coefficient of friction between component materials. In this work, neutron diffraction tests and crack compliance tests showed no correlation between the interface pressure and increased holding torque. Meanwhile, experimental holding torque tests on sample interference-fits showed that for each recurring holding torque failure (slip) in a test cycle, the holding torque increased. Subsequent wear investigations showed that the wear of the surfaces increased throughout the testing and once a specific type of wear had occurred through a 'ploughing' mechanism, significant damage could be done to the more expensive shaft component. These observations suggest that an effective increase in the coefficient of friction between shaft and hub is responsible for the increase in holding torque, while the same level of interface pressure is maintained throughout slipping. The research provides a basis for the optimisation of interference-fit design in order that the working lives of expensive shafts, which are prone to damage through ploughing, and brittle hubs, which are prone to sudden fracture, are maximised when experiencing recurrent slipping.

1. Introduction

Interference-fits are a type of joint consisting of a shaft and a hub. The shaft diameter is manufactured larger than the hub bore diameter creating an overlap or dimensional interference between the two interfacing component surfaces. The joint is then held together by friction and elastic compression. Failure of the joint occurs when it can no longer resist an external load and total slip occurs at the interfaces. The load can be applied via torsion of the shaft within the hub, an axial load, or a combination of the two. A shrink-fit is a special type of heavy interference-fit formed by either heating the outer element, cooling the inner element, or for large interferences, a combination of both. The parts are then returned to ambient temperature to complete the assembly. This

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avoids surface damage and eliminates the large forces required to assemble other types of interference-fits like press-fits. Interference-fits are commonly used for locating parts (bearings, gears, train wheel tyres), in situations where the compressive stresses are advantageous (gun barrels, pressure vessels), or for transmitting torque (gears, wheels, tool holders). In torque transmission, interference-fits excel over traditional keyways, pins, splines and other assembly methods, as no other components and associated invasive machined features on the parts are required.

In previous work using a statistically large sample size of 27 mild steel interference-fitted shafts (diameter 22 mm) and hubs (diameter 60 mm) [5], it was observed experimentally that the failure load to create total slip in torsion, known as the holding torque, increased noticeably when repeatedly loaded (see Fig. 1). Using statistical hypothesis tests, the holding torque distribution after just three independent loading cycles to total slip was statistically different, to a high level of significance, from that of the first loading cycle. This phenomenon is an advantage in applications where the main objective is to resist torque — and can be regarded as 'torque strengthening'. However, repeated slipping can result in wear at the interface of the shaft and hub. In some applications, for example, in large rolls for the hot rolling industry [20] the hub is used like a replaceable tyre possessing different mechanical and thermal properties to the shaft. This is cost effective as the hub can be replaced when worn without having to replace the whole component. Excessive wear of the shaft can be costly though and Fig. 2 shows an example of 'ploughing' damage on an alloy steel shaft used in a large work roll assembly. In these situations, shafts can be redressed and reused up to six times during their working life to remove the damage, but when ploughing is severe and deep, the amount of machining required to resurface the roll is impractical and the shaft becomes unusable. As the shaft is the most expensive part of the roll assembly, this type of failure is costly.

The aforementioned failure occurred in a profiled work roll where the hub had been machined down significantly over time and had failed through fracture. At this point in a roll's life, the holding torque will have been reduced significantly due to the reduced interface pressure caused by the removal of hub material, leading to a higher likelihood of slip. As material was removed, the roll became more susceptible to crack propagation initiated through fire-cracking during the intense heating and cooling encountered in the hot-rolling process. The most profound area of ploughing in the case described was found near the boundary of the thick section of the hub. At this point the interface pressure increases due to edge effects caused by the increase in bulk material. This increased interface pressure further increased the effects of wear. The hub, not shown, had fractured in a brittle and sudden manner, exposing the damaged shaft surface. The hub was made from Spheroidal Graphite Acicular Cast Iron (SGACI) which was considerably harder than the alloy steel shaft material.

Ploughing occurs due to the interfacing surfaces sliding against one another while in the presence of a high contact pressure. The peaks of the surface asperities, imparted by machining of the surfaces to create the interference dimensions on the shaft and hub, meet and deform both elastically then plastically to support the typically high contact pressure. The amount of deformation is dependent on the relative hardness of the interfacing materials and the level of interface pressure. As the two surfaces slide against each other the initial contact points begin to separate and large shear forces develop below the contact points. These forces are enough to deform the asperities and even fracture them. When asperities fracture, broken asperities can become trapped in the interface and cause further damage through a prow and wedge type junction [2,9]. This forms the basis for ploughing and has been observed in interference-fits previously [19].

The objectives of this paper are to determine the fundamental reasons for an observed increase in holding torque with recurrent slipping in interference-fitted assemblies such as the case of a work roll described above. The paper initially reviews the

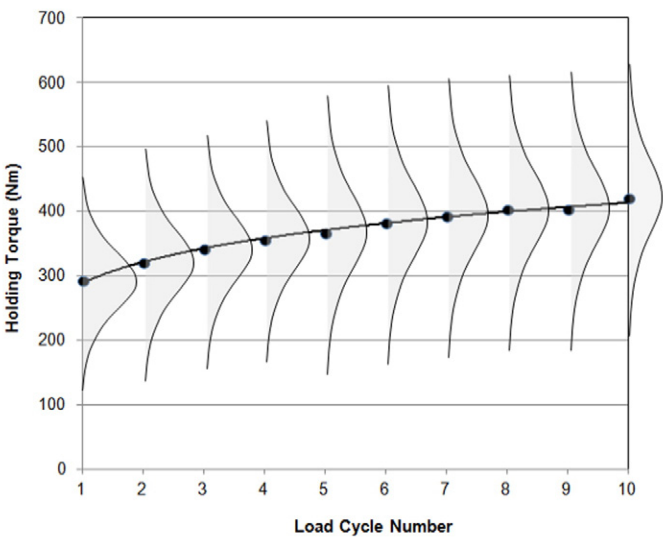

Fig. 1. Distributions of holding torque based on 27 mild steel interference-fitted assemblies (diameter 22 mm shaft, diameter 60 mm hub) after 10 loading cycles showing increasing mean and similar dispersion.