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Study of the interference contribution on the performance of an adhesive bonded press-fitted cylindrical joint

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ABSTRACT

The adhesive bonding technology can be used in combination with other traditional joining methods, such as mechanical fastening techniques (e.g. rivets or bolts) or welding techniques, generating a hybrid joint. Hybrid adhesive joints are designed to exploit the advantages of the different techniques and, if possible, overcome their drawbacks. This study focuses on the interference fitted/adhesive bonded joining technique. This method consists in two cylindrical components coupled together by inserting one into the other, after having placed an adhesive on the mating surfaces. This hybrid joint, generally realized by exploiting acrylic anaerobic systems, has been studied to evaluate the interaction between the tensile field of the components (at the interference level) and the adhesive strength under both static and dynamic loading conditions. Notwithstanding this, the contributions of the adhesive and the interference on the performance of the final joint are still not completely clear. The aim of this research is then to further study the factors affecting the resistance of this hybrid joint. Hub-shaft samples, joined by means of a press fit, were tested under an axial push out load. Hybrid joints were compared to both adhesive joints in clearance conditions and interference joints. In particular, different levels of interference were analyzed in order to clarify the role played by the tensile field between the hub and the shaft, and the influence of the friction effects between them. Numerical simulations were also employed to support the experimental data in the evaluation of the behavior of the adhesive and its relation with all the phenomena influencing the hybrid system. It was found that tribological phenomena played an important role in governing the mechanical behavior of the unbonded samples, while they can be considered negligible in presence of the adhesive. The correlation between bonded and unbonded press-fitted joints was investigated pointing out that the maximum strength of the hybrid joint is mainly related to the resistance of the epoxy adhesive.

1. Introduction

Adhesive bonding is a suitable technology to bond dissimilar materials and it is often used to obtain a good uniform stress distribution in the joint area [1,2]. For this purpose the use of adhesives is increased in many industrial applications replacing existing traditional joining methods such as welding and soldering [3,4]. However, as adhesives have a polymeric composition, they are subjected to durability issues, especially in harsh working conditions. In order to overcome these problems, and in particular joint designs, adhesive bonding can be used in combination with other traditional joining methods, such as mechanical fastening or welding techniques, generating a hybrid joint. Hybrid adhesive joints are designed in order to exploit the advantages of the different techniques and, if possible, to overcome their drawbacks [5].

This study focuses on interference fitted/adhesive bonded cylindrical joints. The interference fit is a common technique to join cylindrical part together. The most common joint geometry consists of a shaft fitted into a hub. In order to guarantee the coupling, the shaft must be inserted into the hub through forcing, implying the presence of an interference (δ) among the hub and the shaft. The two cylindrical components could be assembled through two main methods: "press fit" and "shrink fit". In "shrink fit", the coupling is realized by exploiting the clearance created by thermal expansion, in "press fit" the coupling is realized by means

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of a standing press. As concerns the hybrid technique, besides the interference, the coupling is guaranteed by the adhesives, generally based on acrylic anaerobic systems [6], due to the favorable curing technology in closed metal joints.

It has been demonstrated that incorporating an adhesive into an existing interference fit design can lead to considerable strength enhancement [7–18]. The technical literature focuses on the comprehension of the cooperation between the radial contact pressure due to the interference and the resistance of the adhesive on the resultant strength of the hybrid joint. In particular, it was found [11–13] that in many cases the strength of the hybrid joint is equal to the sum of the resistance provided by the clamping pressure and the one provided by the adhesive, as two independent variables. Nevertheless, it seems that the rule of the superimposition of the effects is not always observed experimentally [14–18] and in some cases the two variables seem dependent. A micro-mechanical model for the static strength of hybrid friction-bonded interfaces was also proposed [14,15] in order to explain this experimental evidence related to the different behavior of lower strength anaerobic adhesives. Indeed, several variables could influence the behavior of this hybrid joint, such as the chemical nature and the type of the curing reaction of the adhesive and the type of the assembly technique used [9,13,14,18,19]. For example, the press-fit technique introduces important parameters like the coupling pressure, the spillage of the adhesive and friction phenomena, that strongly influence the performance of the joints. Further studies of the phenomena acting at the interference level will be useful for the design of particular components that involve this hybrid joint technique.

Recent studies of interference fits show the limitations of the traditional design method based on thick-wall cylinder theory. For shaft-hub applications or gear-wheel connections, stress/strain field can be estimated by means of conventional equations [20,21]. If the examined parts involve more complex shapes and an elasto-plastic behavior [22], the prediction of full field data cannot rely on analytical approaches and it requires more accurate finite element analyses (FEA).

This study focuses on the effect of an epoxy two component adhesive on a press fitted cylindrical joint. The role of the adhesive during both press coupling and decoupling operations was studied in relation to the friction effects due to the forcing between the hub and the shaft. A 3D finite element study of an interference fit assembly subjected to external loads is also presented. A brief overview of the contact formulation used and the numerical model developed in Abaqus/Standard is given.

The hybrid joints resistance is compared to both adhesive joints in clearance conditions and interference joints, in order to understand the contribution of the different parameters, including different levels of interference, to the final strength of the joint. The evaluation of the interaction between the assembled bodies and the changes in the analyzed full field appears to be essential for the test case presented, for which manufacturing processes, design tolerances and tribological aspects play an important role.

2. Materials and methods

2.1. Press fit samples

The role of the adhesive in the presence of different levels of interference was studied in a hub/shaft geometry.

The hollow tubes and the shafts, made of C40 steel, were designed according to the requirements imposed by our traction and fatigue test machines. The technical drawings of the hollow tubes and shafts are illustrated in Fig. 1.

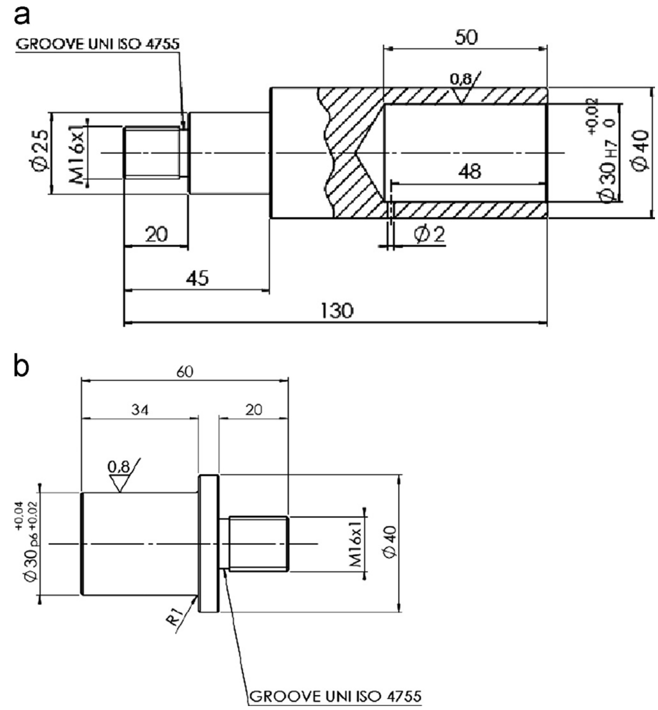

Fig. 1. Dimensions in mm and tolerances of the specimen: (a) hollow tube, (b) shaft [18].

The coupling diameter of the samples was set to 30 mm. The threaded extremities of the samples were designed to be correctly hitched to the decoupling test machine, and also in view of future characterization. The head of the shaft was designed with a diameter of 40 mm after the threaded tip. This part had the same diameter of the external part of the hub and this allowed the alignment of the components during the press coupling. A hole opened on the side of the hub prevents the formation of compressed air inside the joint.

The interference fit joints were assembled according to the press-fit method. The coupling was performed by means of an automatic press in order to assure the same pressing rate for each sample until a coupling length of 10 mm was reached. The alignment between the shaft and the hub was a crucial parameter to obtain repeatable joints. A not-axial assembling induces far higher coupling and decoupling loads than an axial one. Guides, schematically illustrated in Fig. 2, were used to guarantee the alignment of the couples. This method was validated by measuring the eccentricity of the two components, after putting in rotation the coupled joints.

A loose clearance fit or a strong interference fit could be obtained by varying the dimensional tolerances of the shafts. The coupling diameters of each hub and shaft were checked along four sections in the first 10 mm (the coupled length) with a Trimos horizontal measuring and calibration instrument. Then, an average diameter was calculated for each component in order to select the best coupling pairs. The considered interference for every sample is calculated as the difference of mean diameter of the related hub and shaft. The roughness of the samples was also checked.

2.2. Test method

The samples were tested under a static axial pull-out load, performed with a traction test using a Zwick z-100 dynamometer at a crosshead rate of 1.3 mm/min.