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Experimental validation of a simple shear strength model for hybrid friction-bonded interfaces

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ABSTRACT

The paper deals with the experimental measurement of the shear strength in hybrid interfaces, press fitted and bonded with anaerobic adhesives. The aim is to validate and improve the applicability of a constitutive model, which describes the interface behavior up to complete failure, by combining a cohesive law with a pure friction law. This paper presents an extensive experimental test plan, which deeply investigates the shear strength of two strong anaerobic adhesives, over four nominal contact pressure levels. The tests involve cylindrical specimens, butt bonded and pressure reinforced over an annular surface, and seven replications, giving 56 tests. The experimental torque-rotation curves up to complete failure highlight a similar response between the two adhesives, and confirm that the strain energy up to complete failure sums up a cohesive term and a pure friction term. In addition, the main parameters of the model linearly depend from contact pressure through simple relationships.

1. Introduction

The paper experimentally investigates hybrid interfaces, which are pressure-reinforced and bonded with anaerobic adhesive. Anaerobic adhesives are a simple way to remarkably improve the responses of friction joints, where the coupling forces are provided by mechanical clamping [1–6].

Despite the broadband application of hybrid interfaces in mechanical couplings, a constitutive model describing their elastic and post elastic response, up to complete failure, it is not available. Some researchers [7–11] suggest that the static shear strength of hybrid friction bonded joints sums up two contributions: the shear strength of the adhesive and the friction between the interfaces of the joint. Other experimental tests (Dragoni and Mauri [12]), show that the contact pressure promotes an increase of the shear strength in the hybrid joint, but, in addition, the type of adhesive affects the increase rate: the stronger the anaerobic adhesive, the higher the shear strength increase rate. In particular, above a given contact pressure, a weak anaerobic adhesive lowers the joint strength, compared to that of the dry interface, thus acting as a lubricant.

By relying on these experimental results, Dragoni et al. [12–14] propose a simple micro-mechanical model, which assumes that a thin adhesive layer always separates the adherend surface protrusions. First, the model suggests that the adhesive significantly improves its shear strength when loaded by the high local pressure occurring between the adherends protrusions. Second, the curves of the experimental shear stress versus relative sliding of the hybrid joint up to complete failure are the combination of a cohesive fracture energy and a pure friction strain energy.

The applicability of this simple model has been confirmed both by preliminary systematic experimental test plan [15,16] and by a microscopic-scale finite element simulation plan [17,18]. These preliminary studies support the hypothesis that a thin layer of anaerobic adhesive always separates the roughness protrusions of the adherend surfaces. In particular, the tests on a weak and a strong anaerobic adhesive [16] clearly show that the curve of the shear strength of the hybrid joint as a function of the relative sliding linearly increases with the nominal contact pressure in the joint. Moreover, these tests confirm the different increase rate of the shear strength between different anaerobic adhesives, and highlight that all the parameters describing the curve, with exception of the elastic stiffness of the strong adhesive, linearly depend by the contact pressure. In addition, the strong anaerobic adhesive shows a higher scatter in the results, which prevents a reliable identification of the model parameters.

Considering the large use of strong anaerobic adhesives, for example to increase the capability of power transmissions in industrial applications, this work improves the preliminary investigation performed in [16] by focusing specifically on strong anaerobic adhesives. Two are the aims of the work: first, to definitely validate the proposed micro-mechanical model by performing an extensive systematic experimental test plan, involving a statistically significant number of replications. Second, to assess, clearly, the response of strong anaerobic adhesives, in

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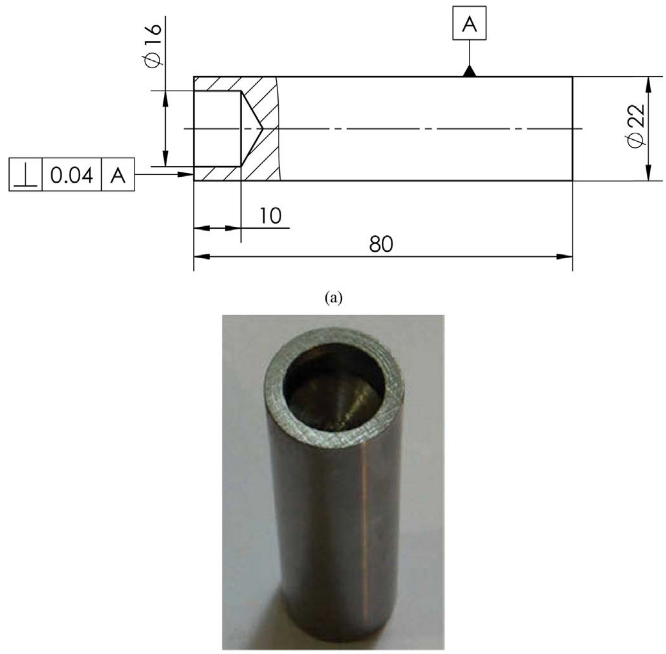

(a)

(b)

Fig. 1. Technical drawing of the adherend used in the experimental tests (a), a picture of the adherend manufactured by turning (b) and a scheme of direction measurement for roughness. All dimensions in millimeter.

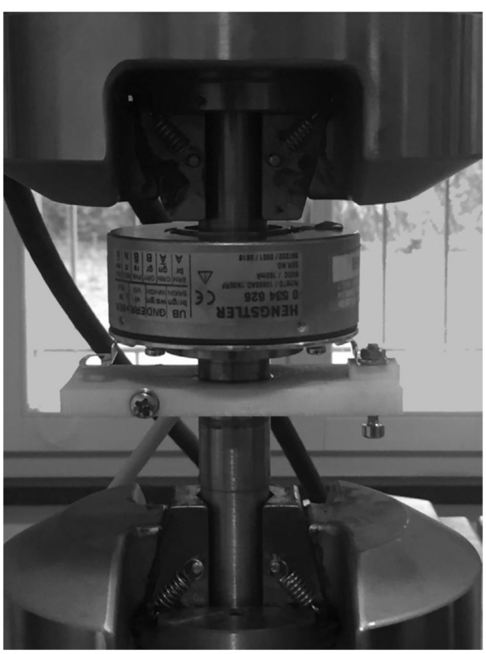

Fig. 2. Picture of the specimen fixed to the testing machine, including the twist angle measurement system.

order to identify a reliable set of parameters that can be used for a constitutive model. The test plan involves two anaerobic adhesives, four contact pressure levels and seven replications for a total of 56 specimens. With regard to the two adhesives, on the one hand, we enriched the investigation of the strong anaerobic [19] already used in [16], due to the high scatter it exhibited, as discussed above. On the other hand, we investigated a second strong anaerobic with similar tribological properties but a slightly higher mechanical strength [20]. In order to allow a direct comparison with the preliminary results in [16], the tests plan focuses on the same four contact pressure levels and uses the same

Table 1
Variables of the experimental test plan.

Variable	Levels			
Adhesive	Loctite 638		Loctite 648	
Nominal contact pressure, *p* (MPa)	0.5	45	90	134

Table 2
Roughness values on the adherends surface.

Specimen	Ra (μm)
Spec #1.1	0.90
Spec #1.2	0.94
Spec #2.1	1.09
Spec #2.2	1.10
Spec #3.1	0.69
Spec #3.2	0.81
Average value	**0.92**
Standard deviation	**0.16**

cylindrical specimens, press-fitted and butt bonded on an annular contact surface. The experimental curves confirm both the effect of the nominal contact pressure on the response up to failure of the hybrid joint, and the response of the strong anaerobic adhesive identified in the preliminary test plan.

2. Method

The tests adopted the same procedure used in the preliminary test plan [16]. Fig. 1a shows the sketch of a tubular adherend used to build the specimen: the adherends were manufactured from a ∅22H7 ground bar made of normalized mild steel (C40), and bonded head to head on the ∅16 × 22 mm annular surface, as shown in Fig. 1b. It comes that the proposed specimen exactly reproduces the configuration of an industrial flanged coupling, but also resembles the contact condition occurring in a threaded connection, or in a conical shaft-hub coupling. The inner and outer dimensions of the bonded surface were designed as the best tradeoff between the maximum axial force (25kN) and torque (200 Nm) that the servo hydraulic testing machine (MTS MiniBionix 858, Eden Prairie, MN, USA) used for the tests can apply, and the need of a simple manufacturing of the adherends. Specifically, this maximum axial force originates a nominal contact pressure equal to about 134 MPa on the hybrid interface. Considering the roughness, contact effectively occurs between the mating surface protrusions of the adherend surfaces.

2.1. Set-up of the test bench

The accurate measurement of the relative rotation angle between the adherend interfaces up to complete failure was performed through a rotational encoder (Hengstler RI 76TD model [21], resolution 0.009°), installed on the specimen, as described in [16]. This system provides an accurate measurement of the relative rotation between the adherends very close to the hybrid interface, thus disregarding the compliances of the kinematic chain of the test machine and a great part of the adherends rotation. In particular, at the failure torque, the relative rotation of the hybrid interface represents from 70 to 80% of the value registered by the encoder, for both the adhesives.

A notebook equipped with a National Instruments USB6251 data acquisition system [22] managed the two signals from each torque-rotation experimental test. In particular, a purposely developed algorithm, implemented through the LabVIEW software [23], synchronized both signals, converted them in the rotation angle and the torque load, respectively, and registered the signals on a text file. Fig. 2 shows a picture of the test set-up on the testing machine.