Adhesives

Mechanical Properties, Technologies and Economic Importance

Dario Croccolo
Editor

MATERIALS SCIENCE AND TECHNOLOGIES

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NOVINKA
New York

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Telephone 631-231-7269; Fax 631-231-8175
Web Site: http://www.novapublishers.com

Library of Congress Cataloging-in-Publication Data

ISBN: 978-1-63117-653-1

Published by Nova Science Publishers, Inc. † New York

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PREFACE

The present book is dedicated to the description of the mechanical properties, the technologies and the economic importance of adhesives.

First of all interference fitted and adhesively bonded joints has been studied as an effective means to increase the transferable load while reducing both the weight and the stress level of the joined components. In such a type of joints the influence of the assembly technique on the shear strength of the joints has been investigated. Therefore the shear strength of hybrid joints realized by 'press fitting', by 'shrink fitting' or by 'cryogenic fitting' were compared in order to suggest the best way of joining both for technological and economic importance.

Then the hybrid interference and some design aspects for practical application in (the automotive steel wheel) have been analyzed. An experimental evaluation of the contributions of the adhesive and the interference to the resultant resistance of the hybrid joint was carried out with particular attention to the phenomena occurring at the interface level and the effect of the adhesive nature, its curing technology and its mechanical response. The outcomes of the laboratory analyses were validated in the steel wheel system. The adhesive contribution mainly affects the static resistance of the hybrid joint, and is strongly related to the type of adhesive exploited. On the other hand, the interference seems to play an important role in the fatigue behavior, especially in the wheel system.

he static and fatigue strength properties of press fitted and adhesively bonded joints has been, also, studied extensively by considering the Engagement Ratio (i.e., the coupling length over the coupling diameter). Coupling and decoupling tests have been performed both on press-fitted and adhesively bonded specimens and on pin-collar samples, considering four different levels for the Engagement Ratio. The study shows that the Engagement Ratio has a negligible effect on the shear strength of the adhesive and also on the relationship between the decoupling and the coupling forces. Moreover, the obtained results show that a too high interference level in press-fitted and adhesively bonded joints may have a detrimental effect on the adhesive strength.

Furthermore the assessment of the adhesive performance of two binders for reassembling fragment porous stones and, more specifically, the effect of nano-titania in the hydration and carbonation of the derived mortars, have been investigated. The nano-titania of anatase form, has been added in mortars containing (a): binders of either lime and metakaolin or natural hydraulic lime and, (b): fine aggregates of carbonate nature. The nano-titania proportion was 4.5-6% w/w of binders. The physicochemical and mechanical properties of the nano-titania mortars were studied and compared to the respective ones of the mortars without the nano-titania addition, used as reference. DTA-TG, FTIR, SEM and XRD analyses indicated the evolution of carbonation, hydration and hydraulic compound formation during a period of one-year curing. The mechanical characterization indicated that the mortars with the nano-titania addition, showed improved mechanical properties over time, when compared to the specimens without nano-titania. The results evidenced carbonation and hydration enhancement of the mortar mixtures with nano-titania. The hydrophylicity of nano-titania enhances humidity retention in mortars, thus facilitating the carbonation and hydration processes. This property can be exploited in the fabrication of mortars for reassembling fragments of porous limestones from monuments, where the presence of humidity controls the mortar setting and adhesion efficiency. The rapid discoloration of methylene blue stains applied to mortars with nano-titania supported the self-cleaning properties of mortars with nano-titania presence. Based on the physico-chemical and mechanical characterization of the studied adhesive mortars with nano-titania, binders of metakaolin-lime and natural hydraulic lime, have been selected as most appropriate formulations for the adhesion of fragment porous stones in restoration applications.

Then the adhesive crack propagation has been investigated for some load bearing applications. Fatigue cracks, either induced by defects or by applied stresses, may appear and propagate, thus becoming potentially harmful for the structural integrity of a part or a whole structure. Therefore, in-situ structural health monitoring (SHM) of bonded joints is essential to maintain reliable and safe operaional life of these structures. This chapter presents various in-situ SHM techniques which are used to monitor bonded composite joints with a focus on fatigue crack monitoring based on the backface strain (BFS) technique. Case studies are presented and discussed for adhesively bonded single lap joint (SLJ). Sensors associated with this technique are also explained, with emphasis on Fibre Bragg Grating (FBG) optical sensors.

Finally a numerical method able to reproduce three-dimensionally the fatigue debonding and/or delamination evolution in bonded structures has been proposed in order to improve their performances. The cohesive zone model previously developed by the authors to simulate fatigue crack growth at interfaces in 2D geometries is extended to 3D cracks under mixed-mode I/II loading

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In: Adhesives
Editor: Dario Croccolo

ISBN: 978-1-63117-653-1

Chapter 1

INFLUENCE OF THE ASSEMBLY PROCESS ON THE SHEAR STRENGTH OF SHAFT–HUB HYBRID JOINTS

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ABSTRACT

Interference fitted and adhesively bonded joints, also known as hybrid joints, are an effective means to increase the transferable load while reducing both the weight and the stress level of the joined components. Many researches evaluated the strength of hybrid joints in dependence of several variables, such as the assembly pressure level, the type of materials in contact, the curing methodology, the operating temperature, and the loading type. To the authors' best knowledge, no data are available about the influence of the assembly technique on the shear strength of hybrid joints. This paper aims at filling the gap, by comparing the shear strength of hybrid joints realized by 'press fitting', by 'shrink fitting' and by 'cryogenic fitting'.

Keywords: Anaerobic adhesives, hybrid joints, shrink fit, press fit, cryogenic fit

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Introduction

Interference fitted and adhesively bonded joints, also known as hybrid joints (HJs), are an effective means to emphasize the transferable load while reducing both the weight and the stress level of the joined components [1]. Hybrid joints usually involve two axisymmetric members and a high strength, single component, anaerobic adhesive like LOCTITE648. Many researches evaluated the strength of HJs in dependence of several variables, such as the assembly pressure level [2,3], the type of materials in contact [4–6], the curing methodology [7], the operating temperature [8,9] and the loading type [10–12]. Interference level can be produced by different joining techniques: by driving the shaft into the hub with a standing press at R.T., by heating the hub then driving the shaft (kept at R.T.) into the hub, and finally by cooling the shaft then driving it into the hub (kept at R.T.). The first technique is called 'press fit', the other two are known as 'shrink fit' and 'cryogenic fit', respectively. To the authors' best knowledge, no experimentation has still been done to assess the static shear strength of HJs in dependence of the method by which interference is obtained. This research aims at filling the gap, by making comparisons between the shear strength of hybrid joints realized by the above mentioned assembly techniques.

Methodology

The experimentation was divided into two steps: the first part run on pin-collar specimens realized according to ISO 10123 [13], and the second one carried out on bigger sized shaft–hub couplings. The bigger sized specimens allow larger gaps for given temperature, so asto make possible the assembly process with practical temperature differentials between the parts; furthermore the bigger size allows to increase the time available for assembly operations. All the specimens were manufactured with C40 UNI EN 10083-2 steel [14], without any surface treatment. All the specimens were pushed out with the same press (Italsigma, 100 kN) and the complete force-displacement diagram was recorded. The push-out speed was set at 0.5 mm/s throughout the experimentation. Press fit specimens were assembled by means of the aforementioned press, while the clearance, shrink fit and cryogenic-fit ones were assembled manually. All the specimens assembled with adhesive cured more than 24 h at a R.T. of 20°C, in order to achieve a complete polymerization [15]. In the case of adhesively bonded joints assembled with clearance, the shear strength of the adhesive tad_cl can be calculated according to:

$$\tau_{ad\_cl} = \frac{F_{tot}}{A} = \frac{F_{ad\_cl}}{A} \tag{1}$$

where A is the coupling surface and Ftot is the push-out force. Eq. (1) holds true for clearance specimens assembled at any temperature. In the case of joints assembledwith interference and no adhesive, Eq. (2) is used, in which m is the mean coefficient of friction between the mating parts, evaluated at decoupling.

$$F_{\text{int}} = P \cdot \mu \cdot A \tag{2}$$

Therefore, the adhesive shear stress of HJs can be expressed as follows:

$$\tau_{ad\_\text{int}} = \frac{F_{tot} - F_{\text{int}}}{A} \tag{3}$$

Pin-Collar Specimens

In order to have a first glance at the performances of LOCTITE648s adhesive in dependence of the assembly temperature of the components, a first set of 13 pin-collar specimens was examined. The specimens are characterized by a mean radial clearance of 0.027 mm (standard deviation of 0.003 mm). The specimen size was chosen in accordance with ISO 10123, because it allows direct comparison with the performances stated into the datasheet of the adhesive. It was demonstrated by Croccolo et al. [12] that if only steel components are involved, the specimens can be pushed out and re-used several times without influencing the strength of the joint, provided that they are cleaned accurately after pushing out. Here, the LOCTITE7063s multi purpose cleaner was used. In the light of that, each of the 13 clearance pairs was used three times; Table 1 summarizes the test plan. It must be remarked that, in this first part of the experimentation, easily achievable heating (+180°C) and cooling (-20°C) temperatures were chosen. The choice was based on the tools readily available in the laboratory (a freezer and a small electric oven).

Table 1. Test plan for ISO 10123 pin-collar specimens, tested with clearance fits

First run	R.T. Adhesive = YES 13 tests
Second run	Collar heated at +180°C Adhesive = YES 13 tests
Third run	Pin cooled at -20°C Adhesive = YES 13 tests

Shaft-Hub Specimens

Pin-collars manufactured according to ISO 10123 have a coupling diameter of about 12.65 mm. When a shrink-fit or a cryogenic-fit has to be performed, a certain radial clearance, and a sufficient assembly time shall be ensured, before the components return to their original dimensions. It is known that a linear relationship exists between the thermal deformation of a metallic body and temperature [16].

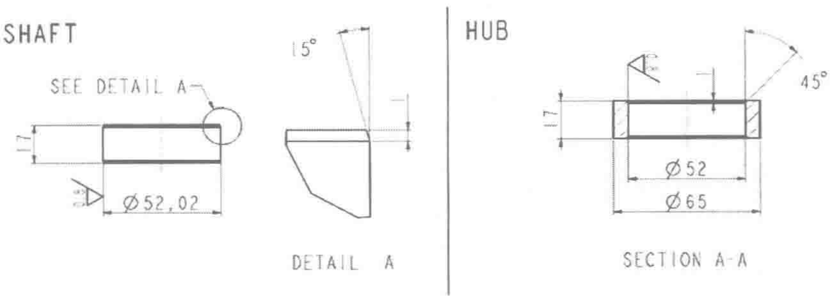

Figure 1. Shaft-hub specimen dimensions.

In the light of that, the relatively small dimensions of pin-collars realized as for ISO 10123 have a double drawback: they allow for small radial displacements, even under great temperature differentials, and they do have a small thermal inertia. In order to avoid assembly issues, the authors designed and realized the specimen shown in Figure 1, to be used in the presence of interference. The bigger size of such shaft–hub specimen, with respect to pin collars, allows for a greater assembly clearance and increases the time available for assembly operations. For example, referring to a nominal coupling diameter D_C = 52 mm, to a radial interference I=0.01 mm, to the coefficient of thermal expansion α_W=1.1 10^{-5} for steel, and to a R.T. of +20°C, a radial assembly clearance of g=0.07 mm is obtained when the hub is heated at +180°C for the shrink fit. Such assembly clearance permits to join the components by hand easily. As for cryogenic fits, by taking into account a coefficient of thermal contraction of α_C=9.5 10^{-6} and a cooling temperature for the shaft of -150°C, a radial assembly clearance of g=0.06 mm is obtained, which is still acceptable. Cryogenic fits are performed by means of liquid nitrogen and the temperatures indicated above are meant at the time of coupling. The coupling length of shaft–hub specimens was defined in order to obtain a push-out force always lower than the limit of the standing press (100 kN) whatever was the coupling condition; the material type was kept unchanged with respect to the pin-collars one. Shaft– hub specimens with interference and without adhesive were used to sample the frictional contribution Fint to be used for calculating the overall release force F_{tot}, as for Eq. (3). A total of 34 shaft–hub specimens were realized, out of which 7 were press fitted without adhesive, 7 were press fitted with adhesive, 10 were shrink fitted with adhesive and, 10 were cryogenically fitted with adhesive. In the case of shrink fit, the adhesive was dispensed on the shaft, while in the other two cases it was dispensed on the hub. Table 2 summarizes the test plan for shaft–hub couplings. Since all shaft–hub couplings were assembled with interference, the adhesive shear strength has to be calculated according to Eq. (3).

Table 2. Test plan for shaft-hub specimens, tested with interference, single run

Press-fit Adhesive = NO 7 tests	Press-fit Adhesive = YES 7 tests	Shrink-fit (Hub heated at +180°C) Adhesive = YES 10 tests	Cryogenic-fit (Shaft cooled at - 150°C Adhesive = YES 10 tests

RESULTS AND DISCUSSION

Pin-Collar Specimens

The results are collected in the following tables: Table 3 refers to slip fit couplings assembled at R.T.; Table 4 refers to slip fit couplings with collars heated at +180°C; and Table 5 refers to slip fit couplings with pins cooled at -20°C. Referring to Table 3, the mean adhesive shear strength of slip fit couplings assembled at R.T. can be calculated. Assuming A=446.33 mm^2, Eq. (1) gives τ_{ad_cle}= 38:5 MPa (standard deviation 3.4 MPa), which is greater than the minimum indicated by the manufacturer in the product data-sheet (τ_{ad_min}= 25 MPa). A picture of the pushed out specimens is given in Figure 2: the polymerised adhesive residue is clearly visible on both the mating surfaces, indicating the expected cohesive failure mode.

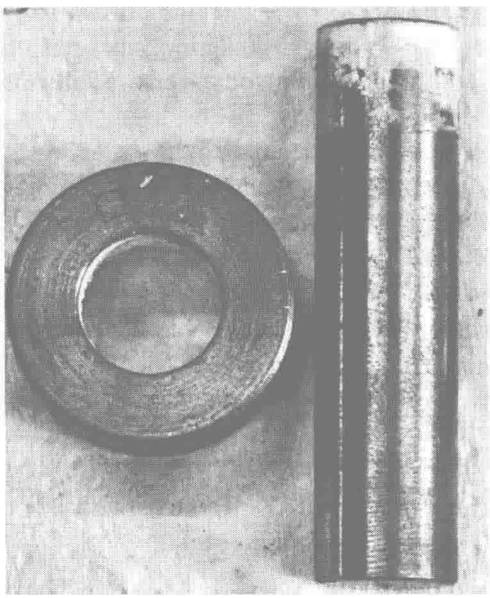

Figure 2. Slip fit coupling assembled at R.T.

Slip fits performed by heating the collars at +180°C produced the results reported in Table 4; the mean adhesive shear strength is here equal to 19.5 MPa (standard deviation 4.3 MPa), which is lower than the minimum suggested by the data sheet of the adhesive. This occurrence can be explained by a certain amount of rust observed on the collar coupling surface, due to heating. Rust is, for anaerobic products, an inert substrate which inhibits the complete polymerization of the adhesive and, therefore, reduces the adhesive performances. Figure 3 shows a cohesive failure mode, while some rust spots are visible on the annular surface of the collar.

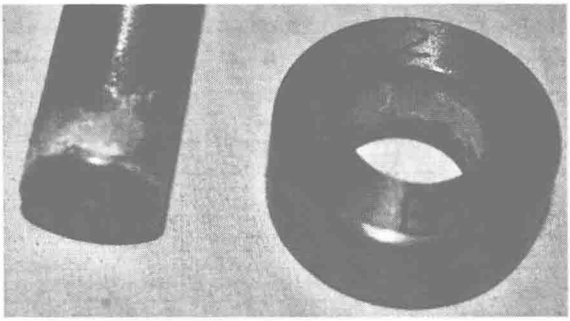

Figure 3. Slip fit coupling assembled after heating the collar at +180°C.

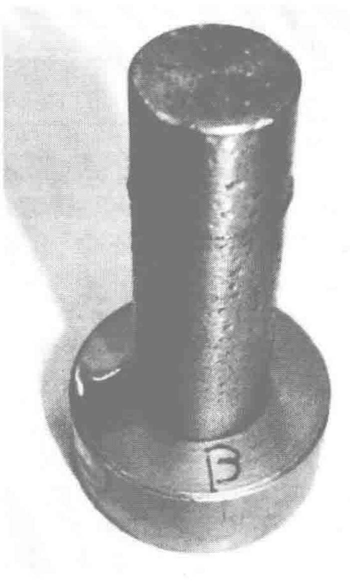

Figure 4. Slip fit coupling assembled after cooling the pin at -20°C.

Slip fits performed by cooling the pins at -20°C produced the results reported in Table 5; the mean adhesive shear strength drops down to 5.7 MPa (standard deviation 1.8 MPa), which is less than one fourth of the minimum suggested by the data sheet. That outcome can be explained by a large