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Influence of the engagement ratio on the shear strength of an epoxy adhesive by push-out tests on pin-and-collar joints: Part I: Campaign at room temperature

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ABSTRACT

This paper focuses on an epoxy adhesive (LOCTITE 9466), which is particularly suitable for applications involving different materials and where a clearance is present between the adherents. The investigated subject is concerned with the effect of the Engagement Ratio (*ER*, coupling length over coupling diameter) on the shear strength of LOCTITE 9466 at room temperature. Motivations arise from the increasing interest in epoxy-adhesive joints in lightweight structures and from the consequent need for design data. Decoupling tests have been performed on pin-and-collar samples manufactured according to current Standards. The height has been adjusted in order to explore a sufficiently wide *ER* range at four different levels. The results have been processed by the tools of the Analysis of Variance and of the Fisher test to investigate the significance or the not significance of *ER* on the joint shear strength. The final outcome was that *ER* significantly affects resistance at a very high confidence level. This result has then been refined by the tool of orthogonality, in order to allocate the differences among the four levels of *ER*. This further analysis has shown that the joint strength is significantly enhanced, when *ER* exceeds 1 and assumes values around 1.3 or higher.

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1. Introduction

Adhesively bonded joints are used in many mechanical applications, because they offer several advantages, such as the reduction of weight, the increasing of strength and the improvement of fatigue and fretting corrosion. These advantages have been demonstrated to be effective in the case of interference fitted and adhesively bonded joints [1], namely, hybrid joints, whatever is the production system. Many researches evaluated the strength of these joints in dependence of several variables, such as the assembly pressure level [2], the type of materials in contact [3–4], the curing methodology [5], the operating temperature [6–7], the loading type [8–9] and type of joining technique [10–11]. In order to reduce the weight and the amount of the material, it is possible to reduce the Engagement Ratio (*ER*), which is the ratio between the coupling length over the coupling diameter. However, the reduction of the *ER* may lead to a reduction in the strength of the joint, therefore, its effect has been deeply investigated in a pin-and-collar set of specimens in the case of anaerobic adhesive [12].

The anaerobic adhesive is really effective in the case of metal parts to be connected and, particularly, in the case of steel components, whereas in the case of aluminium alloy or, worse, of composite material, the adhesive strength is strongly reduced [4]. A more suitable adhesive in such cases is the epoxy one that is, normally, used in slip-fit joints, where a clearance is present between the adherents. An additional and particularly relevant advantage of epoxy adhesives is that they offer the opportunity of bonding materials with different physical and mechanical properties, without triggering detrimental variations of their chemical structure. An important outcome is that epoxy adhesives can be successfully used to bond protective coatings to structural parts, thus achieving simple repair, with many applications in petroleum, aviation and aerospace industries [13–15]. A further application field is related to the development of joints between different materials, usually a steel shaft and a composite hub, mainly in automotive. According to [16], composites are the most suitable materials for many suspension components in racing cars, where lightweight properties are essential for successful race participation. Examples of parts that are better suited to composites are pushrods, A-arms and steering arms, due to the tensile/compressive load they experience in operation conditions and as an effect of their good response in terms of strength and stiffness. Similar design strategies are likely to be followed even in high class car

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List of Symbols

A	Coupling surface [mm^2]
C	Number of columns (levels) in the ANOVA [-]
D_C	Coupling diameter [mm]
$F_{Ad.}$	Decoupling force [N]
$F_{calc.}$	Fisher's ratio [-]
L_C	Coupling length [mm]
$\tau_{Ad.}$	Adhesive static shear strength [MPa]
R	Number of rows (replications) in the ANOVA [-]

List of Acronyms

ANOVA	Analysis of Variance
ER	Engagement Ratio
LSD	Fisher's Least Significant Difference
MSQ	Mean Squares (general term)
MSBC	Mean Square Between Columns
MSW	Mean Square Within Columns
SSBC	Sum of Squares Between Columns
SSQ	Sum of Squares (general term)
SSW	Sum of Squares Within Columns
TSS	Total Sum of Squares
p-v.	*p*-value

mass production. Epoxy adhesives, like LOCTITE 9466, are generally used for bonding composite tubes with steel shafts, thus obtaining mixed material joints, whose strength is often difficult to predict. Consequently, there is an increasing need for design data, involving in particular the effect of the length of the joint: an increased length is indeed able to positively enhance the joint strength, but with the outcome of an overall increase in dimensions and weight. The lack of studies investigating the effect of *ER* inspired the present work, whose subject consists in the experimental investigation of the effect of *ER* on the shear strength of LOCTITE 9466 epoxy adhesive. Tests on pin-and-collar samples have been conducted at room temperature, with the cylindrical geometry of specimens being justified by the aforementioned applications in the automotive field.

2. Materials and methods

First of all, the specimens have been designed and produced, following the Standard ISO 10123 [17] for slip-fit joints. The sketch of the pin-and-collar samples produced and tested is reported in Fig. 1. Since the ISO 10123 suggests to choose an $ER=0.9$ and since the dimensions investigated in [12] are of four types (the half, the double and an intermediate value $ER=1.3$), the *ER*s values were set at the same value for this work. The collars have been designed, so that their diameters were consistent with the recommended values in [17–18]. Their heights have been adjusted, in order to meet the aforementioned values of *ER*, while the chamfer dimensions have been maintained unchanged, as well as the pin dimensions. The material of the samples is C40 UNI EN 10083-2 steel, whereas the adhesive type is the previously mentioned commercial LOCTITE® 9466, which is an epoxy glue with two components. In order to improve the statistical analysis and the definition of the significance of the *ER* parameter, a number of ten replications for each different *ER* has been chosen. The overall sample population consisted therefore of 40 Pin-and-collars for statistical evidence reasons. The whole set of specimens has been measured, in order to accurately determine the coupling diameters and to check their height values. For this purpose, a

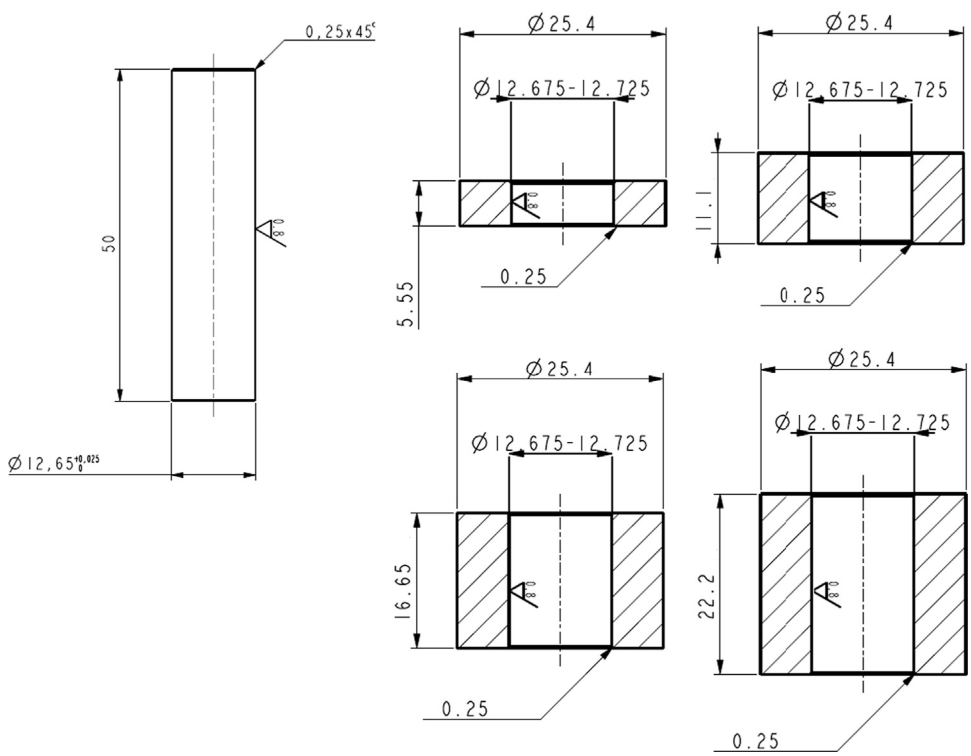

Fig. 1. Pin-and-collar specimens with $ER=0.4$ (a), $ER=0.9$ (b), $ER=1.3$ (c), $ER=1.7$ (d) (all dimensions in mm).

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