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VALUTAZIONE DELLA RESISTENZA DI ADESIONE E DELLA LUNGHEZZA EFFICACE DI INCOLLAGGIO NEI GIUNTI ADESIVI TRAMITE LE LEGGI DELL'EFFETTO SCALA

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Abstract. *In recent years, growing attention has been paid by researchers in structural mechanics to bonded joints in order to provide theoretical and numerical tools for better understanding the interfacial bonding/debonding phenomena. The research efforts in this area regard the formulation of reliable bond-slip models based on experimental data coming from laboratory tests performed on small specimens [1, 2].*
As reported in [3], the mechanical quantities characterizing any interface constitutive law can be derived from the results of the experimental pull tests by a simple procedure making use of a schematization of the structural problem. The application to some single lap joint tests, carried out at the DISAG Laboratory of Palermo University, shows the effectiveness of the procedure.

1 INTRODUCTION

The development of advanced constitutive models, capable to simulate the principal features of experimentally observed mechanical behaviour, generally leads to complex analytical formulations which involve the state variables, the internal variables and a number of material parameters.
The material parameters only in few cases can be evaluated directly from the experimental results and in many cases their identification require *ad hoc* procedures. This is true if the parameters are related to the microstructural properties of the material and/or is difficult to perform experimental tests directly on the material studied.
In the case of bonded joints, where the mechanical analysis is carried out making use of the interface concept, the parameters identification problem is complicated by the difficulty to carry out test at the interface level. Therefore, the available experimental results regard more a structure formed by the adherents and by the joint rather than a material in a general sense.
The parameters identification problem is a typical inverse problem. For an assigned structural system the experimental response is given and making use of a backward calculation the model parameters are identified providing a numerical response which coincides with the experimental one.
The present paper refers to the identification of the interface parameters in glass - POM-C

bonded joints. The assembly is carried out making use of an epoxy resin. The study of adhesion properties has been developed on the basis of an extensive experimental program on single lap joint specimens with different bond lengths.
The goal of the study has been reached through the application of the size effect concept [3] to the above experimental results.

2 BILINEAR INTERFACE MODEL

The mechanical problem is studied making use of the zero-thickness interface concept for which two adherents come into contact through an interaction surface. In particular, for this mechanical problem an elasto-plastic interface model is used to represent the adhesive layer.
The goal of the paper is the study of the decohesion process in presence of a pure shear stress state, therefore, normal stresses and related frictional effects are neglected.
The local interface response in pure mode II adopted here is characterized by an initial linear and elastic branch up to the adhesion strength a_0 and by a softening branch up to the final displacement u_F corresponding to the perfect fracture formation (Figure 1). The bilinear response, for a monotonic displacement history, is expressed as follows:

$$\begin{aligned} \tau = E_I\, u \qquad & \text{for} \quad 0 \le u \le u_E, \\ \tau = s_I\,(u_F - u) \qquad & \text{for} \quad u_E \le u \le u_F, \\ \tau = 0 \qquad & \text{for} \quad u > u_F. \end{aligned} \tag{1}$$

where s_I is the interface softening modulus defined as:

$$s_I = -\frac{E_I\, h}{E_I + h}, \tag{2}$$

being E_I the interface tangential elastic stiffness and $h < 0$ the softening parameter.

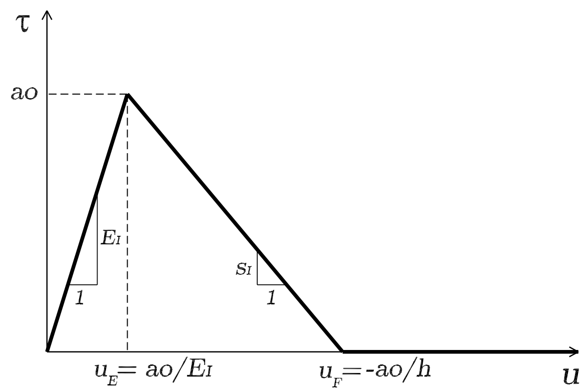


Figure 1: Bilinear bond-slip one-dimensional model.

3 SIZE EFFECT LAWS

In presence of strain-softening materials, the structure strength shows a dependence on the size of the structural element [4]. Geometrically similar structures of different sizes, subjected to the same kind of experimental test, provide different values of the structural strength.

As reported in [3], the size effect can be useful in the identification of the mechanical parameters of the bonded joints. Assuming a deformable plate of width b and axial stiffness K_B bonded to a rigid substrate and adopting the bilinear interface constitutive laws above illustrated, the size effect laws are:

$$\tau_u = \frac{F_U}{bL} = \frac{a_0}{\hat{\alpha} L} \sin(\hat{\alpha} L) \qquad \text{for} \quad 0 \leq L \leq \rho_{ef}, \tag{3}$$

$$\tau_u = \frac{F_U}{bL} = \frac{a_0}{\hat{\alpha} L} \qquad \text{for} \quad L > \rho_{ef}, \tag{4}$$

where L is the variable length, τ_u is the nominal tangential strength evaluated from the ultimate value of the pull force F_U and $\hat{\alpha} = \sqrt{s_I b / K_B}$ is an interface parameter.
The effective bond length ρ_{ef} defines two different class of specimens (long and short plates) and represent the length beyond which any increment of the bond length does not produce an increment of the ultimate load [5, 6].

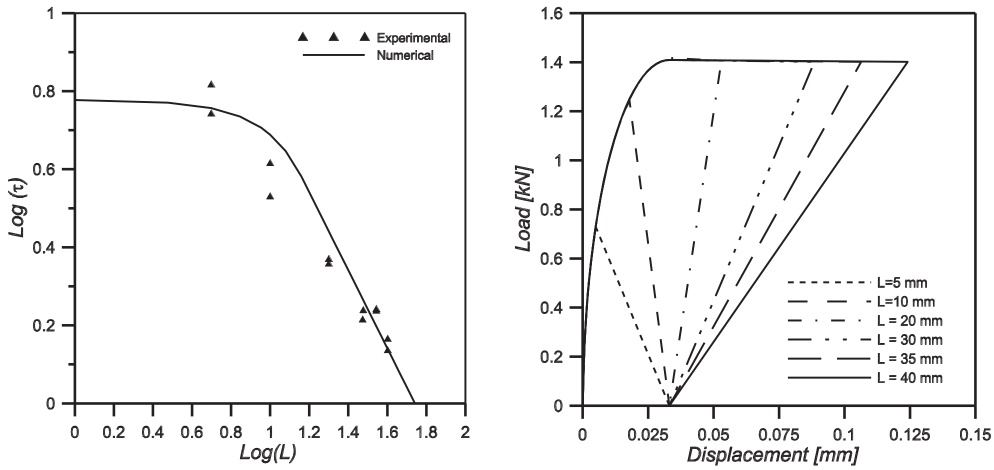
4 APPLICATION EXAMPLE

An extensive experimental program, regarding single lap joint tests on POM-C bonded to glass plates, has been carried out at the DISAG Laboratory of University of Palermo. The force controlled shear pulling tests have been performed on 12 specimens and the results in terms of ultimate force have been used for the identification of the interface adhesion strength and of the effective bond length. The glass plate has cross section of dimension 6 x 25.4 mm and length of 110 mm. The POM-C plates were bonded to the glass with anchor lengths varying from 5 mm to 40 mm. The geometrical and elastic properties of the POM-C plate are illustrated in Table 1. For the application of the size effect laws the glass plate places the role of the rigid substrate and the other adherent is the deformable material. In the first step of the interface parameters identification, the experimental structure strengths, calculated from the ultimate value of the applied load for the bond lengths equal to 5, 10, 20, 30, 35 and 40 mm, have been placed into the bilogarithmic plane. The two parameters a_0 and $\hat{\alpha}$ have been calibrated in order to fit the experimental points by using the size effect laws (3), (4). The sub-optimal parameters value and the effective bond length are reported in Table 2 together with the interface elastic stiffness, the softening modulus and the limit displacements.

In Figure 2a the size effect laws are depicted together with the experimental data. In Figure 2b the load-displacement curves for the different values of the bond length, obtained by the analytical model, are illustrated. It should be observed that the identification of the constitutive parameter $\hat{\alpha}$ leads to the evaluation of the sub-optimal value for the effective bond length of the assembly, posed equal to 14.43 mm. Therefore, the experimental tests, in which the bond length is 5 mm and 10 mm, are relative to a short plate ($L < \rho_{ef}$) and the numerical response beyond the ultimate load is of softening type. The other tests regard long bonded plates ($L > \rho_{ef}$) and the numerical responses exhibit snap-back branches beyond the ultimate load.

type	t	b	K_B
	[mm]	[mm]	[kN]
POM-C	0.2	25.4	393.7

Table 1: Geometrical and elastic properties of the POM-C plate bonded to the glass.



(a) (b)

Figure 2: (a) Experimental tests-size effect laws; (b) Load vs. displacement experimental and numerical plots.

a_0	$\hat{\alpha}$	s_I	ρ_{ef}	E_I	h	u_E	u_F
[N/mm^2]	[1/mm]	[N/mm^3]	[mm]	[kN/mm^3]	[N/mm^3]	[mm]	[mm]
6	0.1088	183.6	14.43	14	-181.3	0.00043	0.033

Table 2: Constitutive parameters values obtained by the proposed identification procedure and adopted for the simulations of the single lap joint tests.

5 CONCLUSIONS

The decohesion process in pure mode II has been studied for the assembly of glass - POM-C plates. In particular, an extensive experimental program on single lap joints has been performed in order to identify the adhesion strength and the effective bond length.
The goal of the work has been achieved through the application of the size effect laws developed for the case of a plate bonded to a rigid substrate.

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