

SYNTHESIS OF THE RESULTS REGARDING THE BREAKING RESISTANCE OBTAINED BY STATIC LOADS AND THE IMPACT BEHAVIOR OF THE ADHESIVE JOINTS

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Abstract: The present paper discusses the results of some investigations, which had in view the establishment the variation mode of the breaking resistance to shear and the maxim breaking energy under impact loading of the adhesive joints, with metallic supports, made with epoxy and/or polyurethane adhesives. The studies were made using the shear and impact tests of the adhesive bonded joints. The influence of loading mode, surface roughness of the adhesion interface, thickness of adhesive layer, superposition length, thickness of substrate, bonded area of the joint specimens and the loading rate on the strength of adhesive joints are investigated in detail.

Key words: bonded joints, adhesive strength, shearing resistance, impact loading

1. GENERAL CONSIDERATIONS

The principal attribute of adhesive is their ability to form strong bonds with surfaces of a wide range of materials and to retain bond strength under expected use conditions. The adhesion between adhesive and substrate is based on physical and chemical interactions at the interface. In more recent years there has been a rapid development of adhesive bonding as an economic and effective method for the fabrication of various components and assemblies. The use of adhesives offers advantages in comparison with conventional techniques such as brazing, welding, riveting, bolting, etc. Some of the advantages are: a) the ability to join efficiently thin sheets, or dissimilar materials; b) an increase in design flexibility; c) an improved stress distribution in the joint which leads to an increase in fatigue resistance of the bonded component; d) convenient and cost effective technique; e) to provide weight reduction in critical structures via the elimination of fasteners; f) enable the fabrication of complex shapes not feasible by other fastening means; g) to permit economic and rapid assembly; h) to prevent or reduce galvanic corrosion; i) to provide thermal and electrical insulation; j) to dampen vibrations [10].

In order to design and dimension an adhesive bonded joint for a critical load application it is necessary to have a detailed knowledge of the strength behaviour of the joint. Generally adhesive strengths are measured using a single lap-shear test specimen. The most simple strength evaluation method of this test specimen is given by the average shearing stress at fracture. In this case the stress concentrates at the bonding edges and this concentration differs depending on the specimen's shape [11]. The joint strength of structural adhesives under impact loading has recently attracted a great deal of attention with their widespread use in industrial applications, the crash worthiness of the products has been proved. The kinetic energy required to break a bonded specimen is measured with a pendulum-type impact machine with considering the effect of stress wave loading [2]. The results of the shearing and dynamic tests do not represent an intrinsic characteristic of the adhesive. They depend on the adhesive's nature and application mode, on the film's thickness and polymerisation cycle, as well as on the support's material, mode of surfaces' preparation, thickness, mechanical characteristics and length of the

supports' superposing, the geometry of the adherends, the geometry of the joint, the surface pre-treatment, the adhesive and its cure cycle and how to assemble the joint [1].

2. EXPERIMENTAL RESULTS

The purpose of the current work is to determine the variation mode of the strength of adhesive joints under static and impact loading. The strength is investigated experimentally. The static and dynamic strength was determined taking into account a series of working hypothesis such as: the thickness of the adhesive layer is constant, the stress are uniformly distributed on the adhesive layer thickness, the adhesive layer thickness is small as compared with the supports, the stress in both the adhesive and supports are uniformly distributed on the joint width, the adhesive is more flexible than the support material, the adhesive must be debonded over portion of its length, the adhesive must be a viscoelastic material that is temperature dependent, the adhesive layer is assumed to be isotropic and homogeneous [2,10,13].

The cooperation with a research team from the "Petru Poni" Institute of Macromolecular Chemistry, Iassy permitted realisation of a new romanian adhesives with higher mechanical properties in conditions of both static and dynamic stress. A thermoreactive liquid, viscous, adhesives, which are strengthened at room temperature, easy handling, comparable as to the mechanical characteristics of the good adhesives but considerably less expensive, was obtained [7,8,9].

This study is referring to a bicomponents adhesive of epoxy resin and a polyurethane adhesive, with one component. Joints through simple superposition have been realised between the steel supports, the shape and dimensions of which are given in ISO 4587, for shearing tests and, respectively, joints tests, as recommended in ISO 9653, for impact tests. All tests have been developed at normal conditions of the temperature and humidity, 1 day after the adhesive's strengthening in the joints. The adherents were made of the same carbon steel. The supports' surfaces have been prepared prior to fixing according to ISO 4588. The elastic constant of the epoxy and respectively polyurethane adhesive and substrate used (E - Young's modulus (static), ν - Poisson's ratio) are: $E_1=3.2\text{GPa}$, $E_2=4.5\text{GPa}$, $E_3=206\text{GPa}$, $\nu_1=0.38$, $\nu_2=0.34$, $\nu_3=0.33$) [5,6].

The static strengths are obtained in a testing machine (Hekert Eus, 200kN). The supports have $25\pm 0.25\text{mm}$ width and the superposition length is 12.5mm for all joints. The experiments to determine the strength of adhesive joints under impact loading were conducted using a impact machine (pendulum-type Charpy). In all cases results represent the average of ten specimens.

The effect of the surface roughness (R_a) and the thickness of adhesive layer (t) on the resistance to shear (τ) and on the maxim energy consumed for breaking the adhesive joints (W) are illustrated in table 1 and table 2 [4,12].

Table 1. Influence of surface roughness of the adhesion interface

R_a [μm]	$\tau[\text{MPa}]$		$W[\text{J}]$	
	Epoxy	Polyurethane	Epoxy	Polyurethane
0.33	41.3	36.9	47	39
0.7	44.2	38	58	48
1.1	43.5	37.2	55	45
1.4	40.4	33.1	41	32

Table 2. Influence of thickness of adhesive layer

t [mm]	$\tau[\text{MPa}]$		$W[\text{J}]$	
	Epoxy	Polyurethane	Epoxy	Polyurethane
0,3	44.2	38	58	48
0,5	43.8	37.1	55	45
0,8	35.1	29.3	46	35
1	34.4	26.2	41	32
3	22.2	14.7	32	22
4	17.3	11	26	16
5	10.1	5.4	20	11
6	6.5	3.1	13	7

The influence of the superposition length (l) and the supports' thickness (s) on the breaking resistance to shear has been established. The superposition lengths have been selected between 8÷50 mm and the thickness values of the two supports between 1÷5mm. The thickness of the adhesive layer was 0.3mm for all adhesive joints. The effect of the thickness of supports on the strength of adhesive joints is illustrated in table 3 [11,14].

Table 3. Influence of the thickness of supports

s [mm ²]	τ [MPa]	
	Epoxy	Polyurethane
1	31.3	28.9
1,6	44.2	38
2	47.5	39.2
4	50.1	40.1
5	53.6	42.3

Variation of the shear strength as a function of the superposition length is presented in table 4 [3].

Table 4. Influence of the superposition length

l [mm]	τ [MPa]	
	Epoxy	Polyurethane
8	42.3	37.3
12,5	44.2	38
20	36.7	34.7
30	30.2	28.2
40	26.5	23.1
50	20.1	18.5

Processing of the obtained results permitted to establish establishment the variation mode of the maxim breaking energy under impact loading of the adhesive joints (W) with metallic supports, made with epoxy and polyurethane adhesives as a function of bonded area of the joint specimens (S) and the loading rate (V). The influence of the bonded area of the joint specimen on the maxim breaking energy under impact is shown in table 5. A linear relation gives the variation [10].

Tabelul 5. Influence of bonded area

S [mm ²]	W[J]	
	Epoxy	Polyurethane
500	50	42
625	58	48
750	70	59
875	82	70
1000	95	84

Variation of the dynamic strength as a function of the loading rate is presented in table 6.

Tabelul 6. Influence of the loading rate

V [m/s]	W[J]	
	Epoxy	Polyurethane
2	47	39
3,4	58	48
4	66	55
5	72	61
6	78	68

3. CONCLUSIONS

In general failure takes in the adhesive (cohesive failure) rather than between the adhesive and adherent or substrate (adhesive failure).

The static and impact tensile strengths of the adhesive joints increase to a maximum at an adhesive layer thickness of about 0.3mm and subsequently decrease. The decrease in the breaking resistance to shear and the maximum breaking energy of the adhesive joints with increasing adhesive layer thickness may be due to the presence of the residual internal stresses or defects in the adhesive bond-line.

A considerable influence on the strength of joints realised with epoxy and polyurethane adhesives is exercised by the support's thickness. With the increase of supports' thickness the whole adhesive layer becomes more actively involved in the load's taking over, while the joint's strength is improved. The estimated results show that the shearing strength increases in accordance with the increase of substrate thickness. Practically doubling of the adherent's thickness causes increases up to four times higher of the joint's strength. The shearing strength of single-lap joints decreases when the lap length increases to more than the substrate thickness.

For structural applications joints with low superposition lengths are preferred. The joints with relatively high superposition lengths and small thickness values of the supports should be avoided. Influence of the superposition length on the shear strength of the adhesive joints under study can be expressed through an exponential variation law. In spite of the fact that one should expect a higher strength of the joint at higher superposition lengths, the variation indicates its pronounced decrease. That is justified firstly if considering the law of tangential stress distribution in the adhesive layer and respectively, the mathematical relation for the calculation of nominal stress. On the other hand, decrease of the breaking stress with the increase of superposition length may be explained, too by the fact that, with the increase of the adhesive amount in a joint, these also increase the possibility that it should contain air bubbles, impurities, generally plans with defects, which form effort concentrators that may weaken the joint's resistance.

The dynamic strength of the adhesive joints increases significantly with increasing loading rate, independent of the adhesive.

The strength of the joints with polyurethane adhesive is always lower than that from epoxy adhesive under static and impact loading.

The result of these investigations does provide the strength data on adhesive joints available for engineering design purposes.

REFERENCES

- [1]. Adams R. D., Harris J. A., *The influence of local geometry on the strength of adhesive joints*, Journal of Adhesion and Adhesives, no. 2, page 69-80, 2002.
- [2]. Lilleheden L., *Mechanical Properties of Adhesives "in situ" and in Bulk*, Journal of Adhesion and Adhesives, no. 13, page 31-37, 2005.
- [3]. Luhowiak W., *L'étude de la résistance au cisaillement d'assemblage des matériaux collés par l'intermédiaire d'une résine époxydique*, Informations Chimie, no. 287, page 19-27, October 1999.
- [4]. Kyogoku H., Sugibayashi T., *Strength Evaluation of Single Lap Joints (Effects of the Adherent Thickness)*, J.S.M.E. International Journal, vol. 49, no. 307, page 160-607, 1994.
- [5]. Mocanu F., Curtu I., *Study of shearing resistance of adhesive joints*, The Fifth World Conference on Timber Engineering, Montreux, Switzerland, vol. 1, page 850-851, August 1998.
- [6]. Mocanu F., Bârsănescu P.D., *Strength evaluation of single lap joints bonded with an epoxide adhesive*, The 27th. Israel Conference on Mechanical Engineering, Haifa, page 623-625, May 1998.
- [7]. Mocanu F., *Considerations on the elaboration of an epoxide adhesive*, Bulletin of Polytechnic Institute of Iasi, Fasc 3-4, Secția V, page 107-112, 1999.
- [8]. Mocanu F., Popa S. C., Bârsănescu P.D., *The influence of the structure upon the dynamic strength of the adhesive*, Bulletin of Polytechnic Institute of Iasi, Fasc. 3-4, Secția V, page 95-100, 1999.
- [9]. Mocanu F., Popa S. C., Bârsănescu P.D., *The influence of the structure upon the breaking resistance to shear of the adhesive*, Bulletin of Polytechnic Institute of Iasi, Fasc. 3-4, Secția V, page 333-337, 1999.
- [10]. Mocanu F., *Adezivi, îmbinări adezive*, Editura Gh. Asachi, Iași, 2001.
- [11]. Mocanu F., *Some observation on stress state in a simple overlapping adhesive joints*, Bulletin of Polytechnic Institute of Iasi, Fasc. 3-4, Secția V, page 63-70, 2003.