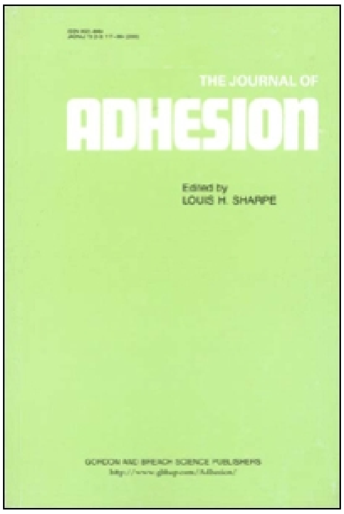

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Properties of Adhesives and their Applications

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Properties of Adhesives and their Applications

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The stress analysis of an adhesively bonded lap joint requires more information on the mechanical properties of adhesives than it is normally furnished by the manufacturers. For this reason the tests were performed on the three types of adhesives covering a large range of properties. In order to get the true stress-strain curves in tension and compression the change in the Poisson's Ratio with strain was investigated. It was found that the Poisson's Ratio increases almost to the constant volume deformation value until the nonrecoverable deformation sets in. From that point the Poisson's Ratio begins to decrease. Considering only the range of the recoverable deformation, the computer programs developed for the stress analysis of metallic materials can be used for an adhesively bonded lap joint. The recoverable viscoelastic deformation was considered non linear elastic and by applying an effective stress-effective strain relationship the analysis was performed.

KEYWORDS: Adhesives, applications, lap joint, mechanical properties, Poisson's ratio, stress analysis.

INTRODUCTION

There are many reasons for the application of adhesive bonding: Separation of dissimilar materials to prevent galvanic corrosion, absorption of vibrations[1] from one component to another and joining cold rolled or heat sensitive materials. However, the most important is transfer of stresses from one surface to another with the minimum weight and the maximum load capacity.[2] Thus, the most common applications are in the aircraft and the space industries where adhesives are used for bonding metallic foils or thin composite structures.

The most useful method for the stress analysis of the simplest adhesive

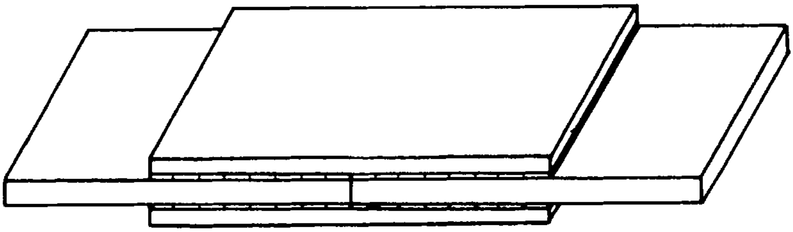

FIGURE 1 Adhesively bonded symmetrical lap joint.

lap joint as shown in Figure 1, is the F.E.M. (Finite Element Method).

Simplified analysis of stresses in adhesives were performed by several investigations. Pirvics,[3] Delale, *et al.*[4] and Wright[5] used a linear model to predict two dimensional stress distribution in an adhesive structure. Gali and Ishai[6] have also considered the two dimensional model but included the nonlinear behaviour of adhesives. The visco-elastic properties of the adhesive were also related to the load transfer in a lap joint by Weitsman.[7]

It has been shown that normal and shear stresses vary significantly across the thickness of the adhesive especially at the edges of the joints, where sharp peaks of stresses were found. Hart-Smith[8] has shown that the stress levels at the edges of the adhesive joint can be considerably reduced by the use of a more ductile adhesive, which also provides a better distribution of load and thus increases the load capacity of the lap joint.

One of the common beliefs about adhesives is that apparent cohesive strength of an adhesive system in a bonded lap joint differs from that of the adhesive in bulk. This does not imply that there is a change in the intermolecular forces of cohesion but that the observed discrepancy is caused by the different distribution of stresses in a bulk specimen from that in the adhesive layer in a lap joint.

The objective of the present study is to obtain the properties of representative commercial adhesives which are necessary for the stress analysis of an adhesively bonded symmetrical lap joint as shown in Figure 1. In such a joint, complex triaxial stresses build up in the adhesive layer; however, failure is caused by the biaxial normal stresses at the edge of an adhesive. Using a modified von Mises criterion, the maximum load capacity of the joint may be predicted provided the mechanical and visco-elastic properties of adhesives are known.

EXPERIMENTAL

It was found from the preliminary calculations of the stress distributions in the lap joint that the major effect is produced by the strain to failure of the adhesive. More flexible adhesives, *i.e.*, those with large strain to failure values, tend to distribute load in a lap joint more uniformly, those with small strain to failure values produce peaks of stresses at both ends of a lap. For that reason three types of adhesives with small, medium and large strains to failure were selected:

1. Two-part structural adhesive EA9320 from Hysol Div., Dexter Corp., a modified epoxy adhesive having high strength and low strain to failure.
2. Two-part "Scotch Weld" structural adhesive EC2216 A/B, from 3M Company, also a modified epoxy, with medium strength and medium strain to failure.
3. An adhesive made of a mixture of Modur CB75 and Multron R221-75 which are a polyisocyanate and a polyester resin, respectively, from Plastics and Coatings Div., Mobay Chemical Corp. This adhesive has a low strength but high strain to failure.

Specimens for tensile and compressive testing were prepared from all three adhesives following manufacturers specifications for the best polymerisation results. Tensile specimens were flat, of a dog bone shape, 0.3 cm thick and of 3 cm gauge length. Compressive specimens had rectangular dimensions of 1.0 × 1.0 × 2.5 cm.

The engineering stress-strain curves are shown in Figures 2 and 3. Values of UTS and strain to fracture are listed in Table 1.

In order to obtain true stress-strain curves the Poisson's Ratios as a function of strain in tension and compression were measured. Lateral and longitudinal strains for the hardest adhesive (EA9320) were measured by strain gauges and for the other two adhesives extensometers were used for both lateral and longitudinal directions. Poisson's Ratios *versus* strain in tension for the adhesive EC2216 is shown in Figure 4.

The decreasing values of Poisson's Ratio over 7% of strain were difficult to explain, therefore additional tests were performed. A series of loading and unloading curves have shown that strain over 7% is not recoverable. This was also confirmed by strain recovery curves which showed permanent viscous strain for specimens elongated over 7%. Permanent strain remained after recovery which was allowed for three

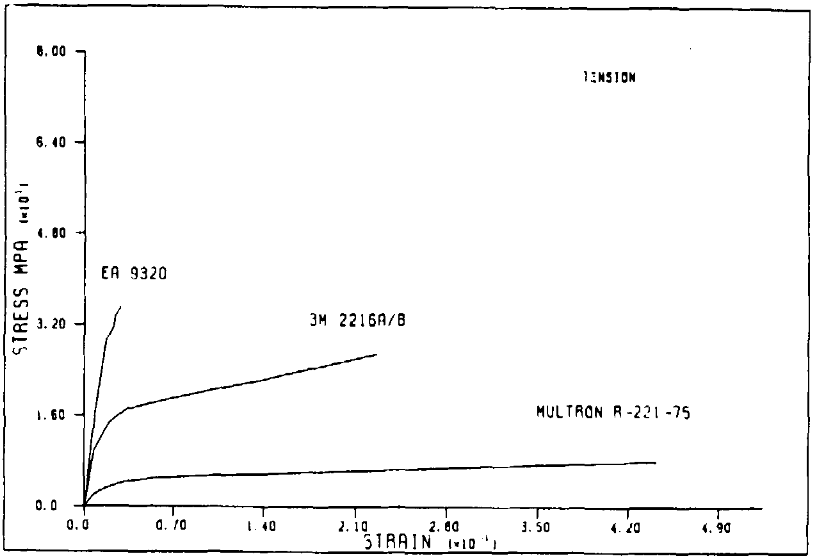

FIGURE 2 Typical engineering stress-strain curves in tension for the three types of adhesives.

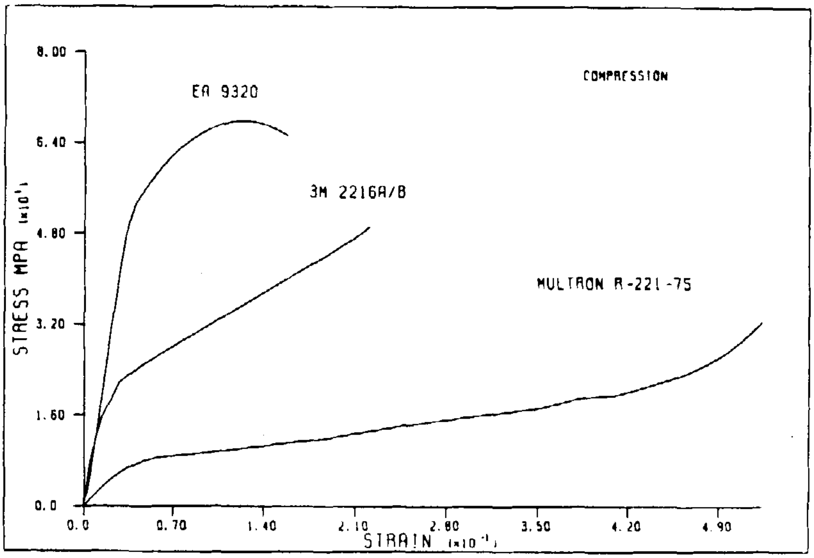

FIGURE 3 Typical engineering stress-strain curves in compression for the three types of adhesives.

TABLE I
Mechanical Properties of the three types of adhesives

	TENSION			COMPRESSION		
ADHESIVE	UTS (MPa)	Tangent Modulus E_T (MPa)	Strain to Fracture	UCS (MPa)	Tangent Modulus E_T (MPa)	Strain to Fracture
EA 9320	47.11 ± 1.0	2347	~4%	61.7 ± 1.19	2347	~30%
3M 2216 A/B	30.41 ± 2.94	1670	~25%	113.9 ± 9.42	1670	~39%
CB75 + MULTRON R221-75	7.69 + 0.84	260	~34%	54.8 ± 9.32	260	~45%

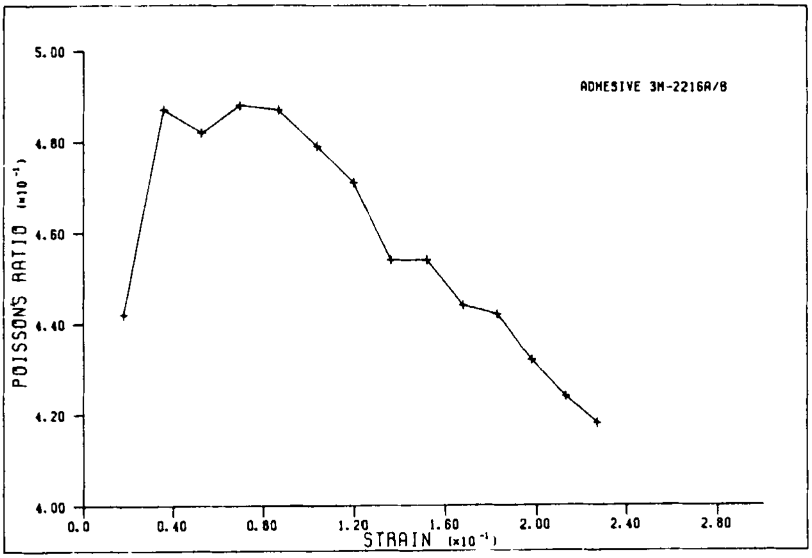

FIGURE 4 Poisson Ratio vs strain for both recoverable and nonrecoverable deformation.

days. Visual observation revealed that whitening of the adhesive occurs when it was strained over 7%.

Since non-recoverable deformation in the adhesively bonded joints cannot be tolerated, similar tests were performed for other materials. A series of curves of Poisson's Ratio *versus* strain were obtained in tension and compression before detectable non-recoverable deformation had occurred for all three adhesives. Results are shown in Figures

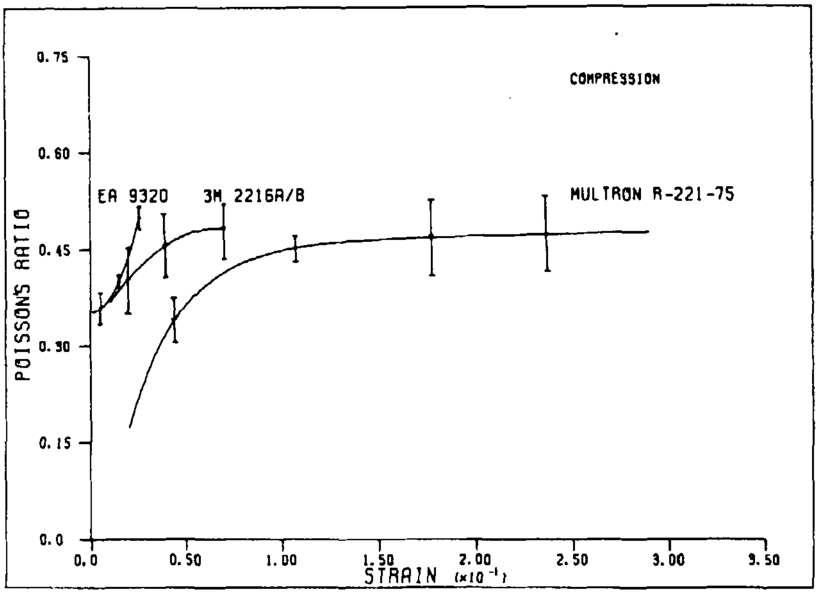

FIGURE 5 Poisson Ratio vs strain for the recoverable deformation in tension of the three types of adhesives.

5 and 6. On the basis of the engineering stress-strain curves and values of Poisson's Ratio, true stress-strain curves were plotted as shown in Figures 7 and 8.

DISCUSSION

The engineering stress-strain curves in Figures 2 and 3 and Table 1 summarise the mechanical properties of the three adhesives tested. They differ greatly in strength, stiffness and strain to fracture. All three of them, however, display viscoelastic behaviour and above certain values of stress or strain the viscoelastic recovery becomes incomplete. Some adhesives show this limit by whitening, on some surfaces crazing may be observed but the best way to assess this limit is by the measurement of the Poisson's Ratio. There is one exception in which the Poisson's Ratio measurement may become unreliable. Most of the commercial adhesives have amorphous molecular structure. There are some, however, which may show a limited crystallinity upon deformation in

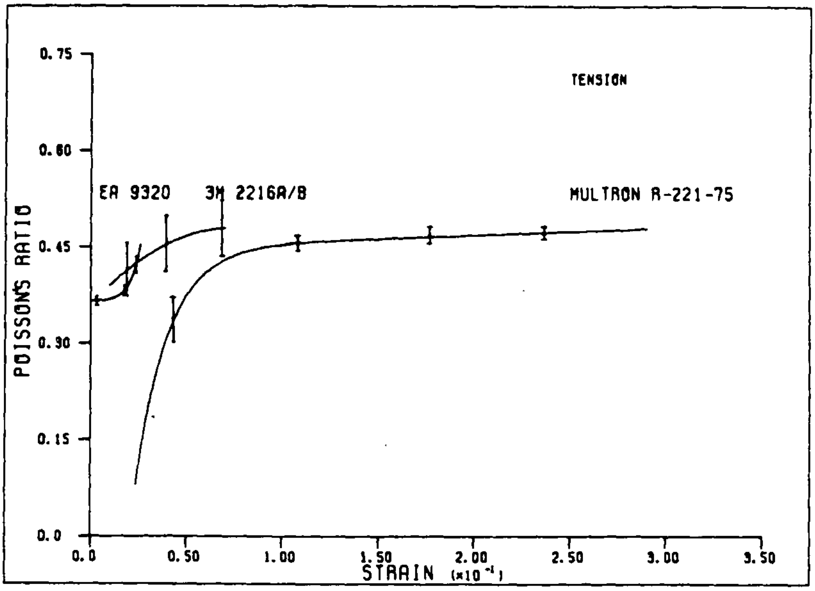

FIGURE 6 Poisson Ratio vs strain for the recoverable deformation in compression of the three types of adhesives.

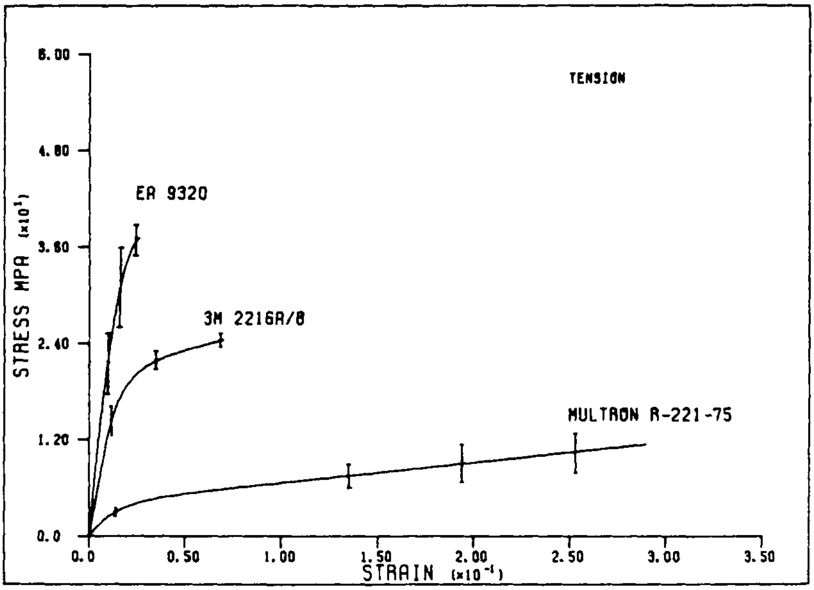

FIGURE 7 True stress-strain curves in tension for the three types of adhesives.

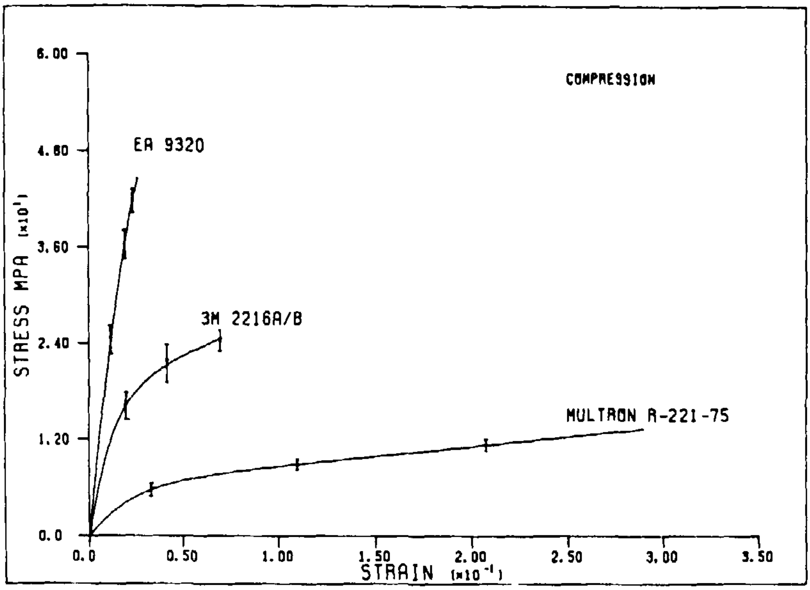

FIGURE 8 True stress-strain curves in compression for the three types of adhesives.

tension. For those adhesives the value of Poisson's Ratio will also decrease while crystallites are formed. Formation of crystallites is generally associated with permanent deformation but also with a strengthening effect. Thus, stress analysis of an adhesive lap joint, for example, becomes more complicated. Assuming that the first loading of the structure would deform the adhesive to the point where crystallinity would form, upon subsequent loadings recoverable deformations would occur but the properties of the adhesive will be significantly different. Thus, designers of an adhesive structure should take this effect into consideration in their stress analysis.

The stress analysis of adhesive structures is relatively new but, to the designer, the limit of recoverable deformation in adhesives is as important as the yield strength in metals.

Although major stresses, transferring load between the adherends, are shear stresses,[9] for large deformations of adhesives the major critical stresses at the edges become normal stresses.[10]

It should also be pointed out that the presented mechanical properties of the adhesives were obtained for the crosshead speed equal to 5 cm/min, therefore the designer should consider the equivalent, or lower, strain rates as a criterion.

It was also assumed that deformations occur at room temperature. For any other conditions a new set of experiments has to be carried out.

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