AAEC/E385

AAEC/E385

AUSTRALIAN ATOMIC ENERGY COMMISSION

RESEARCH ESTABLISHMENT

LUCAS HEIGHTS

THE EFFECTS OF REACTIVE DILUENTS ON THE MECHANICAL BEHAVIOUR OF AN ANHYDRIDE-CURED EPOXY RESIN SYSTEM

by

G.T. STEVENS
A.W. LUPTON

October 1976

ISBN 0 642 99761 6

AUSTRALIAN ATOMIC ENERGY COMMISSION
RESEARCH ESTABLISHMENT
LUCAS HEIGHTS

THE EFFECTS OF REACTIVE DILUENTS ON THE MECHANICAL BEHAVIOUR OF AN ANHYDRIDE-CURED EPOXY RESIN SYSTEM

by

G.T. STEVENS
A.W. LUPTON

ABSTRACT

A study was made of the tensile behaviour at room temperature, 75°C and 100°C, of diglycidyl ether of bisphenol A resin systems modified by the introduction of (i) a linear mono-epoxide aliphatic glycidyl ether, (ii) a highly branched mono-epoxide glycidyl ester of a saturated tertiary monocarboxylic acid, (iii) a mixture of the linear mono-glycidyl and diglycidyl ethers of butanediol and (iv) a low viscosity diepoxide and also an elastomer (Hycar CTBN). Resin systems showing relatively high elongation to failure without severe degradation of strength or stiffness at elevated temperatures were obtained.

National Library of Australia card number and ISBN 0 642 99761 6

The following descriptors have been selected from the INIS Thesaurus to describe the subject content of this report for information retrieval purposes. For further details please refer to IAEA-INIS-12 (INIS: Manual for Indexing) and IAEA-INIS-13(INIS: Thesaurus) published in Vienna by the International Atomic Energy Agency.

ANHYDRIDES; COMPOSITE MATERIALS; EPOXIDES; MEDIUM TEMPERATURE; ORGANIC SOLVENTS; RESINS; STRESSES

CONTENTS

1. INTRODUCTION

Conventional epoxy resins are generally brittle and as the matrix in fibre/epoxy composite laminates they are prone to cracking under stress. In order to overcome the cracking, some form of modification of the resin is required which improves its elongation to failure without lowering its elastic modulus to a value useless for a composite matrix at temperatures of service.

Previous work [Stevens & Lupton 1975a] has shown that a system which exhibits yield and cold-drawing does provide improved resistance to cracking (toughness) in glass fibre/epoxy composites. The resin system in that study incorporated a reactive diluent and used a polyether triamine hardener so that the glass-transition temperature* range was in the vicinity of room temperature (RT) and the composite had limited applications.

The present publication describes a study of the effects of several reactive diluents on an anhydride-cured epoxy resin system which was conducted with a view to obtaining a resin system that displays the yielding phenomenon and is suitable as a composite matrix for service at temperatures around 70°C.

In addition to modifying the mechanical properties of the cured system there is good reason to believe that some of these diluents might facilitate fabrication of composites by improving the viscosity/time/temperature relationship of the uncured resin system.

2. MATERIALS

The epoxy resin system studied here was based on diglycidyl ether of bisphenol A (DGEBA) and cured with the maleic anhydride adduct of methylcyclopentadiene (NMA). Details from the commercial literature of the grades of resins used are given in Table 1.

The following reactive diluents were selected for study:

(i) a linear mono-epoxide aliphatic glycidyl ether (CIBA-GEIGY Epoxide No. 7);

(ii) a highly branched mono-glycidyl ester of a saturated tertiary mono-carboxylic acid (Shell Chemical Co. Cardura E10);

(iii) a mixture of the linear mono-glycidyl and diglycidyl ethers of butanediol (CIBA-GEIGY Diluent DY 022); and

(iv) a low viscosity cycloaliphatic diepoxide-vinylcyclohexene dioxide (CIBA-GEIGY Diluent DY 032).

---

* temperature at which a polymer changes from a glassy to a rubbery state.

The structural formulae of these diluents are given in Table 2 and their properties (from commercial sources) listed in Table 3.

Since previous work [Stevens & Lupton 1975b] had shown that in some cases additions of an elastomer, carboxyl-terminated copolymer of butadiene and acrylonitrile (Hycar CTBN, B.F. Goodrich Chemical Co.), were beneficial in inducing yielding in resins, it seemed worthwhile to study the effects of the elastomer in these systems also. The compositions of systems studied here are listed in Tables 4 - 8.

3. TEST METHODS

3.1 Tensile Testing

Tensile test specimens of the resin, to the form and dimensions shown in Figure 1, were cast in open, PTFE-coated moulds and cured in an air oven with mechanical circulation.

Tensile testing was carried out at RT, 75° and 100°C on a 4.45 kN Instron machine at a strain rate of $1.48 \times 10^{-4} s^{-1}$, with the strain being monitored by an Instron strain gauge extensometer with a 50.8 mm gauge length. Elevated temperature tests were carried out in an Instron environmental chamber with a temperature stability of ± 0.6°C.

In general, only one test was carried out at each condition as experience had shown that, except in the case of brittle behaviour, duplicate tests give reasonable reproducibility and that one test is sufficient to give a qualitative description of ductile behaviour.

The following properties were recorded:

(i) The upper yield stress - the initial maxima in the stress-strain curve.

(ii) The lower yield stress - the minima in the stress-strain curve.

(iii) The fracture stress - the nominal stress at fracture (which may pre-empt the yield processes).

(iv) The elongation to failure.

(v) The 0.5% secant modulus - a measure of the elastic modulus determined by the slope of the line drawn from the origin of the stress-strain curve to the curve at 0.5% strain.

3.2 Deformation Behaviour

When the material exhibited non-elastic deformation, i.e. it showed a yield effect or extensive elongation, evidence for such behaviour could often be obtained from inspection of the specimen after the test. Yielding generally produced a shear band at one shoulder at least and, if the yield drop was extensive, significant reduction in cross section occurred (necking).

At the higher temperatures, uniform drawing of the specimen could result in extensive elongation to failure. The presence of Hycar CTBN often gave rise to fine-scale crazing within shear bands and also fine crazing, normal to the tension axis, throughout the gauge length. Observations such as these were recorded after each test.

4. RESULTS

4.1 Diluent-free Systems

The properties of the diluent-free systems and comments on their deformation behaviour are listed in Table 4, and the stress-strain curves of the low molecular weight (MW) systems presented in Figure 2. The higher MW systems show some ductility at 75°C but are still brittle at RT. The addition of 5 parts per hundred of resin (phr) of Hycar CTBN gives some improvement of low temperature ductility and enables higher fracture stresses to be achieved. It also induces shear band formation at elevated temperatures.

4.2 Epoxide No. 7

The tensile properties of the systems containing Epoxide No. 7 and observation of its deformation behaviour are shown in Table 5. Shear band formation and necking occurred at 75°C without the addition of Hycar CTBN. At the 20 phr diluent level the elastic modulus and strength become severely degraded at elevated temperatures. The addition of 10 phr Hycar CTBN also severely reduces the modulus. The best combination of properties in this system was found at low concentrations ($\leqslant$ 10 phr) of diluent with 5 phr Hycar CTBN.

4.3 Cardura E10

The results given in Table 6 show that the system can tolerate up to 10 phr Cardura E10, with yielding occurring at elevated temperatures without severe degradation of properties. At 15 phr the ductility is reduced. The RT behaviour at all levels studied is brittle and addition of 10 phr Hycar CTBN does not alleviate this but reduces the strength and stiffness at elevated temperatures.

4.4 Diluent DY 022

The results for the systems containing DY 022 are shown in Table 7. Up to at least 30 phr diluent the systems display a yield effect at elevated temperatures while retaining strength and stiffness. Addition of 5 phr Hycar CTBN reduces RT brittleness. The stress-strain curves for this system (ND6) are shown in Figure 3; the system displays a good balance of properties with some capacity for yielding in tension at RT and well developed yielding at 75° and 100°C.

The effect of varying the hardener/resin + diluent ratio at the 30 phr diluent level can also be seen in Table 7 (DN Series). At the lower ratio the elevated temperature properties are degraded (indicative of incomplete cross-linking) while at the higher ratio the system appears to be more brittle with less capacity for yielding.

The effect of increasing the MW of the DGEBA molecule on the properties of the 30 phr diluent system is also shown in Table 7 (FG and GY series). Increasing the MW increases RT strength and modulus of the Hycar CTBN-free formulations but, in general, the properties are not greatly dependent on MW. The yield drop at 75°C is depressed by 5 phr Hycar CTBN in the higher MW systems, while in the low MW system it is enhanced.

4.5 Diluent DY 032

The properties of the system containing DY 032 are listed in Table 8. At 30 phr diluent the system shows good retention of elastic modulus at elevated temperatures but the system is rather brittle with low elongation to failure even at 100°C. No effect of deformation could be observed in the specimens tested at any temperature. Further investigation of this diluent was not pursued.

5. DISCUSSION

The effects of the various diluents on the mechanical behaviour of these resin systems can be qualitatively explained in terms of their structure. Mono-epoxide diluents give rise to breaks in the cross-linked network and so facilitate thermal or stress-induced rearrangement of the structure.

Epoxide No. 7 is a long linear, mono-epoxide molecule which would be expected to contribute some flexibility to the structure. As a consequence, the glass-transition temperature of the system is reduced so that at 20 phr Epoxide No. 7, the system is almost rubbery at 100°C.

Cardura E10, while containing a single epoxide group is, on the other hand, highly branched and thus possesses limited flexibility. Its effect on the glass-transition temperature is less marked than that obtained with Epoxide No. 7. Stress-induced motion is also apparently more difficult and the best yield behaviour was observed at the lower concentrations and the highest temperature.

Diepoxide diluents will enter the cross-linked network without forming breaks. The modification of the structure thus depends on the flexibility and length of the diepoxide diluent molecule. Diluent DY 032 is a short molecule of limited flexibility and so its effect on the glass-transition temperature would be expected to be slight and the capacity of the network for shear deformation would be unlikely to be improved. Our results are in agreement with these proposals.

Diluent DY 022 is a mixture of medium length mono- and diepoxide containing chains with minimum stearic hindrance. The resin system can tolerate fairly large quantities of the mixture, the bifunctional portion apparently preventing drastic reduction in the glass-transition temperature while the monofunctional component gives the network increased freedom of movement.

The role of Hycar CTBN remains unclarified. It forms small spheres (of the order of 100 nm diameter) of a rubber rich phase which are cross-linked to the resin matrix [McGarry & Willner 1968]. These spheres toughen the matrix, principally by inducing small crazes that form normal to the tension axis. The smaller spheres are known to initiate fine-scale shear deformation [McGarry 1970] which might be expected to facilitate the formation of the macroscopic shear band, giving rise to the necking in the tension test. Our results show that such enhancement is sometimes observed at low Hycar CTBN levels.

The resin system showing the best combination of properties is probably Resin ND6 containing 30 phr DY 022 and 5 phr Hycar CTBN. Attempts to improve the initial formulations by varying the quantity of hardener and the molecular weight of the epoxide resin molecule were unsuccessful.

Further investigation of the yield process and the effects of molecular structure and Hycar CTBN could lead to resins with improved mechanical behaviour.

6. CONCLUSIONS

A correlation between the molecular structure of the diluent and the thermo-mechanical behaviour of the resin system was demonstrated. A long linear mono-epoxide diluent increased the ductility of the system but brought about a severe decrease in the glass-transition temperature. A highly branched mono-epoxide diluent showed less effect on the glass transition temperature but had a limited effect on ductility. Short diepoxide molecules of limited flexibility could be tolerated in large amounts without greatly affecting the glass-transition temperature but resulted in a brittle system.

The best combination of properties was found with a diluent composed of a mixture of linear mono- and diepoxide molecules (30 phr Diluent DY 022) with the addition of 5 phr Hycar CTBN.

7. REFERENCES

McGarry, F.J. [1970] - Proc. Roy. Soc. A319: 59.

McGarry, F.J. & Willner, A.M. [1968] - 23rd Ann. Tech. Conf. Reinforced Plastics/Composites Div. SPI, Section 14.B.

Stevens, G.T. & Lupton, A.W. [1975a] - Submitted to J. Mater. Sci.

Stevens, G.T. & Lupton, A.W. [1975b] - Unpublished AAEC internal report MAT/TN56.

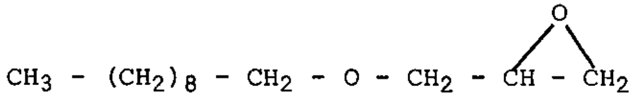
TABLE 1

DETAILS OF DGEBA RESINS

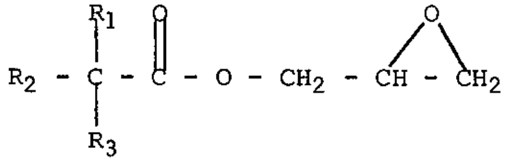
Resin	Epoxide Molar Mass (g)	Viscosity at 25°C (Pa s)
Araldite LY 556	175-210	8-12
Araldite F	182-196	12-16
Araldite 6004	185	5-6
Araldite GY 280	225-290	60-80 (40°C)

TABLE 2

STRUCTURAL FORMULAE OF REACTIVE DILUENTS

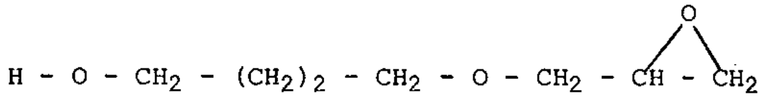


(1) Epoxide No. 7

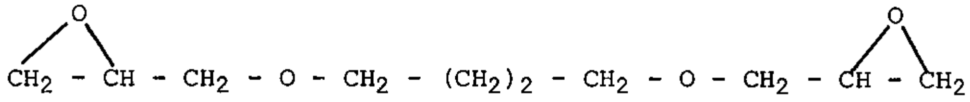


R_1, R_2, R_3 are alkyl groups of which one is a methyl group

(2) Cardura E10 ($C_{13}H_{24}O_3$)

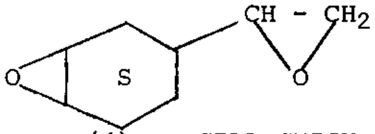


57%



43%

(3) CIBA-GEIGY Diluent DY 022



(4) CIBA-GEIGY Diluent DY 032

TABLE 3

PROPERTIES OF REACTIVE DILUENTS

Diluent	Epoxide Molar Mass (g)	Viscosity at 25°C (Pa s)	Boiling Point at 760 mm Hg (°C)	Vapour Pressure at 100°C (mm Hg)	Flash Point (°C)
Epoxide No. 7	227	0.01	-	-	200
Cardura E10	240-250	0.007	260	0	130
DY 022	127	0.01	260-270	8	145
DY 032	77	0.02	227	< 10	104

TABLE 4

COMPOSITION AND PROPERTIES OF DILUENT-FREE SYSTEMS

TABLE 4a

COMPOSITION

Resin Code	Composition - parts by weight				
	Resin		Hardener	Accelerator	Hycar
	LY 556	GY 280	NMA(3)	DMP-30(1)	CTBN(4)
10	100	0	80	0.75	0
	Araldite F			BDMA(2)	
FG1	50	50	70	1	0
FG2	50	50	70	1	5
GY1	0	100	60	1	0
GY2	0	100	60	1	5

Cure 2 h 100°C, 16 h 150°C

(1) Tris(dimethylaminomethyl)-phenol

(2) Benzyldimethylamine

(3) Maleic anhydride adduct of methylcyclopentadiene

(4) Carboxyl-terminated copolymer of butadiene and acrylonitrile

TABLE 4b

ELASTIC MODULUS AND DUCTILITY

Resin Code	0.5% Secant Modulus (GPa)			Elongation (%)		
	RT*	75°C	100°C	RT*	75°C	100°C
10	2.53	2.48	2.01	2.8	3.0	10.0
FG1	2.87	2.59	2.26	3.2	6.5	4.0
FG2	2.85	2.46	2.07	5.7	6.4	11.0
GY1	2.72	2.33	2.25	3.6	4.2	3.6
GY2	2.54	2.20	1.85	4.3	4.6	6.5

*RT = Room temperature

TABLE 4c

TENSILE STRENGTH

Resin Code	Upper Yield Stress (MPa)			Lower Yield Stress (MPa)			Fracture Stress (MPa)		
	RT	75°C	100°C	RT	75°C	100°C	RT	75°C	100°C
10	-	-	41.4	-	-	31.3	58.2	53.2	31.3
FG1	-	62.1	45.0	-	-	-	68.1	54.9	43.5
FG2	-	56.7	41.4	-	-	31.8	80.2	49.3	31.8
GY1	-	56.0	42.4	-	-	-	70.7	55.2	39.8
GY2	-	49.3	33.9	-	-	-	70.5	43.6	27.1

TABLE 4d

OBSERVATIONS OF DEFORMATION BEHAVIOUR

Resin Code	RT	75°C	100°C
10	no effect	no effect	slight necking
FG1	no effect	slight necking	no effect
FG2	no effect	moderate shear band fine crazing	moderate shear band moderate crazing
GY1	no effect	no effect	no effect
GY2	no effect	slight shear band fine crazing	moderate necking slight shear band slight crazing

TABLE 5

COMPOSITION AND PROPERTIES OF SYSTEMS CONTAINING EPOXIDE NO. 7

TABLE 5a

COMPOSITION

Resin Code	Composition - parts by weight				
	Resin Araldite F	Hardener NMA(1)	Diluent Epoxide No. 7	Accelerator BDMA(2)	Hycar CTBN(3)
SF1	100	86.5	10	1	0
SF8	100	89.8	15	1	0
SF2	100	93	20	1	0
SF3	100	100	30	1	0
SF5	100	83.3	5	1	5
SF9	100	84.9	7.5	1	5
SF10	100	86.5	10	1	5
SF6	100	86.5	10	1	10
SF4	100	93	20	1	10

Cure 2 h 100°C, 16 h 150°C

(1) Maleic anhydride adduct of methylcyclopentadiene

(2) Benzyldimethylamine

(3) Carboxyl-terminated copolymer of butadiene and acrylonitrile

TABLE 5b

ELASTIC MODULUS AND DUCTILITY

Resin Code	0.5% Secant Modulus (GPa)			Elongation (%)		
	RT(4)	75°C	100°C	RT	75°C	100°C
SF1	2.96	2.42	1.86	2.6	6.9	36.1
SF8	2.19	2.35	1.73	2.9	7.0	52.5
SF2	3.01	2.32	0.93	2.1	16.8	63.5
SF3	3.03	1.84	0.25	2.4	37.5	36.9
SF5	2.94	2.13	1.93	5.3	6.5	31.2
SF9	2.72	2.22	1.77	3.2	8.2	18.8
SF10	2.67	2.35	1.89	3.0	4.9	7.3
SF6	2.34	1.69	0.86	6.7	40.0	73.5
SF4	2.80	1.63	0.55	4.1	27.6	45.8

(4) Room temperature

TABLE 5c

TENSILE STRENGTH

Resin Code	Upper Yield Stress (MPa)			Lower Yield Stress (MPa)			Fracture Stress (MPa)		
	RT	75°C	100°C	RT	75°C	100°C	RT	75°C	100°C
SF1	-	48.5	28.8	-	37.6	23.6	64.2	-	-
SF8	-	45.7	23.4	-	38.0	19.0	65.8	-	24.1
SF2	-	38.9	10.8	-	30.8	10.1	56.0	-	-
SF3	-	30.1	-	-	25.9	-	59.9	-	5.3
SF5	-	50.8	35.2	-	44.0	27.4	78.3	-	27.7
SF9	-	47.9	28.9	-	39.3	23.0	67.3	-	-
SF10	-	49.3	28.9	-	45.4	23.7	66.7	-	-
SF6	62.3	30.2	12.9	59.4	25.8	10.9	-	26.9	16.4
SF4	-	28.9	-	-	24.8	-	64.7	-	12.2

TABLE 5d

OBSERVATIONS OF DEFORMATION BEHAVIOUR

Resin Code	RT	75°C	100°C
SF1	no effect	necking moderate shear band	gl(5) drawn
SF8	no effect	no effect	slight shear band gl drawn
SF2	no effect	necking slight shear band	gl drawn
SF3	no effect	slight shear band gl drawn	gl drawn
SF5	no effect	necking slight shear band crazing in gl	moderate shear bands crazing in gl
SF9	no effect	slight shear band slight crazing in gl	slight shear band slight crazing in gl
SF10	no effect	distinct shear band crazing in gl	slight crazing in gl
SF6	no effect	slight shear band gl drawn	gl drawn
SF4	no effect	slight shear band gl drawn	slight shear band gl drawn

(5) Gauge length

TABLE 6

COMPOSITION AND PROPERTIES OF SYSTEMS CONTAINING CARDURA E10

TABLE 6a

COMPOSITION

Resin Code	Composition - parts by weight				
	Resin Araldite F	Hardener NMA(1)	Diluent Cardura E10	Accelerator BDMA(2)	Hycar CTBN(3)
CF1	100	83.1	5	1	0
CF2	100	86.2	10	1	0
CF3	100	89.3	15	1	0
CF4	100	86.2	10	1	10

Cure 2 h 100°C, 16 h 150°C

(1) Maleic anhydride adduct of methylcyclopentadiene

(2) Benzyldimethylamine

(3) Carboxyl-terminated copolymer of butadiene and acrylonitrile

TABLE 6b

ELASTIC MODULUS AND DUCTILITY

Resin Code	0.5% Secant Modulus (GPa)			Elongation (%)		
	RT(4)	75°C	100°C	RT	75°C	100°C
CF1	2.87	2.66	2.42	2.3	6.3	8.4
CF2	2.82	2.37	2.18	2.1	6.1	8.2
CF3	2.92	2.37	2.12	2.3	4.1	4.3
CF4	2.55	2.03	1.46	2.6	4.5	15.5

(4) Room temperature

TABLE 6c

TENSILE STRENGTH

Resin Code	Upper Yield Stress			Lower Yield Stress			Fracture Stress		
	RT	75°C	100°C	RT	75°C	100°C	RT	75°C	100°C
CF1	-	61.9	46.1	-	-	35.4	57.0	55.6	-
CF2	-	55.5	38.1	-	47.2	29.4	52.6	-	29.5
CF3	-	-	36.3	-	-	34.4	56.8	54.3	-
CF4	-	-	23.1	-	-	19.6	54.0	41.7	-

TABLE 6d

OBSERVATIONS OF DEFORMATION BEHAVIOUR

Resin Code	RT	75°C	100°C
CF1	no effect	slight shear band	slight shear band
CF2	no effect	distinct shear band	distinct necking distinct shear band
CF3	no effect	no effect	no effect
CF4	no effect	slight crazing in gl	slight necking gl slightly drawn

TABLE 7

COMPOSITION AND PROPERTIES OF SYSTEMS CONTAINING DY 022

TABLE 7a

COMPOSITION

Resin Code	Composition - parts by weight				
	Resin Araldite F/GY 280	Hardener NMA(1)	Diluent DY 022	Accelerator BDMA(2)	Hycar CTBN(3)
ND1	100/0	91	10	1	0
ND2	100/0	101	20	1	0
ND3	100/0	111	30	1	0
ND5	100/0	101	20	1	5
ND6	100/0	111	30	1	5
ND4	100/0	101	20	1	10
DN1	100/0	104	30	1	0
DN2	100/0	104	30	1	5
DN3	100/0	125	30	1	0
DN4	100/0	125	30	1	5
FG3	50/50	100	30	1	0
FG4	50/50	100	30	1	5
GY3	0/100	90	30	1	0
GY4	0/100	90	30	1	5

Cure 2 h 100°C, 16 h 150°C

(1) Maleic anhydride adduct of methylcyclopentadiene

(2) Benzyldimethylamine

(3) Carboxyl-terminated copolymer of butadiene and acrylonitrile

TABLE 7b

OBSERVATIONS OF DEFORMATION BEHAVIOUR

Resin Code	RT(4)	75°C	100°C
ND1	no effect	slight necking slight shear band	slight necking distinct shear band
ND2	no effect	slight necking distinct shear band	distinct necking slight shear band
ND3	no effect	slight shear band	slight shear band gl(5) drawn
ND5	no effect	slight necking slight shear band slight crazing in gl	slightly drawn gl
ND6	slight crazing in gl	slight necking slight shear bands moderate crazing in gl	slight shear band slight crazing in gl gl drawn
ND4	no effect	distinct necking moderate shear band distinct crazing in gl	gl drawn
DN1	no effect	distinct necking moderate shear band	gl drawn
DN2	no effect	moderate necking slight shear band slight crazing in gl	gl drawn
DN3	no effect	no effect	two moderate necks
DN4	slight crazing	moderate necking slight shear band crazing in gl	gl drawn
FG3	no effect	slight necking slight shear band	gl drawn
FG4	slight crazing in gl	slight necking moderate shear band crazing in gl	gl drawn
GY3	no effect	moderate necking slight shear band	slight necking
GY4	no effect	distinct necking distinct shear band crazing in gl	gl drawn

(4) Room temperature

(5) Gauge length

TABLE 7c

ELASTIC MODULUS AND DUCTILITY

Resin Code	0.5% Secant Modulus (GPa)			Elongation (%)		
	RT	75°C	100°C	RT	75°C	100°C
ND1	2.80	2.59	2.32	5.3	5.6	4.5
ND2	2.98	2.57	1.94	2.3	9.0	12.3
ND3	2.90	2.44	2.21	3.3	7.0	22.5
ND5	2.74	2.26	1.70	3.8	4.7	9.5
ND6	2.83	2.56	1.77	6.0	13.4	34.3
ND4	2.75	2.15	1.64	3.1	6.2	36.0
DN1	3.05	2.35	1.49	2.5	6.0	>47.5
DN2	2.92	2.19	0.53	4.9	14.4	>70.0
DN3	2.60	2.43	2.08	2.2	7.0	19.8
DN4	2.87	2.28	1.78	5.4	6.5	31.9
FG3	3.40	2.38	1.18	3.8	14.8	41.9
FG4	3.05	2.06	0.75	4.1	9.6	>46.9
GY3	3.43	2.40	1.68	6.2	12.0	17.2
GY4	2.85	2.15	1.05	5.6	9.9	58.1

TABLE 7d

TENSILE STRENGTH

Resin Code	Upper Yield Stress (MPa)			Lower Yield Stress (MPa)			Fracture Stress (MPa)		
	RT	75°C	100°C	RT	75°C	100°C	RT	75°C	100°C
ND1	-	61.1	46.2	-	-	-	82.4	54.4	42.2
ND2	-	58.1	33.0	-	-	-	58.4	45.3	25.4
ND3	-	52.5	35.6	-	-	26.5	69.1	44.6	-
ND5	-	49.1	26.7	-	42.3	22.5	73.2	-	-
ND6	76.8	47.9	28.7	-	36.5	22.8	76.2	-	24.7
ND4	-	42.3	23.7	-	-	19.3	60.9	34.8	21.2
DN1	-	45.2	18.0	-	34.1	15.3	60.4	34.1	>20.6
DN2	75.5	37.3	-	-	29.4	-	74.8	29.4	>12.5
DN3	-	53.2	36.3	-	-	27.7	50.5	43.7	28.0
DN4	-	48.5	28.3	-	-	23.4	79.5	39.5	25.1
FG3	-	44.9	13.7	-	32.9	10.4	78.5	-	13.4
FG4	-	39.0	8.6	-	30.6	7.5	75.1	-	12.2
GY3	94.6	45.6	21.0	-	35.2	17.9	93.4	-	18.4
GY4	73.2	37.9	13.7	-	31.4	12.8	71.8	-	17.8

TABLE 8

COMPOSITION AND PROPERTIES OF SYSTEM CONTAINING DY 032

TABLE 8a

COMPOSITION

Resin Code	Composition - parts by weight			
	Resin Araldite 6004	Hardener NMA(1)	Diluent DY 032	Accelerator DY 063(2)
VF1	100	120	20	0.75

Cure 11 h 160°C

TABLE 8b

ELASTIC MODULUS AND DUCTILITY

Resin Code	0.5% Secant Modulus (GPa)			Elongation (%)		
	RT(3)	75°C	100°C	RT	75°C	100°C
VF1	3.83	2.62	2.21	2.2	2.4	5.8

TABLE 8c

TENSILE STRENGTH

Resin Code	Upper Yield Stress (MPa)			Lower Yield Stress (MPa)			Fracture Stress (MPa)		
	RT	75°C	100°C	RT	75°C	100°C	RT	75°C	100°C
VF1	-	-	38.1	-	-	-	73.0	48.5	32.7

(1) Maleic anhydride adduct of methylcyclopentadiene

(2) Tertiary amine salt

(3) Room temperature

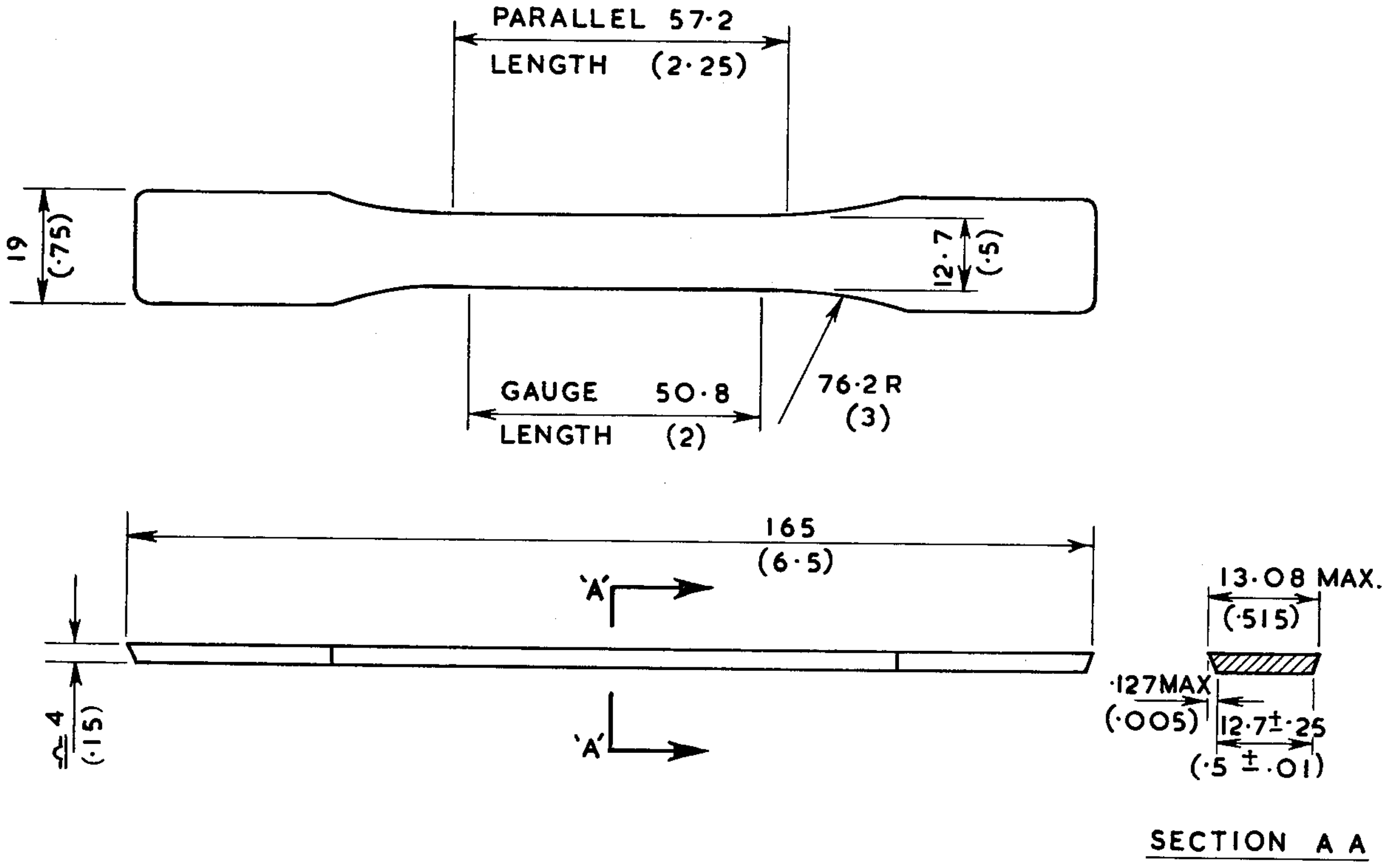


FIGURE 1. DIMENSIONS OF RESIN TEST SPECIMEN (CONFORMS TO ASTM D-638 TYPE I)

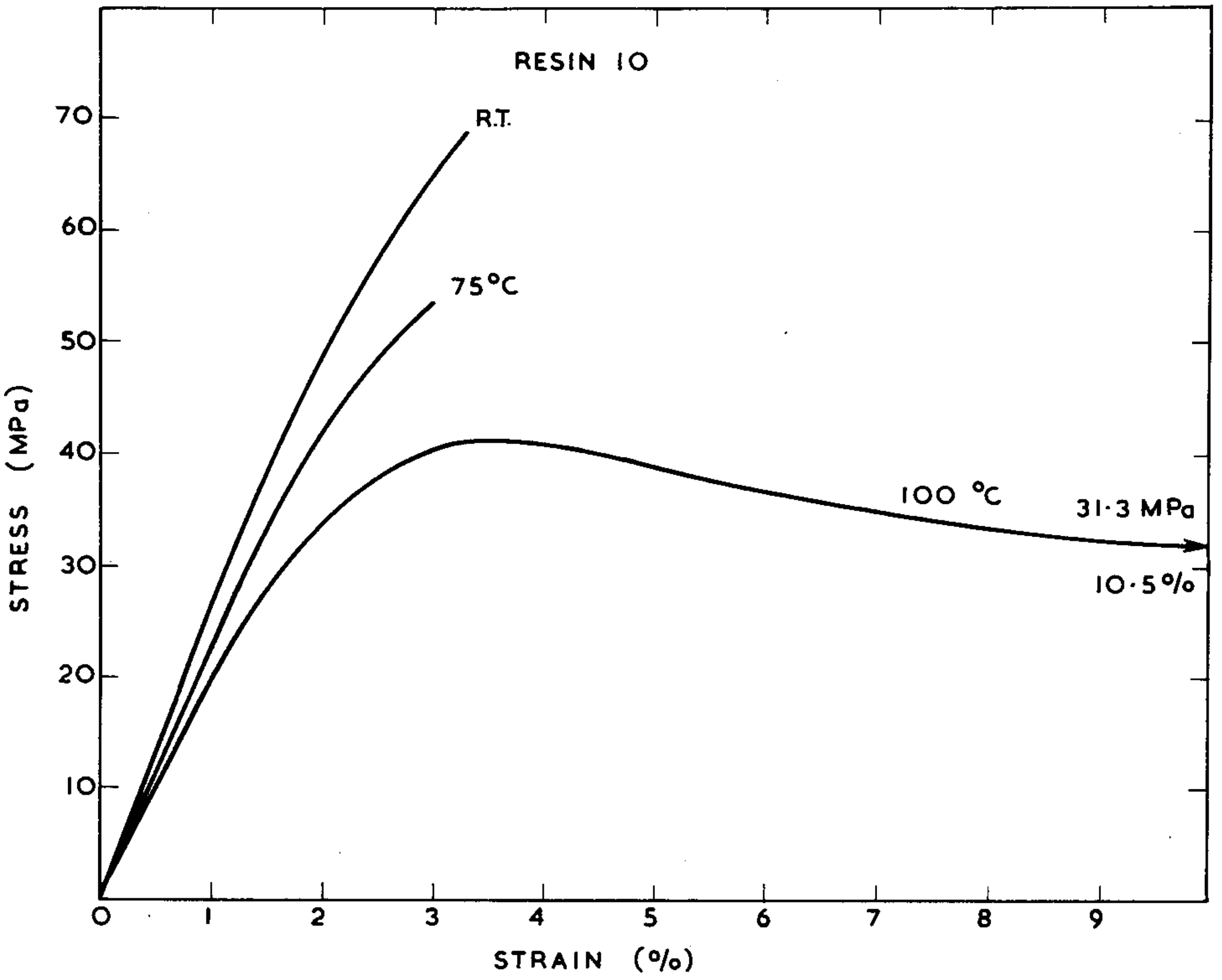


FIGURE 2. STRESS-STRAIN CURVES OF DILUENT-FREE LOW MOLECULAR WEIGHT RESIN SYSTEM

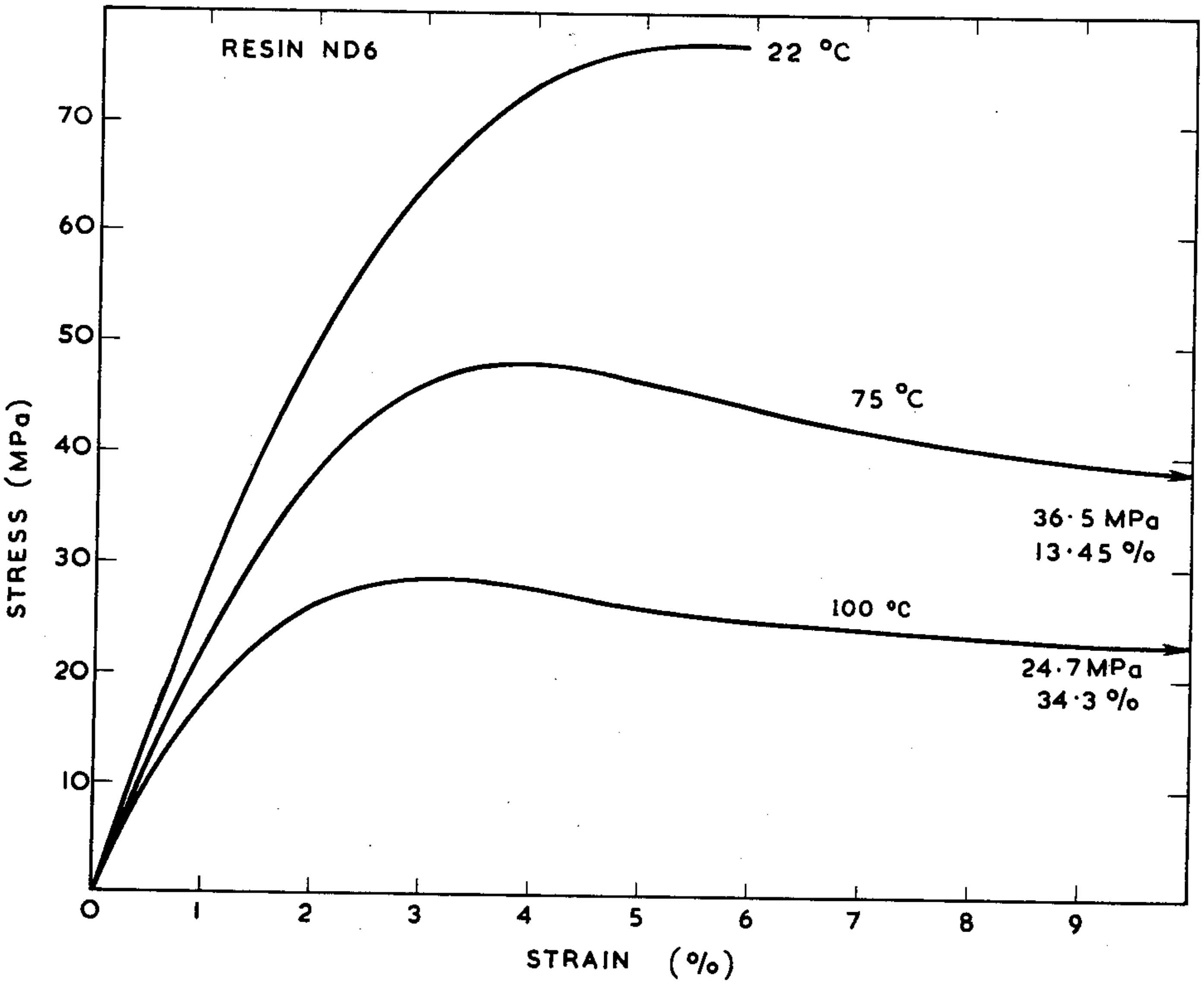


FIGURE 3. STRESS-STRAIN CURVES FOR RESIN SYSTEM CONTAINING 30 phr DILUENT DY 022 AND 5 phr HYCAR CTBN