CHAPTER 4

MECHANICAL PROPERTIES

This chapter illustrates the mechanical properties of the cured epoxy, siliconized epoxy, bismaleimides modified epoxy and siliconized epoxy matrix systems and composites.

4.1 TENSILE PROPERTIES

4.1.1 Effect of siloxane

The values of tensile strength of epoxy and siliconized epoxy systems (matrix systems A to D) are presented in Table 4.1. Introduction of 5%, 10% and 15% siloxane (by wt%) into epoxy resin (systems B, C and D) decreases the tensile strength (Figure 4.1) by 36.6%, 46.8% and 57.9% respectively when compared with unmodified epoxy system (A). This may be explained due to the presence of flexible siloxane linkage, free rotation of -Si-O-Si- bond and weak intermolecular attraction of pendent methyl groups present in the siloxane molecule as well as weak interface boundary between siloxane and epoxy matrix. The values of tensile modulus obtained for the unmodified epoxy and epoxy modified with siloxane are also presented in Table 4.1 and they exhibit similar trend as in the case of tensile strength (Figure 4.2).

4.1.2 Effect of Bismaleimides

The values of tensile strength of epoxy and siliconized epoxy systems modified with BMI-1, BMI-2, BMI-3 and BMI-4 are presented in

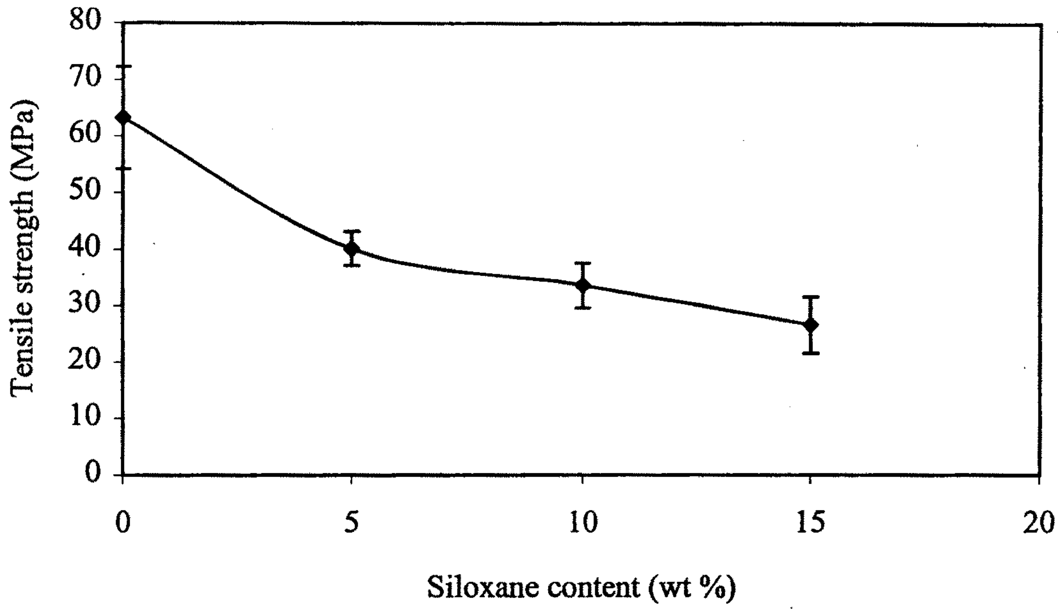

Figure 4.1 Effect of siloxane content on tensile strength of epoxy system

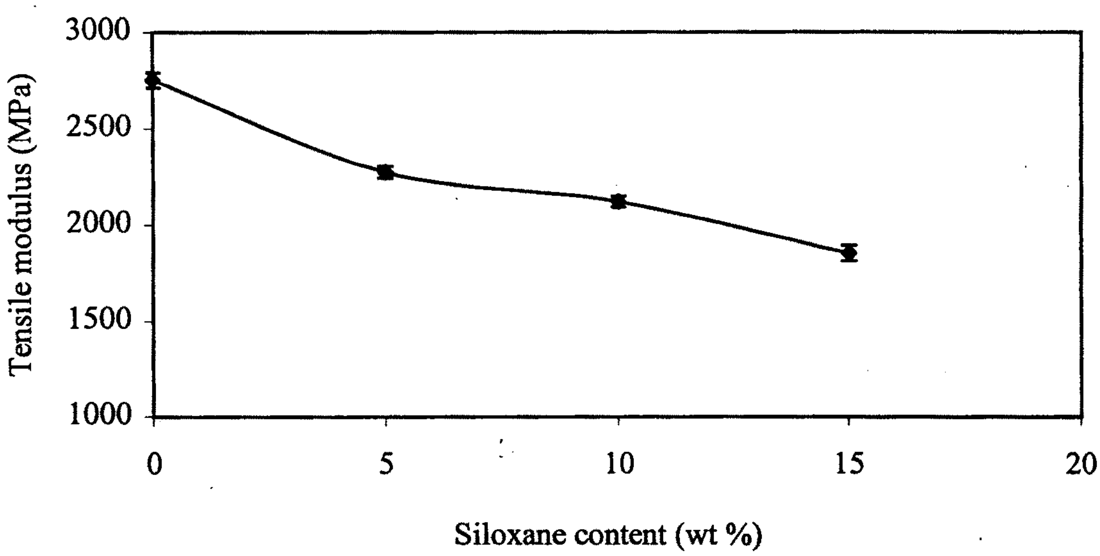

Figure 4.2 Effect of siloxane content on tensile modulus of epoxy system

Tables 4.1, 4.2, 4.3 and 4.4, and in Figures 4.3, 4.5, 4.7 and 4.9 respectively. Introduction of BMI-1, BMI-2, BMI-3 and BMI-4 into epoxy and siliconized epoxy systems increases the tensile strength with increasing concentrations (Han *et al.*, 1998; Han *et al.*, 1998a) . In the case of BMI-1 modified epoxy systems, the introduction of 5%, 10% and 15% enhance the value of tensile strength by 4.7%, 12.3% and 35.1% respectively. For the case of BMI-2, the values of tensile strength are increased by 6.5%, 19.9% and 38.8% respectively. Similarly in the case of BMI-3, the values are enhanced by 3.5%, 7.8%, and 19.8% respectively and for BMI-4, the values are enhanced to1.4%, 5.5% and 12.9% respectively. This may be explained as due to the formation of intercrosslinking network between bismaleimides and epoxy resin.

Among the bismaleimides used for epoxy resin modification, it is observed that the considerable improvement in tensile strength was noticed in the case of aromatic bismaleimides (BMI-1 and BMI-2) modified epoxy systems (Tables 4.1 and 4.2) when compared to aliphatic bismaleimides (BMI-3 and BMI-4) modified epoxy systems (Tables 4.3 and 4.4). This may be due to the presence of rigid phenyl groups in the former. Among the aromatic bismaleimides modified epoxy systems, (BMI-1 (Table 4.1) and BMI-2 (Table 4.2)), the increase in tensile strength is higher in the case of BMI-2 modified epoxy systems when compared with the same percentage of BMI-1 modified epoxy systems. For example, the improvement in tensile strength for 10% BMI-2 modified epoxy system is 19.9% whereas the improvement in tensile strength for the same percentage (10% by wt) of BMI-1 modified epoxy system is 12.3%. The reason for higher improvement in the case of BMI-2 may be due to the presence of higher number of reactive molecules in BMI-2 modified epoxy systems than BMI-1 modified epoxy systems, which inturn enhances crosslinking density and rigidity. Since, the molecular weight of BMI-1 is higher than that of BMI-2 and further, the presence of methylene group in BMI-1 imparts flexibility to the system.

In the case of aliphatic bismaleimides modified epoxy systems (BMI-3 and BMI-4), the improvement in tensile strength is higher in the case of BMI-3 modified epoxy systems (Table 4.3) when compared to that of the same percentage of BMI-4 modified epoxy systems (Table 4.4). For example 10% BMI-3 modified epoxy system shows improvement in tensile strength by 7.8% whereas the same percentage of BMI-4 modified epoxy system shows an increase in tensile strength by only 5.5%. The lesser improvement in tensile strength for BMI-4 modified epoxy systems is due to the presence of less number of reactive molecules when compared with the same weight percentage of BMI-3 modified epoxy systems, which in turn reduce the crosslink density and further, the presence of long aliphatic chain in BMI-4 also contributes flexibility to the system. Moreover, in the case of BMI-4 modified systems, the rate of partial Michael addition reaction (addition reaction of BMI-4 with aromatic amine) may be slightly higher than that of the homopolymerization reaction, which in turn increase the molecular weight, reduce the crosslink density and rigidity. Hence, lower improvement in tensile strength value is observed.

However, the introduction of both siloxane and bismaleimides (BMI-1, BMI-2, BMI-3 and BMI-4) into epoxy resin alters the tensile strength according to their percentage content. The values of tensile strength of siliconized epoxy systems increase with increasing bismaleimides content. This is due to the formation of intercrosslinking network between bismaleimides and siliconized epoxy systems. The improvement in tensile properties is maximum in the case of aromatic bismaleimides (BMI-1 and BMI-2) modified siliconized epoxy systems (Tables 4.1 and 4.2) when compared to that of aliphatic bismaleimides (BMI-3 and BMI-4) modified systems (Tables 4.3 and 4.4) and is due to the presence of aromatic rigid skeleton. Among the aromatic bismaleimides modified siliconized epoxy systems, highest tensile strength value 64.5 MPa (Table 4.2) is obtained for the system having the percentage composition of 5% siloxane and 15% BMI-2, (system G2) because of high crosslink density. In the case of BMI-1 modified siliconized epoxy systems, the highest tensile strength 61.8 MPa (Table 4.1) is obtained for the system having the percentage composition of 5% siloxane and 15% BMI-1 (system G1). Among the aliphatic bismaleimides modified siliconized epoxy systems, the BMI-3 modified systems show higher improvement in tensile properties when compared to BMI-4 modified systems. The highest tensile strength value of 58.6 MPa is obtained for BMI-3 (Table 4.3) modified siliconized epoxy system (system G3) with percentage composition of 5% siloxane and 15% BMI-3. The maximum tensile strength obtained for the BMI-4 (Table 4.4) modified siliconized epoxy system is 57.2 MPa (system G4) with percentage composition of 5% siloxane and 15% BMI-4. The values of tensile modulus obtained for the unmodified epoxy, bismaleimides modified epoxy and bismaleimides modified siliconized epoxy systems are presented in Tables 4.1, 4.2, 4.3 and 4.4, and Figures 4.4, 4.6, 4.8 and 4.10 respectively and they exhibit similar trend as in the case of tensile strength.

4.2 FLEXURAL PROPERTIES

4.2.1 Effect of Siloxane

Flexural behaviour of unmodified epoxy and epoxy modified with siloxane are presented in Tables 4.1 and Figures 4.11 and 4.12. Introduction of 5%, 10% and 15% siloxane (by wt%) into epoxy resin (system B, C and D)

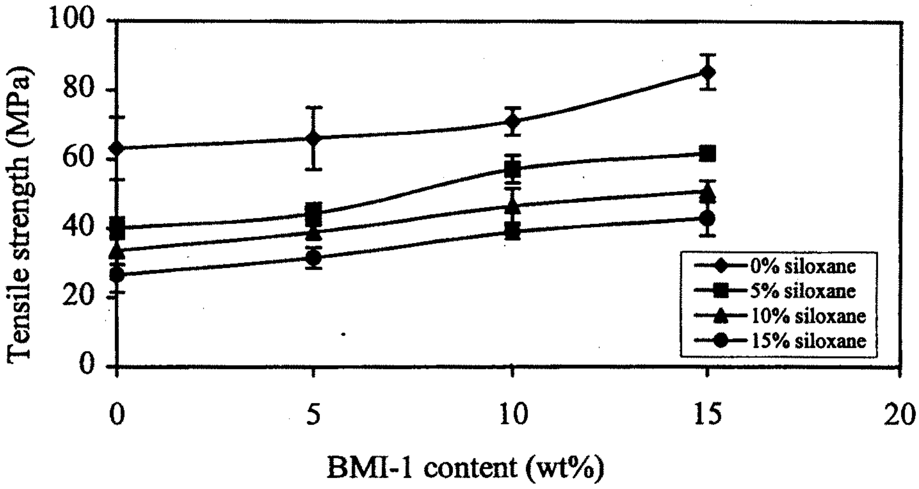

Figure 4.3 Effect of BMI-1 content on tensile strength of epoxy and siliconized epoxy systems

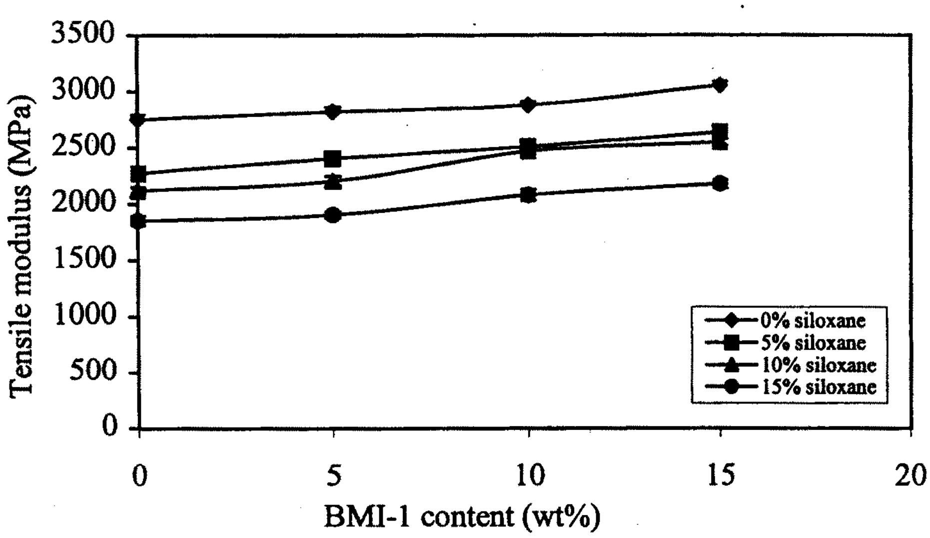

Figure 4.4 Effect of BMI-1 content on tensile modulus of epoxy and siliconized epoxy systems

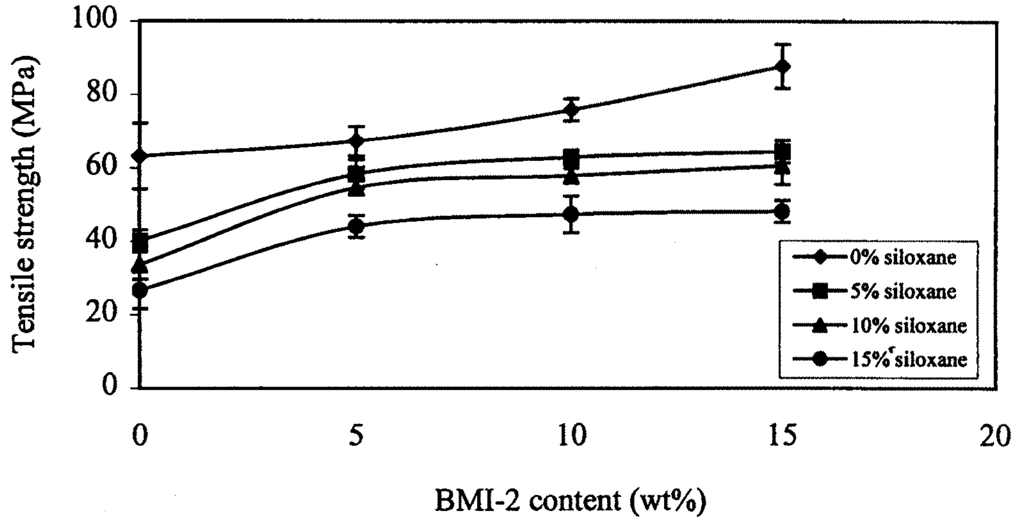

Figure 4.5 Effect of BMI-2 content on tensile strength of epoxy and siliconized epoxy systems

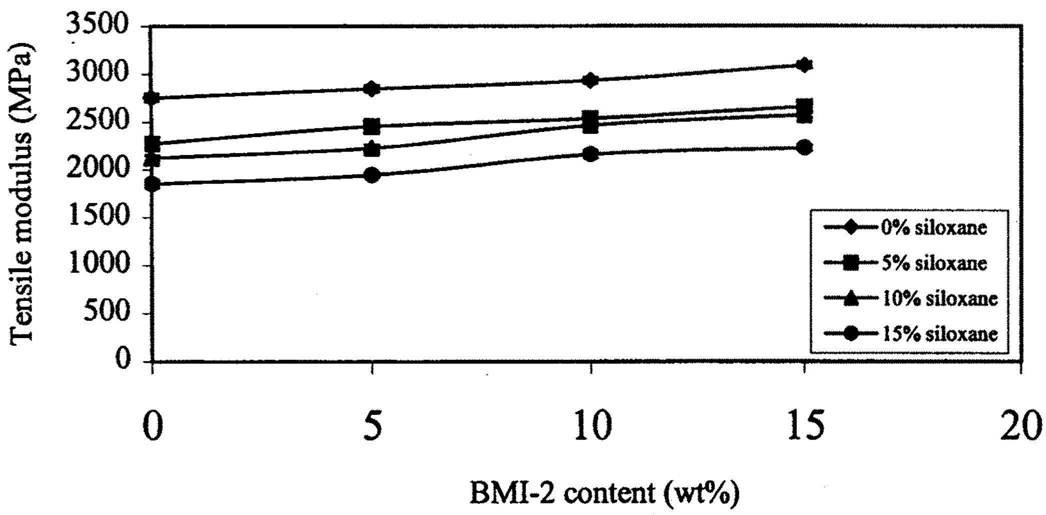

Figure 4.6 Effect of BMI-2 content on tensile modulus of epoxy and siliconized epoxy systems

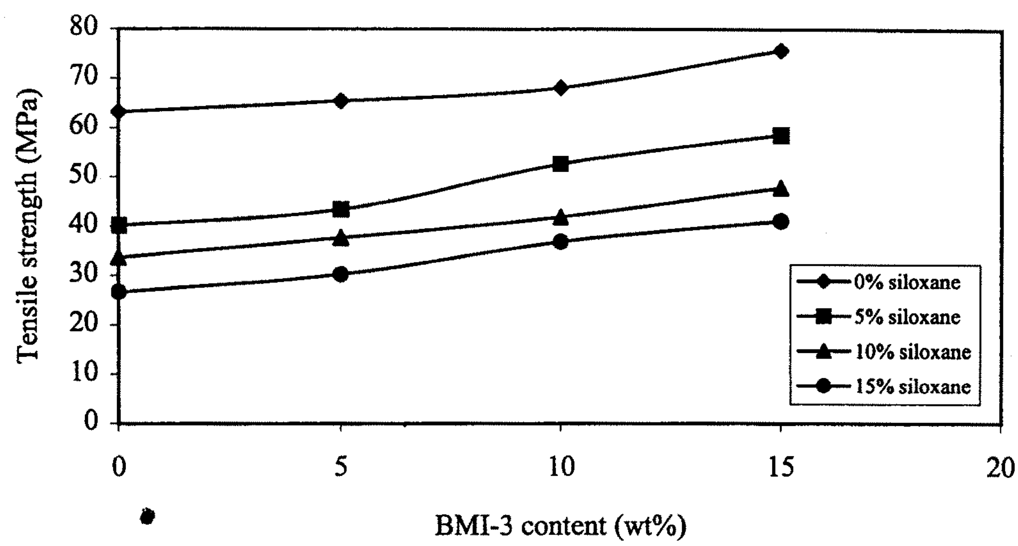

Figure 4.7 Effect of BMI-3 content on tensile strength of epoxy and siliconized epoxy systems

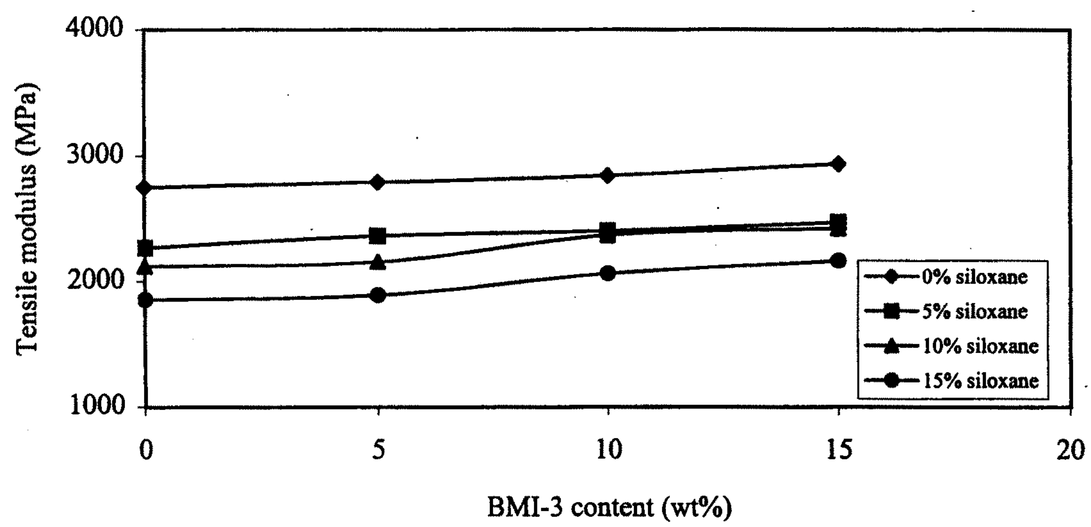

Figure 4.8 Effect of BMI-3 content on tensile modulus of epoxy and siliconized epoxy systems

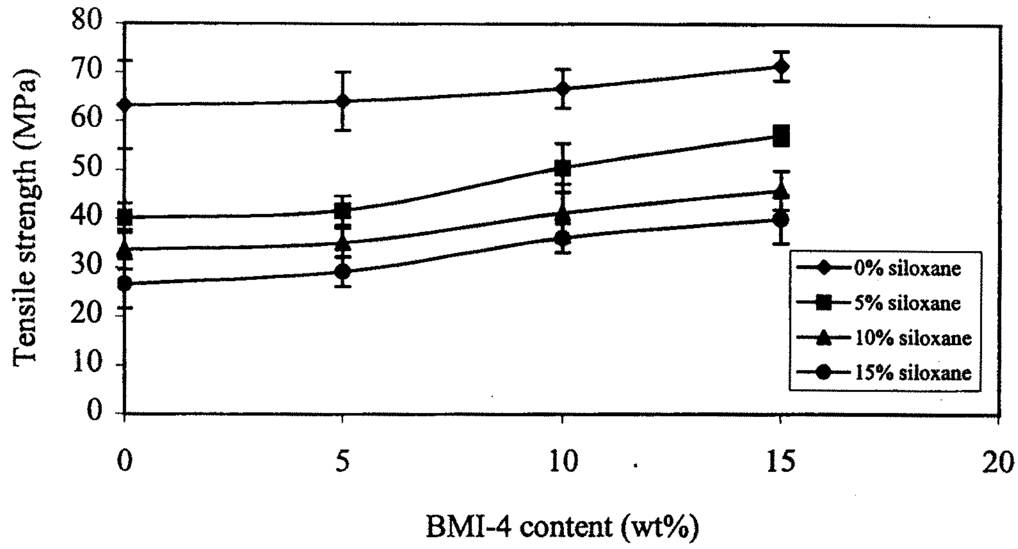

Figure 4.9 Effect of BMI-4 content on tensile strength of epoxy and siliconized epoxy systems

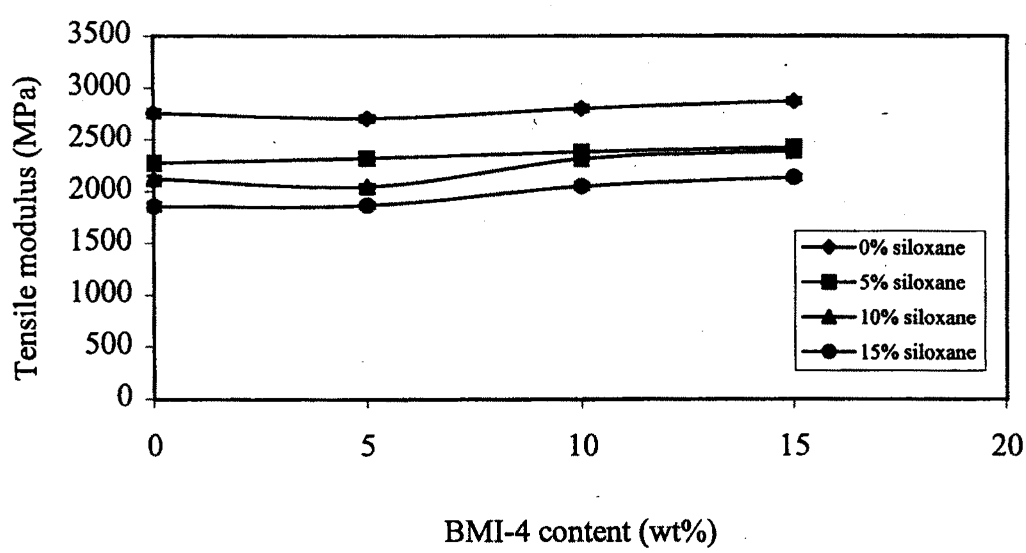

Figure 4.10 Effect of BMI-4 content on tensile modulus of epoxy and siliconized epoxy systems

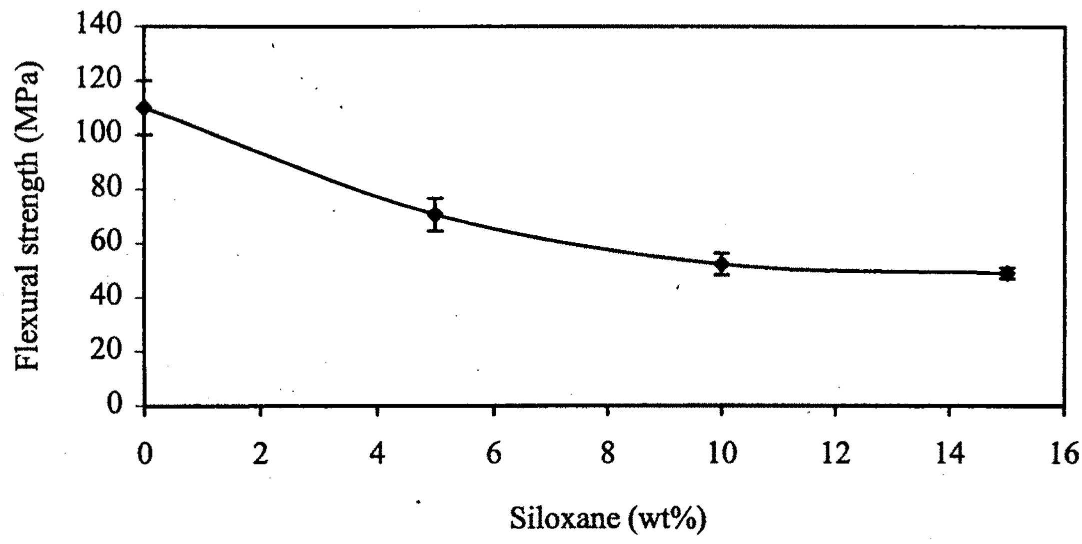

Figure 4.11. Effect of siloxane content on flexural strength of epoxy system

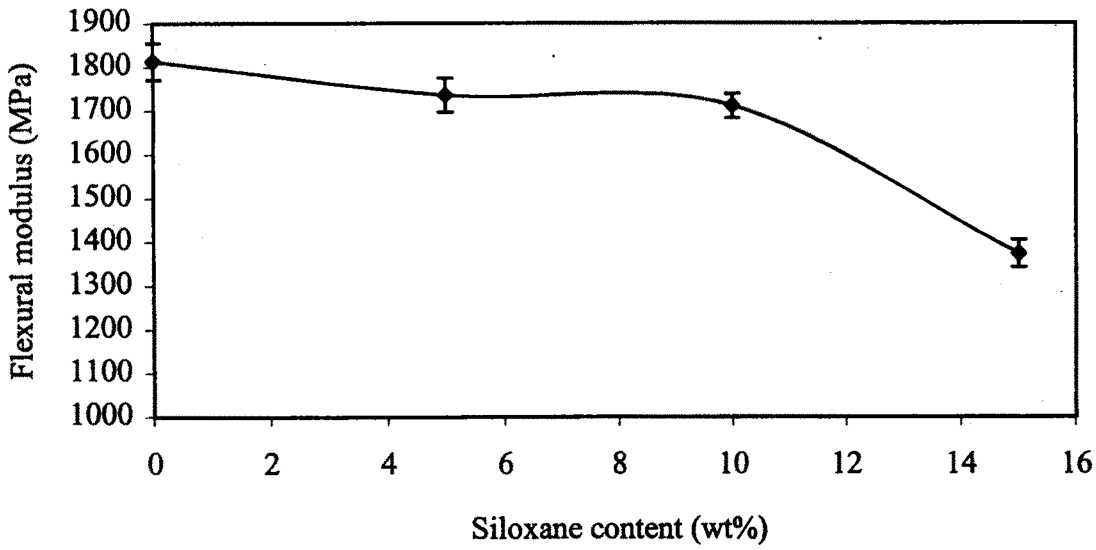

Figure 4.12. Effect of siloxane content on flexural modulus of epoxy system

decreases the flexural strength by 35.8%, 52.5% and 55.4% respectively when compared with unmodified epoxy system (A). This may be attributed to the weak interface boundary between siloxane and epoxy matrix. The flexural modulus also follows the similar trend (Figure 4.12).

4.2.2 Effect of bismaleimides

The flexural behaviour of bismaleimides (BMI-1, BMI-2, BMI-3 and BMI-4) modified epoxy and siliconized epoxy systems are presented in Tables 4.1 - 4.4 and Figures 4.13 - 4.20.

Incorporation of bismaleimides viz., BMI-1, BMI-2, BMI-3 and BMI-4 reveals an enhancement in the values of flexural strength according to their nature and percentage concentration as observed in the case of tensile strength (Woo *et al.,* 1987; Kim *et al.,* 1995; Musto *et al.,* 1998). Among the bismaleimides modified epoxy systems, the aromatic bismaleimides (BMI-1 (Table 4.1) and BMI-2 (Table 4.2)) incorporated systems yield higher values of flexural strength than that of aliphatic bismaleimides (BMI-3 (Table 4.3) and BMI-4 (Table 4.4)) incorporated epoxy systems. The enhancement in the value of flexural strength is influenced by the presence of aromatic rigid skeleton in the case of aromatic bismaleimides. Among the aromatic bismaleimides, the BMI-2 (Table 4.2) imparts higher flexural value than that of BMI-1 (Table 4.1). For example the increase in flexural strength value for 5%, 10% and 15% of BMI-2 modified epoxy systems are 10.9%, 19.7% and 23.2% respectively, whereas the improvement imparted by same percentages of BMI-1 modified epoxy systems are 7.3%, 15.5% and 20.5% respectively. The higher improvement in the case of BMI-2 modified epoxy systems may be explained due to the increased crosslink density, induced by higher number of reactive

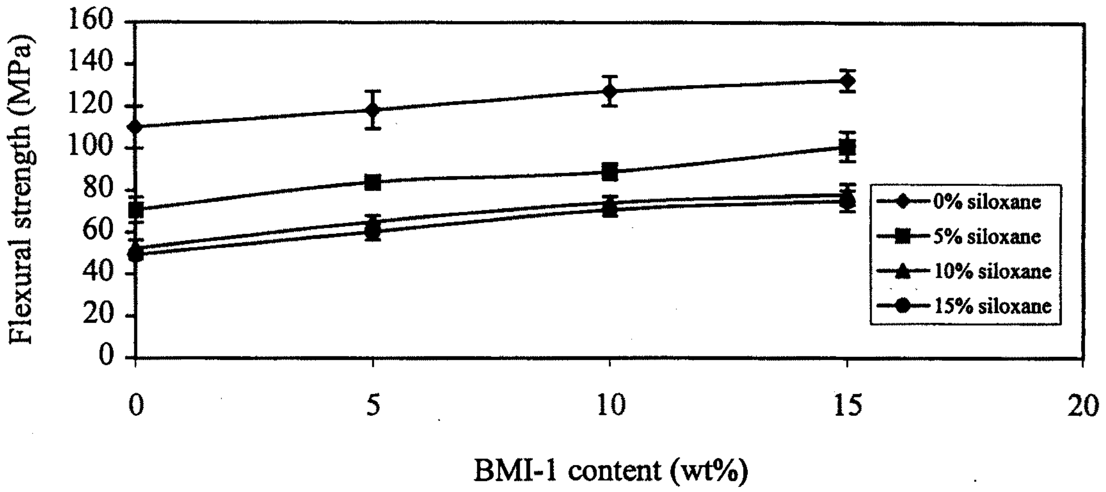

Figure 4.13. Effect of BMI-1 content on flexural strength of epoxy and siliconized epoxy systems

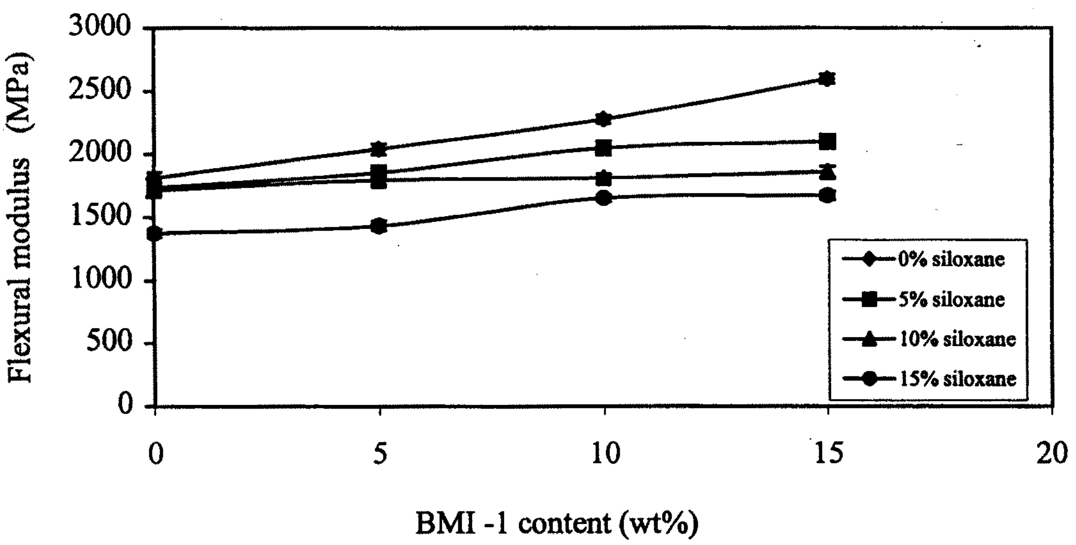

Figure 4.14. Effect of BMI-1 content on flexural modulus of epoxy and siliconized epoxy systems

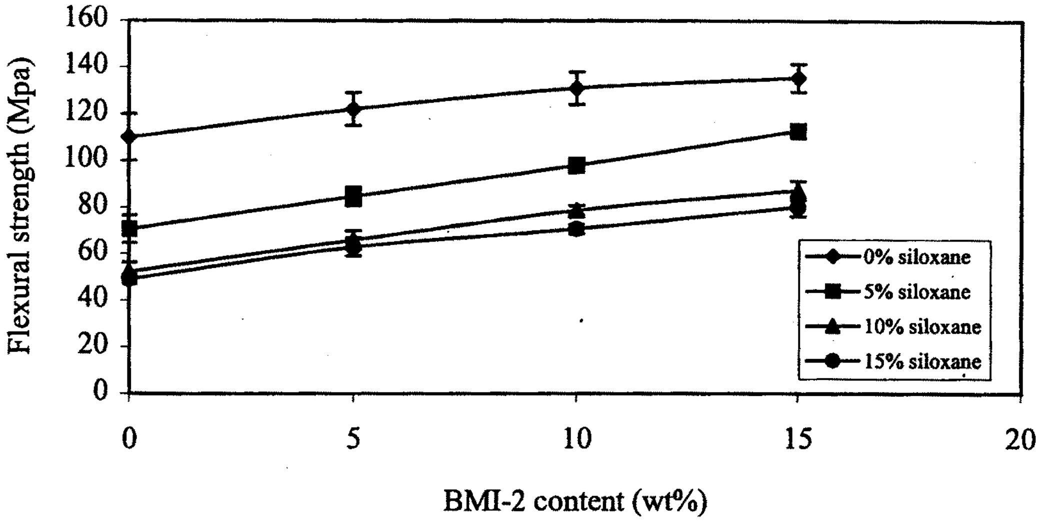

Figure 4.15 Effect of BMI-2 content on flexural strength of epoxy and siliconized epoxy systems

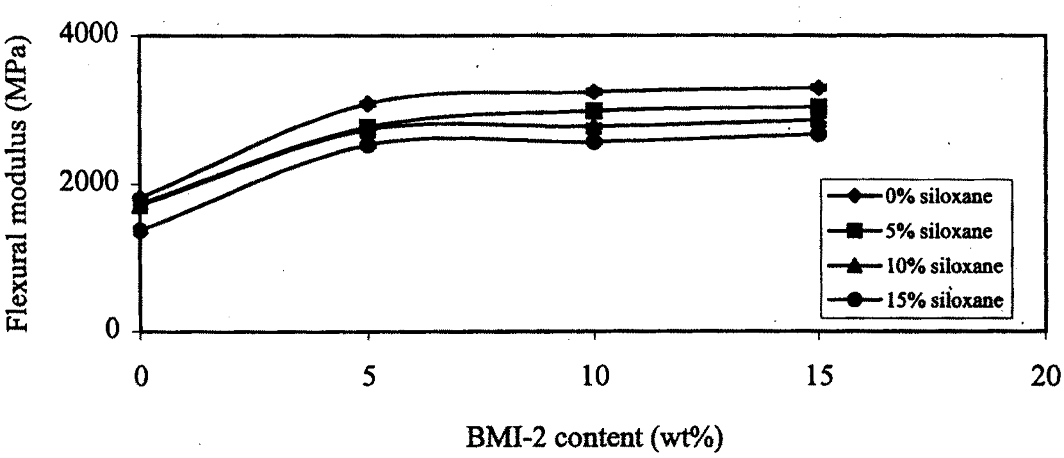

Figure 4.16 Effect of BMI-2 content on flexural modulus of epoxy and siliconized epoxy systems

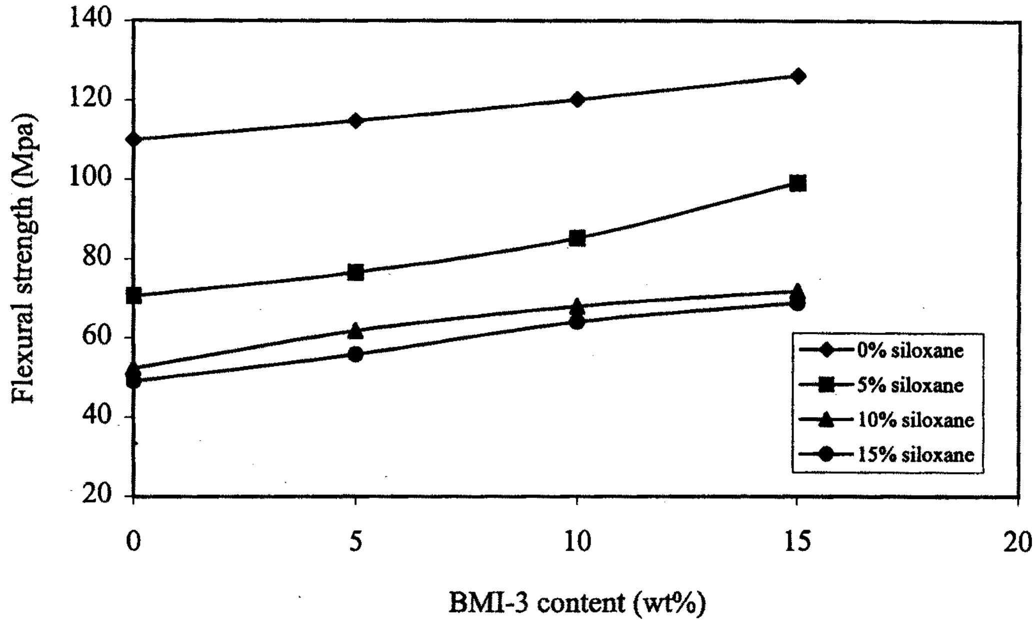

Figure 4.17 Effect of BMI-3 content on flexural strength of epoxy and siliconized epoxy systems

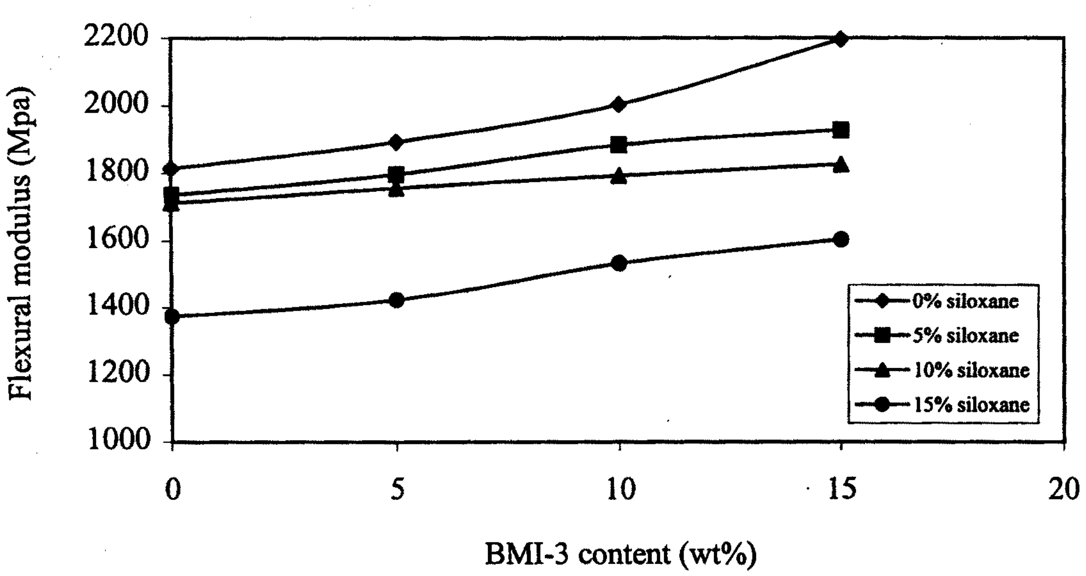

Figure 4.18 Effect of BMI-3 content on flexural modulus of epoxy and siliconized epoxy systems

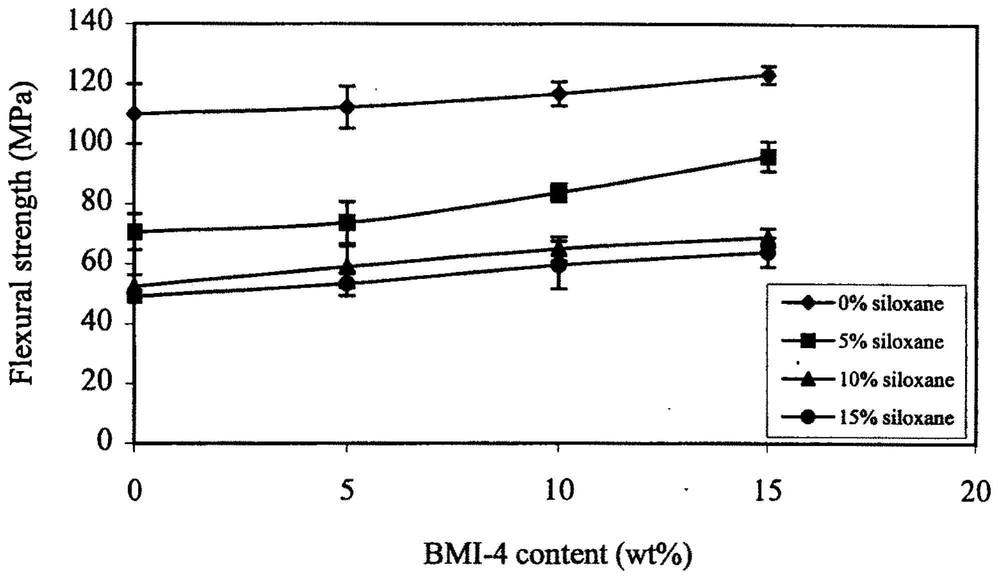

Figure 4.19 Effect of BMI-4 content on flexural strength of epoxy and siliconized epoxy systems

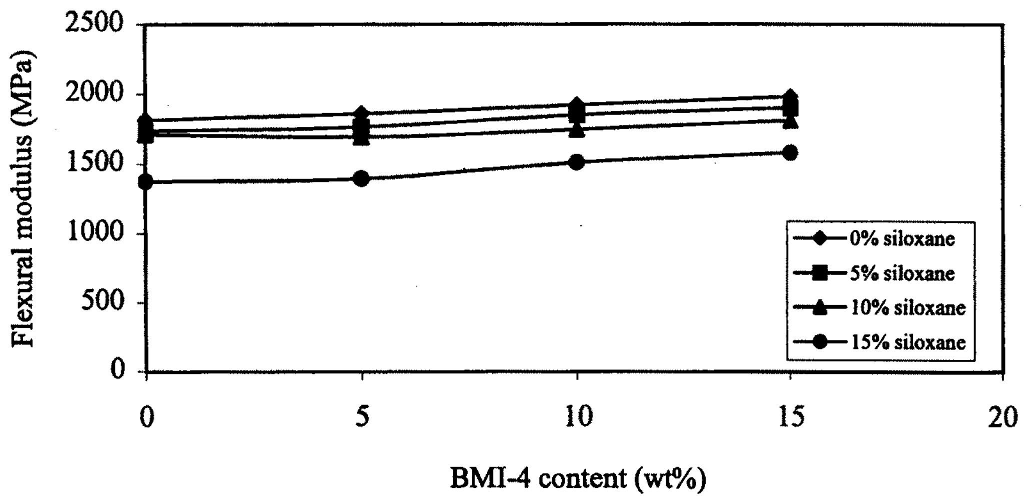

Figure 4.20 Effect of BMI-4 content on flexural modulus of epoxy and siliconized epoxy systems

molecules present in the BMI-2 modified systems when compared with the same percentages of BMI-1 modified epoxy systems. Further, the lesser improvement of flexural strength in the case of BMI-1 is explained due to the presence of methylene spacer group between the two aromatic rings of BMI-1 imparts flexibility. In the case of aliphatic bismaleimides modified epoxy systems, BMI-3 incorporated epoxy systems show steady improvement in flexural strength (Table 4.3) than BMI-4 incorporated epoxy systems (Table 4.4). The improvement in the values of flexural strength for 5%, 10% and 15% BMI-3 modified epoxy systems are 4.3%, 9.3% and 14.7% respectively and for BMI-4 the values are 2.0%, 6.2% and 11.8%. Like flexural strength, the flexural modulus also follows the similar trend (Figures 4.13 – 4.20).

The improvement in the values of flexural strength is observed, when bismaleimides (BMI-1, BMI-2, BMI-3 and BMI-4) are incorporated into siliconized epoxy systems (Tables 4.1 to 4.4). However, the improvement is influenced by nature and concentration of bismaleimides, and concentration of siloxane.

For example, the highest value 113 MPa (Table 4.2) is obtained for the case of BMI-2 (15%) incorporated siliconized (5%) epoxy system (system G2). Similarly the lowest value 53.3 MPa (Table 4.4) is obtained in the case of BMI-4 (5%) incorporated siliconized (15%) epoxy system (system G4).

The values of flexural strength and modulus of both bismaleimides incorporated epoxy and siliconized epoxy systems are comapared in Figures 4.14 - 4.20.

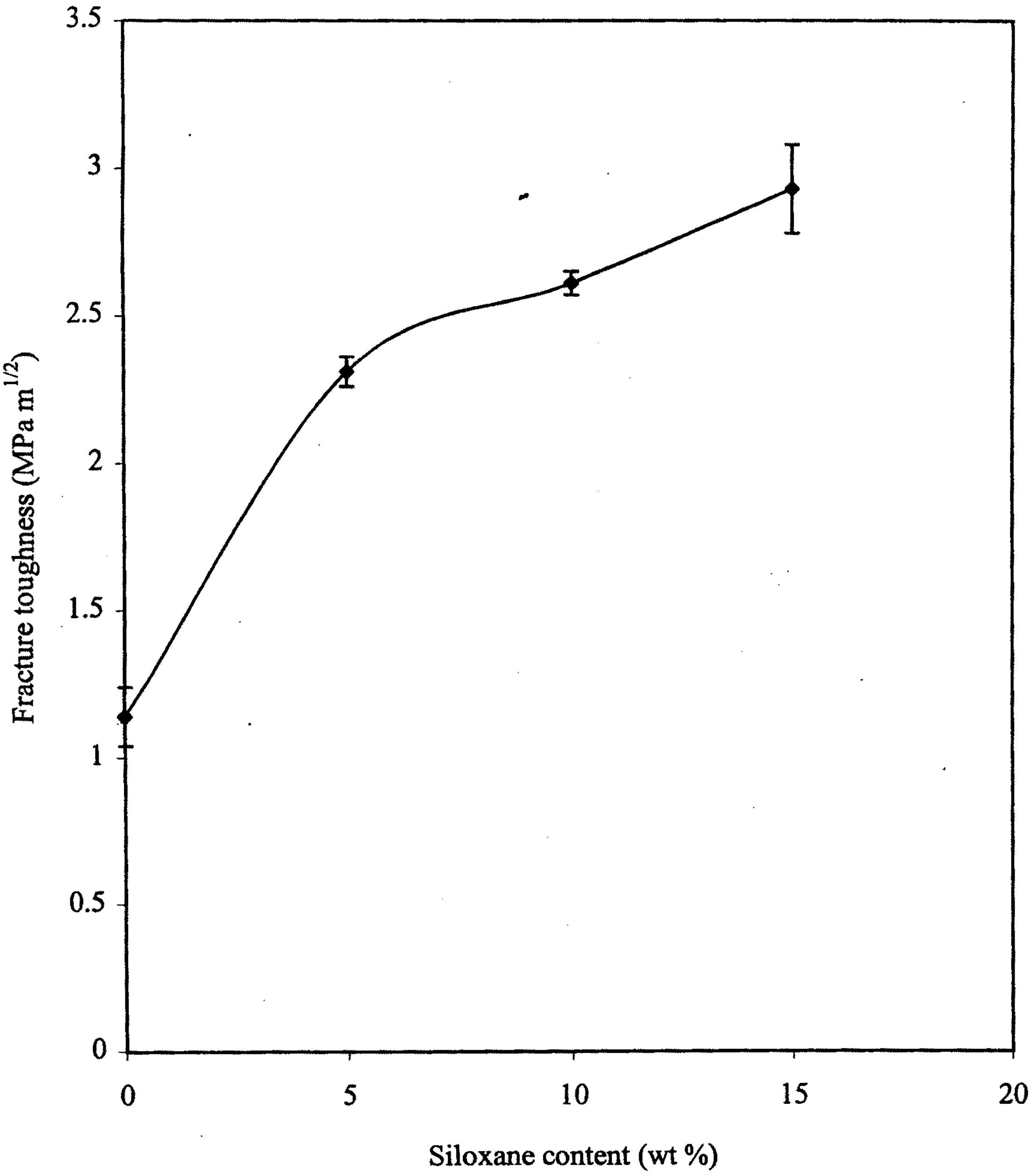

Figure 4.21 Effect of siloxane content on plain strain fracture toughness of epoxy system

4.3 PLAIN STRAIN FRACTURE TOUGHNESS

4.3.1 Effect of Siloxane

The values of plain strain fracture toughness of epoxy and siliconized epoxy matrices (systems A to D) are presented in Table 4.1 and Figure 4.21. Siloxane incorporation into epoxy resin improves the toughness according to the percentage content of siloxane and is due to high-energy absorption and resilient behaviour of flexible siloxane molecule. The improvement in toughness imparted by 5%, 10% and 15% siloxane incorporation are 102%, 129.5%, and 157.0% respectively (Figure 4.21).

4.3.2 Effect of bismaleimides

The plain strain fracture toughness behaviour of bismaleimides (BMI-1, BMI-2, BMI-3 and BMI-4) modified epoxy and siliconized epoxy systems are presented in Tables 4.1 to 4.4 and Figures 4.22 to 4.25.

The toughness behaviour of unmodified epoxy and siliconized epoxy systems are lowered with the incorporation of bismaleimides (BMI-1, BMI-2, BMI-3 and BMI-4) (Han *et al.*, 1998; Han *et al.*, 1998a). The reduction in the values may be explained due to the formation of intercrosslinking network between bismaleimides and epoxy resin systems, which in turn enhances the rigidity.

The reduction in the values of toughness varies according to the nature and concentration of bismaleimides. Among the different bismaleimides used for the modification of epoxy and siliconized epoxy resin systems, the aliphatic bimaleimides incorporated systems exhibit higher reduction in the

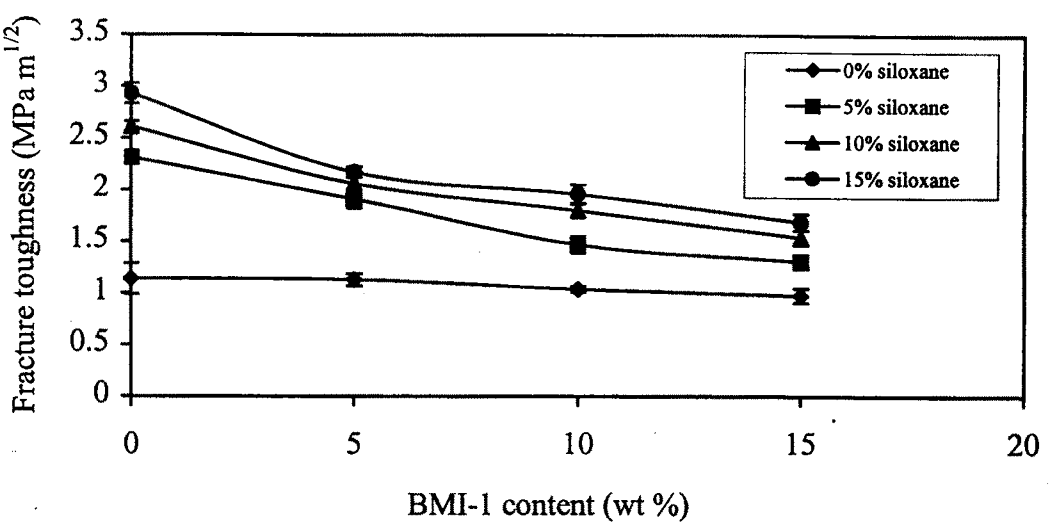

Figure 4.22 Effect of BMI-1 content on plain strain fracture toughness of epoxy and siliconized epoxy systems

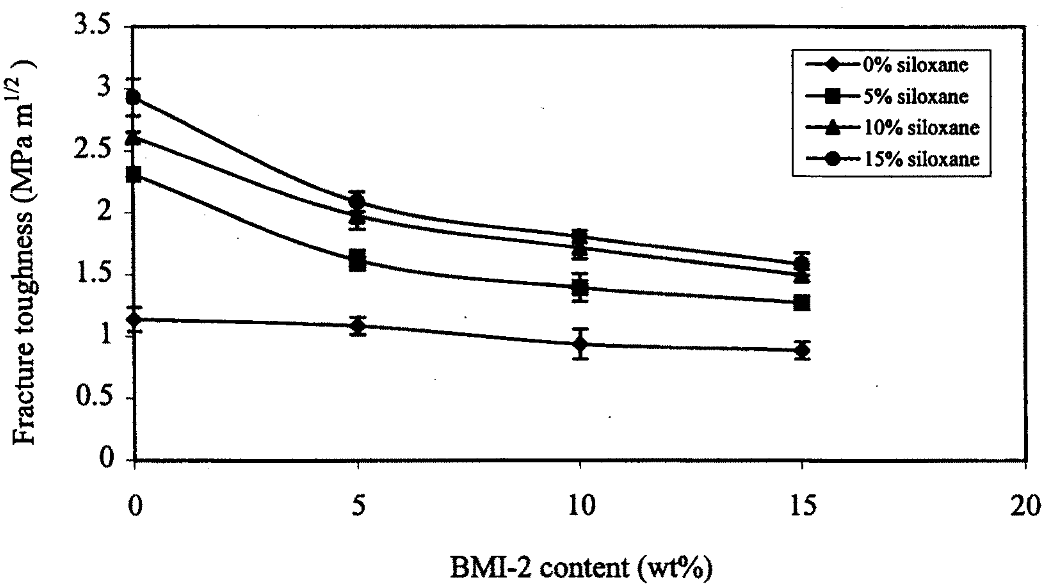

Figure 4.23 Effect BMI-2 content on plain strain fracture toughness of epoxy and siliconized epoxy systems

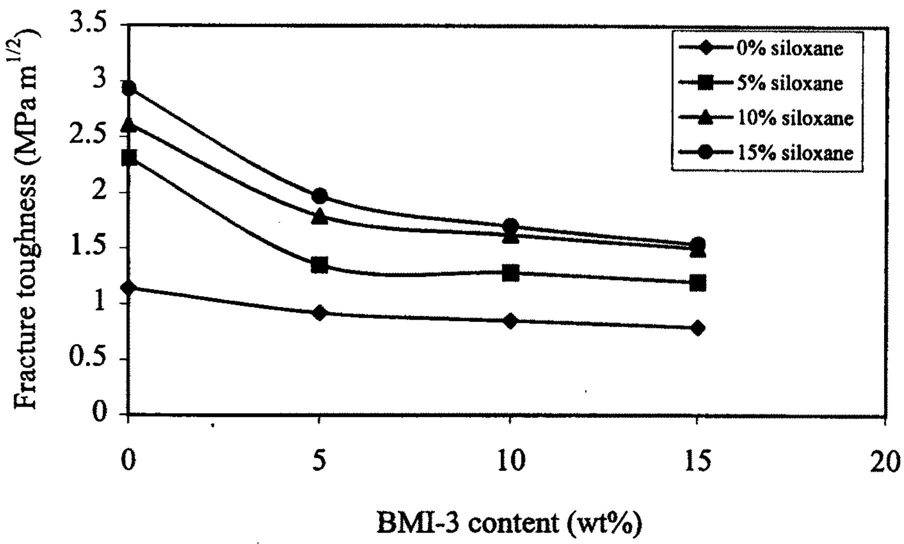

Figure 4.24 Effect of BMI-3 on plain strain fracture toughness of epoxy and siliconized epoxy systems

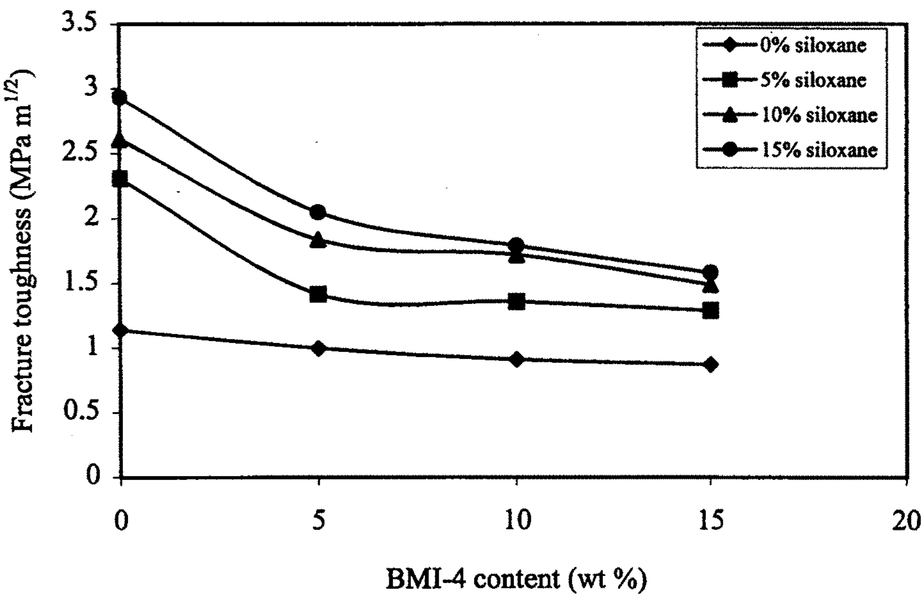

Figure 4.25 Effect of BMI-4 content on plain strain fracture toughness of epoxy and silconized epoxy systems

values of toughness (Tables 4.3 and 4.4). This may be explained due to the fact that the available free volume in the case of aliphatic bismaleimides are lesser than that of aromatic bismaleimides modified systems, because of linear molecular structure, which in turn favours close rigid packing and hence reduces the molecular relaxation. However, in the case of aromatic bismaleimides modified systems (Tables 4.1 and 4.2), the complex shapes prevent close packing coupled with high energy of absorption of the aromatic ring structure and more free volume is available for molecular relaxation.

In the aliphatic bismaleimides (BMI-3 and BMI-4) modified systems, the maximum decrease in the value of toughness 30.7% is observed in the case of BMI-3 modified epoxy system with 15% concentration (Table 4.3), whereas the same 15% BMI-4 modified epoxy system results in reduction in the value of toughness by 23.7% (Table 4.4). This may be explained due to the presence of shorter aliphatic chain in the former and the presence of longer aliphatic chain in the latter, which in turn imparts flexibility to the system. Further, higher number of reactive molecules are present in the BMI-3 incorporated systems than that of the same percentage of BMI-4 incorporated systems, enhance the crosslink density and rigidity and thereby reducing its toughness.

In the case of aromatic bismaleimides (BMI-1 and BMI-2) incorporated epoxy systems, the maximum reduction in toughness value is observed for 15% BMI-2 modified system (21.9%) when compared with the same 15% BMI-1 modified system (14%) (Tables 4.1 and 4.2). This can be explained due to higher crosslink density in the former and the presence of methylene spacer group in the latter providing flexibility to the system.

The bismaleimides (BMI-1, BMI-2, BMI-3 and BMI-4) incorporation into siliconized epoxy systems also decreases the toughness behaviour and follows the similar trend as observed in the case of bismaleimides modified epoxy systems. The results are presented in Tables 4.1 to 4.4 and Figures 4.22 to 4.25.

4.4 HARDNESS

The hardness value for unmodified epoxy system is found to be 85. The hardness value of epoxy decreases with introduction siloxane according to its percentage concentration. For example, the hardness values for 5%, 10% and 15% siloxane modified epoxy systems are 83, 80 and 76 respectively. This is due to the presence of flexible –Si-O-Si- linkage in the siloxane modified epoxy systems. There is a slight enhancement in the hardness values are obtained for epoxy and siliconized epoxy systems modified with bismaleimides BMI-1, BMI-2, BMI-3 and BMI-4 and the values lie between 87 and 95.

4.5 FIBRE REINFORCEMENT

A significant improvement in mechanical properties is noticed when epoxy, siliconized epoxy and bismaleimides (BMI-1, BMI-2, BMI-3 and BMI-4) modified epoxy and siliconized epoxy systems are reinforced with E-glass fibre (Table 4.5).

4.5.1 Effect of siloxane

The values of tensile strength, flexural strength, tensile modulus, flexural modulus and interlaminar shear strength of glass fibre reinforced epoxy and siliconized epoxy systems are presented in Table 4.5. From the Table 4.5, it is observed that the siloxane incorporation decreases both tensile and flexural properties. The values (Table 4.5) of interlaminar shear strength (ILLS) also follow the similar trend. The reason is the same as discussed in the case of tensile properties of siliconized epoxy systems.

4.5.2 Effect of bismaleimides

From Table 4.5, it is also observed that bismaleimides (BMI-1, BMI-2, BMI-3 and BMI-4) incorporation into epoxy and siliconized epoxy systems enhances the tensile and flexural properties, and interlaminar shear strength.

Table 4.1 Mechanical properties of BMI-1 modified epoxy and BMI- 1 modified siliconized epoxy systems

Matrix System	Epoxy/ HTPDMS/ BMI-1 composition	Tensile Strength (MPa)	Tensile Modulus (MPa)	Flexural Strength (MPa)	Flexural Modulus (MPa)	Plain Strain Fracture Toughness (K_{IC} MPa $m^{1/2}$)
A	100/00/00	63.2 ± 9	2751.7± 39	110.0 ± 10	1812.9 ± 42	1.14 ± 0.10
B	100/05/00	40.1 ± 3	2272.9 ± 30	70.6 ± 6	1735.4 ± 39	2.31 ± 0.05
C	100/10/00	33.6 ± 4	2119.9 ± 29	52.3 ± 4	1710.9 ± 28	2.61 ± 0.04
D	100/15/00	26.6 ± 5	1852.1 ± 40	49.1 ± 2	1373.4 ± 31	2.93 ± 0.15
E1	100/05/05	44.4 ± 3	2405.4 ± 25	83.8 ± 3	1854.1 ± 40	1.91 ± 0.10
F1	100/05/10	57.2 ± 4	2509.4 ± 32	88.8 ± 4	2050.3 ± 25	1.47 ± 0.06
G1	100/05/15	61.8 ± 2	2638.9 ± 39	101.0 ± 7	2099.3 ± 27	1.31 ± 0.07
H1	100/10/05	39.0 ± 2	2206.3 ± 42	64.9 ± 3	1795.2 ± 32	2.06 ± 0.09
I1	100/10/10	46.6 ± 5	2470.2 ± 31	74.0 ± 3	1814.9 ± 29	1.80 ± 0.08
J1	100/10/15	50.9 ± 3	2550.6 ± 29	78.0 ± 5	1863.9 ± 41	1.54 ± 0.05
K1	100/15/05	31.6 ± 3	1903.1 ± 27	60.2 ± 4	1434.2 ± 37	2.17 ± 0.06
L1	100/15/10	39.0 ± 2	2079.7 ± 49	70.7 ± 3	1652.9 ± 27	1.96 ± 0.03
M1	100/15/15	43.0 ± 5	2177.8 ± 36	75.0 ± 5	1672.6 ± 31	1.69 ± 0.07
N1	100/00/05	66.2 ± 9	2820.4 ± 40	118.3 ± 9	2040.5 ± 41	1.13 ± 0.05
O1	100/00/10	71.0 ± 4	2876.3 ± 31	127.3 ± 7	2275.9 ± 32	1.04 ± 0.09
P1	100/00/15	85.4 ± 5	3053.9 ± 37	132.6 ± 5	2596.8 ± 35	0.98 ± 0.08

Table 4.2 Mechanical properties BMI-2 modified epoxy and BMI-2 modified siliconized epoxy systems

Matrix System	Epoxy/ HTPDMS/ BMI -2 composition	Tensile Strength (MPa)	Tensile Modulus (MPa)	Flexural Strength (MPa)	Flexural Modulus (MPa)	Plain Strain Fracture Toughness (K_{IC} MPa $m^{1/2}$)
A	100/00/00	63.2 ± 9	2751.7± 39	110.0 ± 10	1812.9 ± 42	1.14 ± 0.10
B	100/05/00	40.1 ± 3	2272.9 ± 30	70.6 ± 6	1735.4 ± 39	2.31 ± 0.05
C	100/10/00	33.6 ± 4	2119.9 ± 29	52.3 ± 4	1710.9 ± 28	2.61 ± 0.04
D	100/15/00	26.6 ± 5	1852.1 ± 40	49.1 ± 2	1373.4 ± 31	2.93 ± 0.15
E2	100/05/05	58.3 ± 4	2452.5 ± 20	84.6 ± 4	2765.4 ± 32	1.62 ± 0.08
F2	100/05/10	62.9 ± 2	2531.9 ± 27	98.0 ± 3	2982.2 ± 27	1.40 ± 0.11
G2	100/05/15	64.5 ± 3	2658.5 ± 32	113.0 ± 3	3032.3 ± 25	1.28 ± 0.05
H2	100/10/05	54.6 ± 2	2226.8 ± 34	65.9 ± 4	2727.2 ± 28	1.98 ± 0.11
I2	100/10/10	57.9 ± 2	2460.5 ± 29	78.7 ± 2	2771.3 ± 31	1.72 ± 0.09
J2	100/10/15	60.6 ± 5	2570.2 ± 27	87.3 ± 4	2856.7 ± 38	1.50 ± 0.05
K2	100/15/05	44.0 ± 3	1943.7 ± 25	62.9 ± 4	2524.1 ± 32	2.09 ± 0.08
L2	100/15/10	47.3 ± 5	2158.2 ± 41	70.7 ± 2	2561.4 ± 27	1.81 ± 0.05
M2	100/15/15	48.2 ± 3	2226.8 ± 32	80.2 ± 4	2668.3 ± 27	1.59 ± 0.09
N2	100/00/05	67.3 ± 4	2845.8 ± 35	122.0 ± 7	3080.3 ± 32	1.09 ± 0.07
O2	100/00/10	75.8 ± 3	2931.5 ± 32	131.7 ± 7	3237.3 ± 35	0.94 ± 0.12
P2	100/00/15	87.7 ± 6	3090.1 ± 31	135.5 ± 6	3296.2 ± 34	0.89 ± 0.07

Table 4.3 Mechanical properties of BMI-3 modified epoxy and BMI-3 modified siliconized epoxy systems

Matrix System	Epoxy/ HTPDMS/ BMI-3 composition	Tensile Strength (MPa)	Tensile Modulus (MPa)	Flexural Strength (MPa)	Flexural Modulus (MPa)	Plain Strain Fracture Toughness (K_{IC} MPa $m^{1/2}$)
A	100/00/00	63.2 ± 9	2751.7± 39	110.0 ± 10	1812.9 ± 42	1.14 ± 0.10
B	100/05/00	40.1 ± 3	2272.9 ± 30	70.6 ± 6	1735.4 ± 39	2.31 ± 0.05
C	100/10/00	33.6 ± 4	2119.9 ± 29	52.3 ± 4	1710.9 ± 28	2.61 ± 0.04
D	100/15/00	26.6 ± 5	1852.1 ± 40	49.1 ± 2	1373.4 ± 31	2.93 ± 0.15
E3	100/05/05	43.4 ± 3	2366.2 ± 25	76.6 ± 3	1795.8 ± 30	1.35 ± 0.08
F3	100/05/10	52.7 ± 3	2405.4 ± 28	85.2 ± 2	1882.6 ± 25	1.28 ± 0.11
G3	100/05/15	58.6 ± 4	2472.1 ± 20	99.2 ± 4	1927.3 ± 32	1.20 ± 0.05
H3	100/10/05	37.7 ± 4	2160.2 ± 35	61.8 ± 3	1756.0 ± 27	1.79 ± 0.11
I3	100/10/10	41.9 ± 3	2371.4 ± 30	68.0 ± 3	1792.1 ± 35	1.62 ± 0.09
J3	100/10/15	47.9 ± 5	2425.4 ± 31	71.8 ± 4	1825.2 ± 31	1.50 ± 0.05
K3	100/15/05	30.2 ± 4	1891.9 ± 27	55.8 ± 3	1422.5 ± 30	1.97 ± 0.08
L3	100/15/10	36.9 ± 4	2061.8 ± 31	64.1 ± 4	1532.2 ± 25	1.70 ± 0.05
M3	100/15/15	41.1 ± 3	2166.2 ± 26	68.9 ± 3	1602.7 ± 27	1.54 ± 0.09
N3	100/00/05	65.4 ± 5	2792.7 ± 30	114.8 ± 5	1891.8 ± 27	0.92 ± 0.07
O3	100/00/10	68.1 ± 6	2843.3 ± 35	120.2 ± 4	2002.3 ± 33	0.85 ± 0.12
P3	100/00/15	75.7 ± 4	2935.4 ± 37	126.2 ± 7	2196.2 ± 38	0.79 ± 0.07

Table 4.4 Mechanical properties BMI-4 modified epoxy and BMI-4 modified siliconized epoxy systems

Matrix System	Epoxy/ HTPDMS/ BMI-4 composition	Tensile Strength (MPa)	Tensile Modulus (MPa)	Flexural Strength (MPa)	Flexural Modulus (MPa)	Plain Strain Fracture Toughness (K_{IC} MPa $m^{1/2}$)
A	100/00/00	63.2 ± 9	2751.7 ± 39	110.0 ± 10	1812.9 ± 42	1.14 ± 0.10
B	100/05/00	40.1 ± 3	2272.9 ± 30	70.6 ± 6	1735.4 ± 39	2.31 ± 0.05
C	100/10/00	33.6 ± 4	2119.9 ± 29	52.3 ± 4	1710.9 ± 28	2.61 ± 0.04
D	100/15/00	26.6 ± 5	1852.1 ± 40	49.1 ± 2	1373.4 ± 31	2.93 ± 0.15
E4	100/05/05	41.7 ± 2	2321.0 ± 27	73.7 ± 5	1764.8 ± 27	1.42 ± 0.05
F4	100/05/10	50.5 ± 5	2382.8 ± 21	83.7 ± 3	1850.2 ± 31	1.36 ± 0.09
G4	100/05/15	57.2 ± 3	2427.2 ± 25	96.0 ± 7	1900.7 ± 29	1.29 ± 0.11
H4	100/10/05	35.1 ± 4	2046.4 ± 28	58.9 ± 3	1691.2 ± 32	1.84 ± 0.07
I4	100/10/10	41.2 ± 6	2314.2 ± 21	65.0 ± 4	1746.2 ± 26	1.72 ± 0.05
J4	100/10/15	45.9 ± 3	2390.2 ± 23	69.0 ± 7	1810.2 ± 29	1.49 ± 0.12
K4	100/15/05	29.2 ± 5	1864.8 ± 30	53.3 ± 5	1393.0 ± 32	2.05 ± 0.02
L4	100/15/10	36.1 ± 3	2048.3 ± 34	59.6 ± 8	1508.8 ± 35	1.79 ± 0.11
M4	100/15/15	40.0 ± 3	2135.3 ± 27	64.0 ± 4	15783.7 ± 28	1.58 ± 0.07
N4	100/00/05	64.1 ± 3	2701.4 ± 29	112.2 ± 3	1859.8 ± 31	1.00 ± 0.04
O4	100/00/10	66.7 ± 4	2799.7 ± 31	116.8 ± 4	1921.2 ± 28	0.91 ± 0.13
P4	100/00/15	71.4 ± 6	2872.2 ± 29	123.9 ± 7	1981.2 ± 32	0.87 ± 0.09

Table 4.5 Mechanical Properties of E-glass fibre reinforced epoxy, siliconized epoxy, and bismaleimides (BMI-1, BMI-2, BMI-3 and BMI-4) modified epoxy and siliconized epoxy composites

Matrix System	Epoxy/ HTPDMS/ BMI composition	Tensile Strength (MPa)	Tensile Modulus (MPa)	Flexural Strength (MPa)	Flexural Modulus (MPa)	Interlaminar Shear Strength (MPa)
Unmodified epoxy system						
A	100/00/00	362.8	11031.3	380.5	19026.5	37.3
Siliconized epoxy system						
B	100/05/00	302.3	10604.4	294.3	17191.4	34.1
C	100/10/00	259.5	10004.2	264.9	17050.5	29.2
D	100/15/00	249.1	09810.0	186.6	16299.3	22.5
N,N'-bismaleimido-4,4'-diphenyl methane modified siliconized epoxy systems (BMI-1)						
I1	100/10/10	332.6	10763.5	372.3	18991.8	32.1
O1	100/00/10	376.7	11754.3	396.3	22994.6	41.7
N,N'-bis(maleimido)benzene (BMI-2)						
I2	100/10/10	351.6	11352.1	411.3	19088.6	33.9
O2	100/00/10	403.2	12600.9	429.4	25864.1	43.1
N,N'-bis(maleimido)ethane (BMI-3)						
I3	100/10/10	291.6	10398.6	355.8	18914.9	31.3
O3	100/00/10	364.3	11134.4	381.7	21405.4	40.1
N,N'-bis(maleimido)hexane (BMI-4)						
I4	100/10/10	268.9	8938.9	341.6	17285.2	30.5
O4	100/00/10	335.6	10400.6	344.3	19552.9	39.1