CHAPTER 5

ELECTRICAL PROPERTIES

Chapter five describes the insulation characteristics (like dielectric strength, surface resistivity, volume resistivity and arc resistance) of epoxy, siliconized epoxy and bismaleimides modified epoxy and siliconized epoxy systems.

5.1 DIELECTRIC STRENGTH

Dielectric strength is defined as the voltage gradient at which an insulating material fails as a dielectric due to electrical break down and the values of dielectric strength of the samples are presented in Table 5.1.

5.1.1 Effect of siloxane

The dielectric strength properties of epoxy resin system increases with increasing siloxane concentration. For example the dielectric strength value of unmodified epoxy system is 18.4 kV/mm, whereas the values for 5%, 10% and 15 % siliconized epoxy systems are 20.2 kV/mm, 23.4 kV/mm and 26.8 kV/mm respectively. The improvement in the values of dielectric strength of siliconized epoxy systems is due to the presence of inorganic -Si-O-Si- skeleton, which imparts better dielectric characteristics (Gutman *et al.*, 1997).

5.1.2 Effect of bismaleimides

The dielectric strength values of both epoxy and siliconized epoxy systems increases with the introduction of bismaleimides (BMI-1, BMI-2, BMI-3 and BMI-4) according to their percentage incorporation and nature of their skeletal structure. This may be due to the formation of intercrosslinking network between bismaleimides and epoxy systems, which in turn increase the crosslink density. Further, the negligible tendency to moisture absorption behaviour of bismaleimides also plays major role.

Among the bismaleimides modified epoxy systems and siliconized epoxy systems, the aromatic bismaleimide modified systems exhibit higher improvement in dielectric strength than that of aliphatic bismaleimides modified systems. This may be due to the presence of rigid aromatic ring in the former. Among the aromatic bismaleimides modified systems, the BMI-2 modified systems show higher improvement in dielectric strength when compared with BMI-1 modified systems. For example the dielectric strength value of 10% BMI-1 modified epoxy system is 23.9 kV/mm, whereas the value of dielectric strength for the same 10% BMI-2 modified epoxy system is enhanced to 25.1 kV/mm. This may be due to the presence of higher crosslink density in the BMI-2 modified systems than BMI-1, since higher number of reactive molecules are present in BMI-2 modified systems than that of the same weight percentage of BMI-1 modified epoxy systems (molecular weight of BMI-2 is lower than that of BMI-1).

Among the aliphatic bismaleimide modified epoxy systems the BMI-3 modified systems show higher improvement in dielectric strength than BMI-4 modified systems. For example the value of dielectric strength for 10%

Table 5.1 Dielectric strength of epoxy, siliconized epoxy, and bismaleimides modified epoxy and siliconized epoxy systems

Dielectric strength (kV/mm)				
Percentage of siloxane content in epoxy system	0%	5%	10%	15%
	18.4	20.2	23.4	26.8
Percentage of BMI content in epoxy system	0%	5%	10%	15%
BMI-1	18.4	21.1	23.9	26.1
BMI-2	18.4	23.8	25.1	28.1
BMI-3	18.4	20.5	21.9	24.3
BMI-4	18.4	19.8	20.5	22.1
Percentage of BMI content in 10% siliconized epoxy system	0%	5%	10%	15%
BMI-1	23.4	25.1	26.2	27.9
BMI-2	23.4	25.9	26.8	30.2
BMI-3	23.4	24.1	25.8	26.1
BMI-4	23.4	23.9	24.8	25.9

BMI-3 modified system is 21.9 kV/mm, whereas the value for the same 10% BMI-4 modified system is 20.5 kV/mm. The lower improvement in dielectric strength for BMI-4 modified systems is due to the presence of longer aliphatic chain and due to the presence of lower number of reactive molecules that reduce the crosslink density of BMI-4 modified systems when compared with the same weight percentage BMI-3 modified systems (molecular weight of BMI-4 modified systems is higher than that of BMI-3 modified systems).

5.2 SURFACE RESISTIVITY

The values of surface resistivity of epoxy, siliconized epoxy and bismaleimides modified epoxy and siliconized epoxy systems are presented in Table 5.2.

5.2.1 Effect of siloxane

The values of surface resistivity of epoxy system increase with incorporation of siloxane. For example the surface resistivity of unmodified epoxy system is 4.28 x 10^{12} ohm, whereas the values for 5%, 10% and 15% siloxane incorporated systems are 1.07 x 10^{14} ohm, 4.76 x 10^{14} ohm and 8.86 x 10^{14} ohm respectively. This may be due to inherent hydrophobic nature of siloxane linkage (Gutman *et al.*, 1997).

5.2.2 Effect of bismaleimides

Bismaleimides (BMI-1, BMI-2, BMI-3 and BMI-4) incorporation into epoxy and siliconized epoxy systems increase the surface resistivity according to their percentage concentration and nature of their molecular

Table 5.2 Surface resistivity of epoxy, siliconized epoxy, and bismaleimides modified epoxy and siliconized epoxy systems

Surface resistivity (ohm)				
Percentage of siloxane content in epoxy system	0%	5%	10%	15%
	4.28×10^{12}	1.07×10^{14}	4.76×10^{14}	8.86×10^{14}
Percentage of BMI content in epoxy system	0%	5%	10%	15%
BMI-1	4.28×10^{12}	2.09×10^{14}	4.16×10^{14}	7.12×10^{14}
BMI-2	4.28×10^{12}	3.12×10^{14}	5.11×10^{14}	8.01×10^{14}
BMI-3	4.28×10^{12}	1.91×10^{14}	3.81×10^{14}	6.42×10^{14}
BMI-4	4.28×10^{12}	3.91×10^{13}	1.11×10^{14}	2.98×10^{14}
Percentage of BMI content in 10% siliconized epoxy system	0%	5%	10%	15%
BMI-1	4.76×10^{14}	5.12×10^{14}	6.29×10^{14}	8.11×10^{14}
BMI-2	4.76×10^{14}	6.09×10^{14}	7.18×10^{14}	9.02×10^{14}
BMI-3	4.76×10^{14}	5.01×10^{14}	6.12×10^{14}	7.09×10^{14}
BMI-4	4.76×10^{14}	4.98×10^{14}	5.16×10^{14}	6.02×10^{14}

structure. Among the bismaleimides modified systems aromatic bismaleimides modified systems show higher improvement in surface resistivity than aliphatic bismaleimides modified systems. This may be due to the presence of rigid aromatic-heterocyclic ring structure in the former.

Among the aromatic bismaleimides modified systems BMI-2 modified systems exhibit higher improvement in surface resistivity when compared to BMI-1 modified systems. For example the value of surface resistivity for 10% BMI-1 modified system is 4.16 x 10^{14} ohm, whereas the value of surface resistivity for the same 10% BMI-2 modified system is enhanced to 5.11 x 10^{14} ohm. The reason is same as explained in the case of dielectric strength. In the case of aliphatic bismaleimides modified systems, the BMI-3 modified systems show higher improvement than that of BMI-4 modified systems. (Table - 5.2)

5.3 VOLUME RESISTIVITY

The values of volume resistivity of epoxy and siliconized epoxy systems increase with the introduction of bismaleimides according to their concentrations and nature of the molecular structure. The values lie in between 9.9 x 10^{14} ohm cm and 7.2 x 10^{15} ohm cm.

5.4 ARC RESISTANCE

5.4.1 Effect of siloxane

Incorporation of siloxane into epoxy resin improves the value of arc resistance according to its percentage concentrations. For example the value of arc resistance for unmodified epoxy system is 86 seconds, where as the values

of arc resistance for 5%, 10% and 15% siloxane incorporated systems are 97, 121 and 127 seconds respectively. This may be explained as the incorporation of siloxane reduces the possibility of forming continuous carbonized path when the matrix system is subjected to a high voltage arc. Because of the presence of -Si-O-Si- linkage, there is a discontinuity in the carbon chain, which does not allow the formation of continuous carbonized path and that reduces the leakage or fault path across the surface of the siliconized epoxy matrix. (Simmons *et al.*, 1997) (Table 5.3).

5.4.2 Effect of bismaleimides

The incorporation of bismaleimides BMI-1, BMI-2, BMI-3 and BMI-4 into epoxy and siliconized epoxy systems enhance the values of arc resistance. This may be due to the formation of intercrosslinking network between bismaleimides and epoxy systems which in turn increase the cross link density (Table 5.3).

Among the bismaleimides modified systems the aromatic bismaleimides modified systems show higher improvement in arc resistance when compared to aliphatic bismaleimides modified systems, due to the presence of rigid phenyl ring in the former. Among the aromatic bismaleimides modified systems, BMI-2 modified systems exhibit higher improvement in the values of arc resistance than that of BMI-1 modified systems. For example the value of arc resistance for 10% BMI-1 modified system is 120 seconds whereas, the value of arc resistance for the same 10 % BMI-2 modified system is enhanced to 125 seconds. The reason is similar as explained in the case of dielectric strength. In the case of aliphatic bismaleimides modified systems, the BMI-3 modified systems show higher improvement in arc resistance than that

of BMI-4 modified systems. For example the value of arc resistance for 10% BMI-4 modified system is 113 seconds whereas, for the same 10% BMI-3 modified system, the value of arc resistance enhanced to 119 seconds and the reason is same as discussed in dielectric strength. Similar trend is observed in the case of bismaleimide modified siliconized epoxy systems. However the values of arc resistance of bismaleimides modified siliconized epoxy systems are slightly higher than that of bismaleimides modified epoxy and siliconized epoxy systems. This may be due to the combined effect of bismaleimides and siloxane (HTPDMS) (Table 5.3).

Table 5.3 Arc resistance of epoxy, siliconized epoxy, and bismaleimides modified epoxy and siliconized epoxy systems

Arc resistance (seconds)				
Percentage of siloxane content in epoxy system	0%	5%	10%	15%
	86	97	121	127
Percentage of BMI content in epoxy system	0%	5%	10%	15%
BMI-1	86	96	120	128
BMI-2	86	100	125	130
BMI-3	86	95	119	125
BMI-4	86	93	113	120
Percentage of BMI content in 10% siliconized epoxy system	0%	5%	10%	15%
BMI-1	121	124	126	131
BMI-2	121	126	129	135
BMI-3	121	123	125	127
BMI-4	121	122	123	125