EPOXY RESIN SYSTEMS FOR HIGH PERFORMANCE FRP MOULDS

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ABSTRACT

Three epoxy resin systems have been developed and studied for various properties from process and performance point of view. All three systems are versatile in nature and suitable for most of the process techniques including Resin Infusion (RI), Hand Molding and RTM. Process properties such as mix viscosity at different temperature, rise in viscosity with respect to time and temperature, pot life at working temperature have been determined and reported to ease the selection of a resin system for composite applications. Several performance properties in neat state and with reinforcement have also been studied at standard conditions. The epoxy systems developed and reported in this study has varying pot life from 27 minutes to more than 600 minutes. Mix viscosities of epoxy systems are suitably low to achieve faster impregnation of reinforcement. The cured systems are capable to achieve glass transition temperature from 114 to 206^{0}C. Test results of physiochemical properties, reactivity, process and performance properties make these epoxy systems suitable for high performance composite tooling applications.

INTRODUCTION

Composite materials have emerged as a major class of structural elements and are either used or being considered as substitution for metals / traditional material in tooling for aerospace, automotive and other industries due to their high specific stiffness, high strength and controlled anisotropy which make them very attractive structural materials.

Use of plastics in tooling applications was introduced during World War II to alleviate a critical shortage of tooling metals. Initial tooling plastics were Phenolic and later polyesters; however, these materials posed a number of disadvantages which limited their versatility. [1]

Epoxies are one of the most widely used engineering resins and are well know for their use in composites with high strength fibers. Epoxy resins form a glass network, exhibit excellent resistance to corrosion & solvents, good adhesion, reasonably high glass transition temperatures and adequate electrical properties. [2]

Epoxies were introduced as tooling resin in about 1950 and with passage of time have gained wide acceptance. Currently, they are being employed in about 90% of all plastic tooling applications

Use of epoxy formulations in tooling applications offers several advantages like speed and ease of manufacturing, dimensional stability, excellent strength by using anisotropy to advantage, high strength to wt ratio, and low shrinkage during cure which permits close tolerance reproduction. [1]

Epoxy tooling was initially introduced in aircraft and automobile production which continues to be one of the major applications.

In aircraft, where production runs are short and often complicated by design changes, epoxies have proved of particular value. [3]

In automobile industry, epoxy metal forming tools are not suited for long production runs but such tools are useful as serving for prototypes for metal tooling and can be used to cut the time required by 25-50%. [4]

Tooling parts can be manufactured by various processing methods like castings, hand Lay up, resin infusion, RTM or various other traditional processing techniques.

In the present study, we have selected three epoxy systems which are most suitable for different processing technique like resin infusion, hand molding and RTM. These systems are of varying viscosities, pot life / gel time, glass transition temperature and mechanical strength.

EXPERIMENTAL WORK

Materials

Following three Lapox epoxy resins and suitable curing agents were selected:

System	Resin	Hardener
System-1	ARL-140	AH-419
System-2	ARL-138	AH-417
System-3	ARL-138	AH-433

Measurement and Testing

Viscosity and rise in viscosity measurement at different temperatures was done using rotational viscometer make Brookfield - model LVDV II+ Pro with software. Glass transition temperature was measured using Mettler Toledo DSC model 823e. Pot lives were determined using Gardco, USA pot life tester. Mechanical properties like tensile and flexural strength, modulus and elongation of bare and reinforced epoxy samples were determined by using Instron model -3369, USA Universal Testing Machine. The crosshead speed of 1 $mm.min^{-1}$ for tensile and 2 $mm.min^{-1}$ for flexural strength as per ISO 527 and ISO 178 was used respectively.

Sample Preparations

Samples for tensile strength and flexural strength of casted epoxy systems were prepared by specimen moulds. Dimensions of specimens were as per ISO 527 and ISO 178 standards respectively. Glass fiber reinforced samples were prepared by infusion process using two layers of UD glass fiber, 1200 gsm. Curing schedule for different epoxy systems are tabulated as below:

Tab. 1 Details of mixing ratio and curing schedule for different system

Sr No	System	Resin: Hardener mixing ratio (pbw)	Curing Schedule
System-1	ARL-140 / AH-419	100:42	80ºC/2h + 120ºC/2h + 160ºC/2h + 200ºC/4h
System-2	ARL-138 / AH-417	100:30	80°C/2h + 100°C/2h + 120ºC/8h
System-3	ARL-138 / AH-433	100:25	80°C/2h + 100°C/2h + 150ºC/8h

RESULTS

Physical properties

Viscosity

Table-2 shows the initial mix viscosity at three different temperatures 25ºC, 35ºC and 45ºC. The viscosity decreases with increase in temperature. Values vary in the range of 224 cPs to 1612 cPs at 25ºC. System-1 shows the highest viscosity whereas system-2 has the lowest viscosity at 25ºC.

Tab. 2 Initial mix viscosity of epoxy resin systems at different temp.

System	System	Test Method	25ºC	35ºC	45ºC
System-1	ARL-140 / AH-419	ISO 3219	1612	824	376
System-2	ARL-138 / AH-417	ISO 3219	225	200	179
System-3	ARL-138 / AH-433	ISO 3219	978	485	295

Rise in Viscosity

Figure 1 shows rise in viscosity at 25ºC w.r.t time for different epoxy systems.

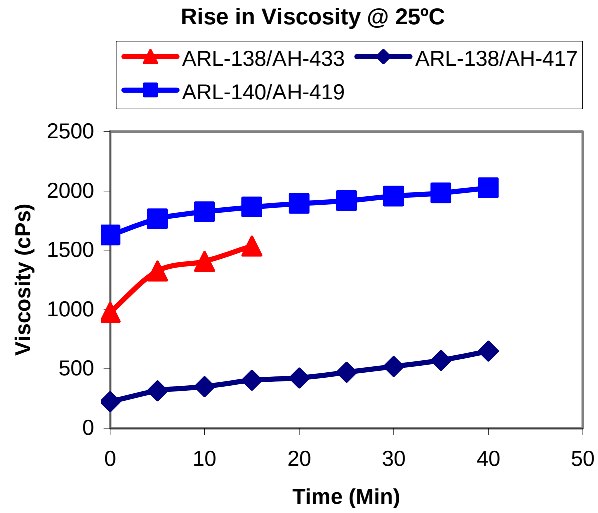


Fig. 1 Rise in viscosity at 25ºC for different epoxy systems

It was observed that system-3, ARL-138/AH-433 has higher reactivity compared to other two systems and about 55% rise in viscosity was observed within 15 min. System-2 ARL-138/AH-417 has lowest initial viscosity of 225 cPs at 25ºC suitable for infusion process. System-1 ARL-140/AH-419 has highest initial mix viscosity of 1612 cPs at 25ºC and at 50ºC it is 300 cPs which is reasonably low. Here rise in viscosity is slow which makes it suitable for infusion at temperature of 50ºC.

Processing Properties

Pot Life / working Life

Reactivity of all systems was determined at standard temperature of 25ºC. Samples were conditioned for 24hr in incubator at 25ºC before test. Figure 2 illustrates that system-3 has fastest reactivity and gels within 27 min. System-2 has moderate reactivity whereas system-1 has very long pot life.

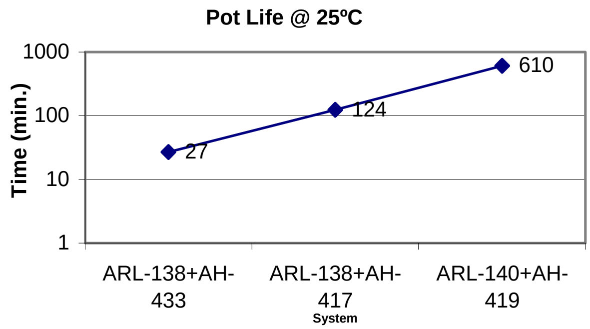


Fig. 2 Pot life of different epoxy system at 25ºC.

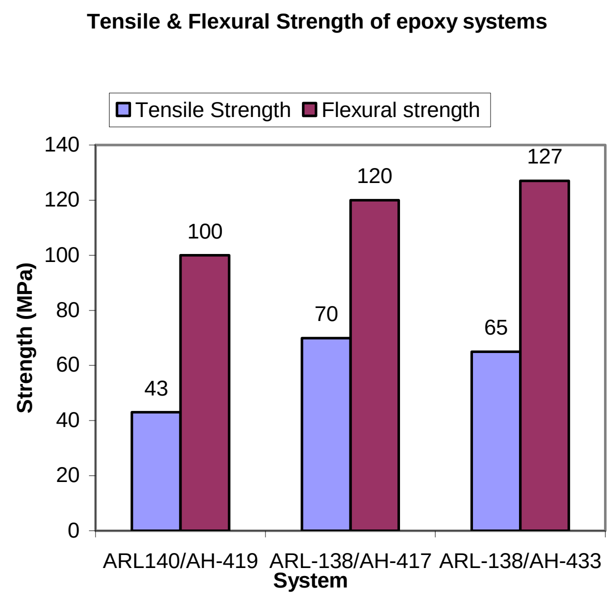
Cured system Properties

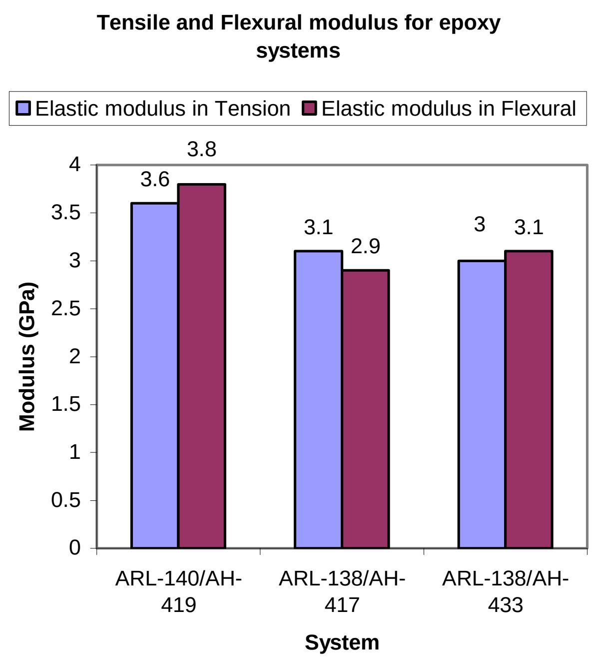
Three different epoxy resin systems with stoicheomatric ratio of resin:hardener were prepared and cured as per the schedule mentioned in Table 1. Table 3 shows the properties of system in cured state.

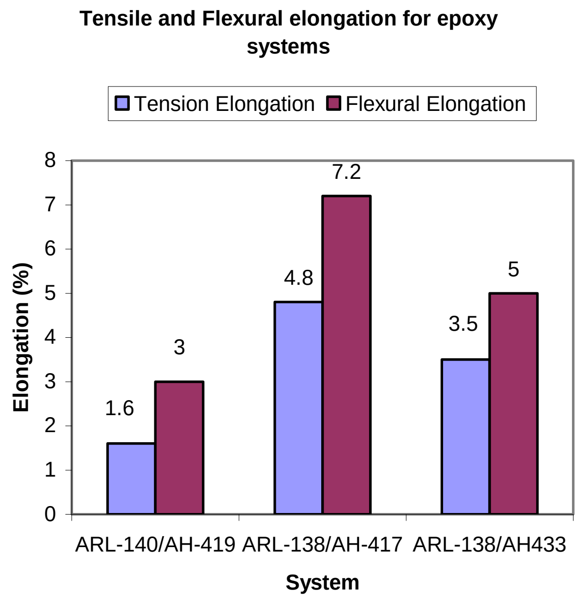
A wide range of Tg was achieved ranging from 114 - 206ºC for different systems. System-1 shows very high modulus whereas system-2 shows highest tensile strength in neat resin system.

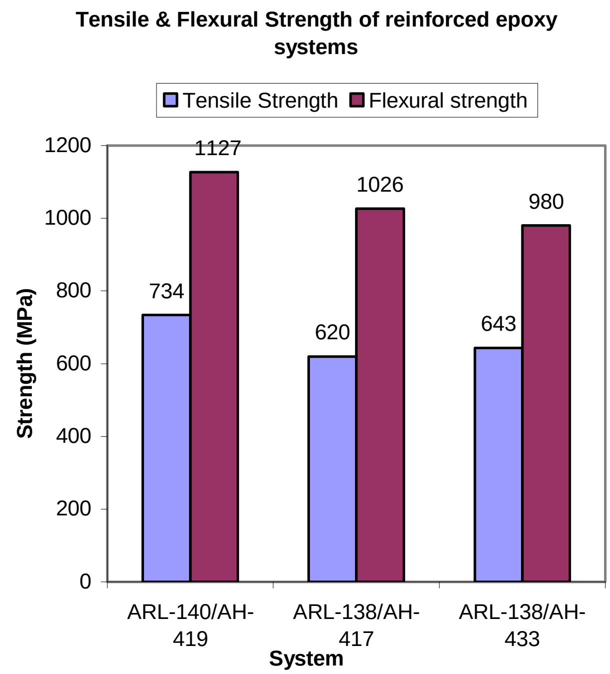
Tab. 3 properties of different casted unreinforced epoxy systems in cured state

Test Description	Unit	Test Method	ARL 140 / AH419	ARL-138 / AH-417	ARL 138 / AH-433
Glass Transition Temp – Tg	ºC	ISO 11375-2	206	114	152
Tensile Strength	MPa	ISO / 527	43	70	65
Tensile Elongation	%	ISO / 527	1.6	4.8	3.5
Elastic modulus in Tension	GPa	ISO / 527	3.6	3.1	3.0
Flexural strength	MPa	ISO / 178	100	120	127
Flexural Elongation	%	ISO / 178	3.0	7.2	5
Elastic modulus in Flexural	GPa	ISO / 178	3.8	2.9	3.1



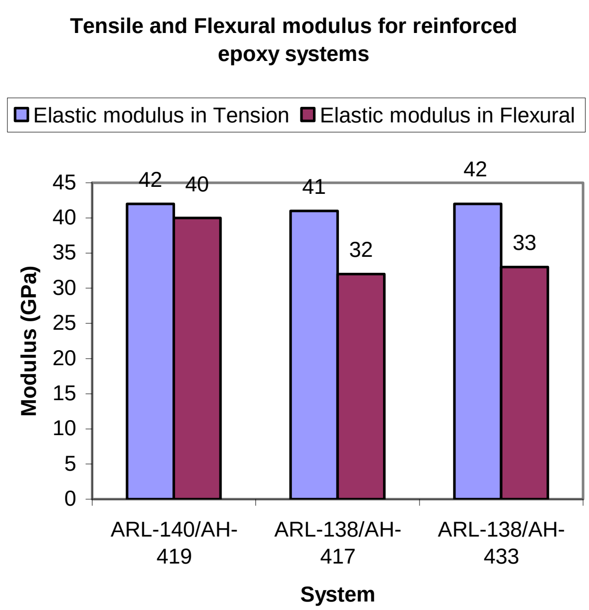


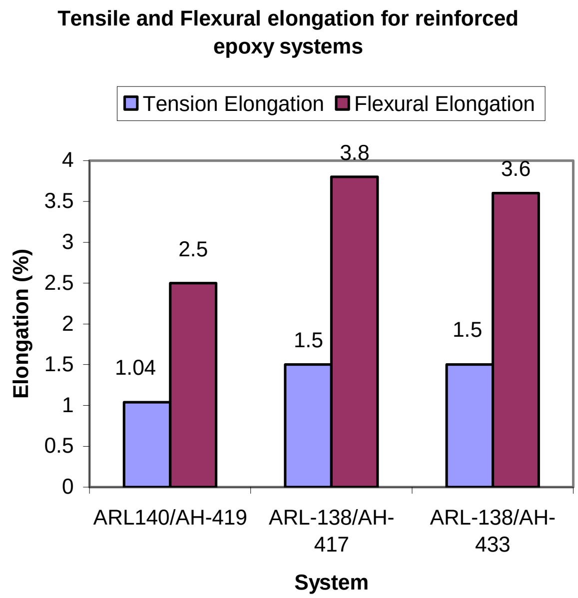




Tab. 4 Mechanical Properties of different reinforced epoxy system

Test Description	Unit	Test Method	ARL 140 / AH-419	ARL-138 / AH-417	ARL 138 / AH-433
Tensile Strength	MPa	ISO / 527	734	620	643
Tensile Elongation	%	ISO / 527	1.04	1.5	1.5
Elastic modulus in Tension	GPa	ISO / 527	42	41	42
Flexural Strength	MPa	ISO / 14125	1127	1026	980
Flexural Elongation	%	ISO / 14125	2.5	3.6	3.8
Elastic modulus in Flexural	GPa	ISO / 14125	40	32	33





CONCLUSION

The three systems developed and available commercially with Atul-Ltd, offer low to moderate mix viscosity, varying reactivity and pot life, and fast impregnation of reinforcement at ambient conditions. Their suitable mix viscosity and reactivity at processing conditions make them ideal for most of the composite processing techniques including Resin Infusion (RI), Hand Molding, and Resin Transfer Molding (RTM). The varying glass transition temperature of these systems, which is an important property for material selection, is ranging from 114 to 206^{o}C Therefore, a FRP composite can be fabricated from these resins which can work at extreme conditions of temperature. The mechanical properties obtained in tension and bending mode are excellent and suitable for most of the applications. More importantly elastic modulus of these systems are directly proportional to their Tg and have shown very high value in tension and bending mode. Easy processability due to appropriate viscosity, reactivity, high mechanical strength, and modulus, and high glass transition temperature (Tg) value of these versatile epoxy systems makes them most suitable for fabrication of FRP tools (molds) using various process techniques described above. Molds manufactured by these systems can be suitably used for manufacturing of FRP components for aerospace, automobile, wind turbine blades, sports articles, components for defense, recreation, general, and electrical engineering components.

FUTURE WORK

Further study can be done for shrinkage, impact strength, fracture toughness, dynamic properties in various modes, weight loss by TGA, and fatigue properties.

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Dr Mahesh Soni – GM R&D and Business Development. He has a doctorate (Ph.D) in polymer composites. Dr Soni has 20 years of rich experience in the field of polymeric resins, formulations and application development in the field of composites, electrical, civil and coatings. He has worked for 7 years outside the India and has rich experience of serving global customers for product development and technical services.

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