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Technical Paper

Predicting Composite Elastic Modulus with Polymer Castings Test Data

Abstract

Procedures and charts in ASME RTP-1 can be used to quite accurately predict composite modulus values. However, the lack of accurate resin modulus data at elevated temperatures has limited the use of this fine tool for the design of composite structures. Recently, AOC has measured the modulus values from castings of many different resins. Further data from pipe venders and other sources have validated the usefulness of the calculated modulus procedures. The usefulness of this prediction ability is especially desirable for external pressure, buckling or bending load requirements. Generally, the modulus of filament wound vinyl ester pipe at high temperatures [about 200°F(93.3°C)] is shown to be half or less the value at ambient temperature. Using the castings mechanical property data, predictions can be made for chopped fiber ducts or for many other composite structures.

Introduction

The ASME RTP-1 has provided graphical aids (Appendix M-3 and in this document, Figure A) for accurate modulus prediction for fiberglass composites, but the available resin modulus data has been lacking for elevated temperature applications. Resin companies provide test results for castings at room temperature and for composites at elevated temperatures, but in most cases the composite tests have been made on Class II laminates (as defined in RTP-1) which contain substantial percentages of woven roving fabrics. The effect of resin modulus on a laminate with the fibers parallel to the stress direction is nearly zero, so there is little temperature effect in these laminates. In directions away from parallel, the effect of the resin modulus may be quite high as can be seen in the angular filament wound structures shown in the RTP-1 tables. Chopped strand (Class I) mat laminates show a large effect of resin modulus as can be seen in Figure A (derived from a chart in RTP-1, Appendix M-3), and these laminates are easy to make and test. The glass is assumed to be E-glass (the most common type) with a specific gravity of 2.54, but the specific gravity of resins will vary. Figure B shows the relationship of composite modulus with resin modulus at 17.2% volume glass content. Figure C is the same information except with 15.7% volume glass.

Many past laminate tests on filament wound structures have shown that the predicted modulus is accurate using the curves in ASME RTP-1 for mat or filament wound laminates. Resin castings are easily tested, and the results accurately predict the modulus values of a composite mat structure. The new data at elevated temperature can extend the usefulness of the ASME RTP-1 procedures.

One might ask, "What is the emphasis for elastic modulus? Isn't strength the most important property?" This is true for many structures, but the elastic modulus is the primary focus for buckling failure and for deflection in many specifications. It can be noted in data supplied by filament wound pipe manufacturers that the modulus of vinyl ester pipe at 200° F (93.3°C) is half that at room temperature. This has the effect of reducing the design factor by half for buckling or bending of thin wall pipe or ducts. Therefore, it is important to have good resin modulus information as a design tool.

Experimental

A number of the tensile modulus tests have been accomplished, together with similar tests on tensile strength and flexural modulus properties using castings, chopped strand and Class II (mat and woven roving) laminates. The resins used in these tests include one isophthalic polyester and five vinyl ester resins, as shown in Table 1.

Comparisons of predicted mat modulus values and test results were made to illustrate the usefulness of the data.

The test procedure used for obtaining the tensile modulus of mat laminates and castings was ASTM D 638, "Standard Test Method for Tensile Properties of Plastics." The sample thickness averaged about 1/8 inch (3 mm) and the length and width were as directed by ASTM D 638. Five replicates were made for each condition.

This paper focuses on the modulus results for resin castings and mat laminates. These data points are the only values listed for the six polyester and vinyl ester resins. The industry has learned that the heat distortion (HDT) is an important attribute which is related to the test results.

The modulus test results for composite modulus, resin casting modulus and derived values for composite modulus have been plotted for each resin type versus temperature.

Results and Discussion

Results of various resins are on Figure D (Vipel® F701-S, low styrene isophthalic polyester, LSIP), Figure E (K022-AC, brominated epoxy vinyl ester, BEVE), Figure F (F010, standard bisphenol A epoxy vinyl ester, BAEVE), Figure G (K095, brominated novolac vinyl ester, BNVE) Figure H (F085, standard novolac vinyl ester, NVE), and Figure I (F086, high HDT novolac vinyl ester, HTNVE). The results show that all of the resins had a marked change in slope of modulus vs temperature, beginning just below the heat distortion temperature. This is not surprising in that the resin changes from a glassy material to a pliant, semi-liquid material at the HDT. Thus, one could expect that the resin modulus would be plunging toward zero in that higher heat zone.

Three of the six resins showed agreement between the predicted mat laminate modulus values as compared to the tested values from mat laminates; the others were fairly close at the point of sharp change of slope, but differed in slope in the lower temperatures. The three with the greatest differences were resins BEVE, BNVE AND NVE. Two of these were the novolac epoxy vinyl esters, but the high HDT version, HTNVE, gave good agreement between the casting values and the derived values. The reason for the differences in the novolacs is obscure.

The two halogenated resins have a slightly higher specific gravity values, and Figures E and G illustrate the effect of these values on the composite modulus of these laminates. The halogenated resin laminates are about five percent (5%) lower in volume for the same weight percent of glass.

Summing the results, it may be desirable to run more tests at other temperatures and include a highly brominated vinyl ester resin to more narrowly define these results. As most of us know, the scatter of test results for composites is generally large leading to uncertainty for designers and higher design factors for structures. The use of the castings modulus values would be more conservative than the results derived from ASME RTP-1. The mechanical values of the mat laminate will allow greater levels of confidence for elevated temperature designs of composite materials than in the past.

Conclusion

1) Generally, the ASME RTP-1 predicted values for tensile modulus at elevated temperatures reasonably well. However, the use of high temperature mat properties will provide a more accurate prediction of RTP-1 class II composite properties.

2) Even though there is some variation in three of the resins, the predicted values from ASME RTP-1 are valid.

Acknowledgements

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References

1. ASME RTP-1-2005, "Reinforced Thermoset Plastic Corrosion Resistant Equipment"

J.Albert Rolston, PE, FAIChE, has been an independent consulting engineer for over thirty years, with a practice primarily devoted to fiberglass structures. Most of his work has been concerned with the design of corrosion related fiberglass structures such as pipe and tanks. He attended North Carolina State University achieving bachelors and masters degrees in chemical engineering. He is a registered engineer in Virginia, Ohio, Washington, and Oregon. He taught physical metallurgy at the University of Virginia for ten years and worked as a research engineer for Owens Corning Fiberglas for twelve years. He is a retired Air Force Lt Colonel having been a B-29 navigator during WWII.

Bruce Curry is the corrosion product leader for AOC. He has 41 years experience with polyester and vinyl ester resins. He has an honor bachelor of science degree from the University of Waterloo, Ontario, Canada.

Figure A

ASME RTP-1-2000

REINFORCED THERMOSET PLASTIC
CORROSION RESISTANT EQUIPMENT

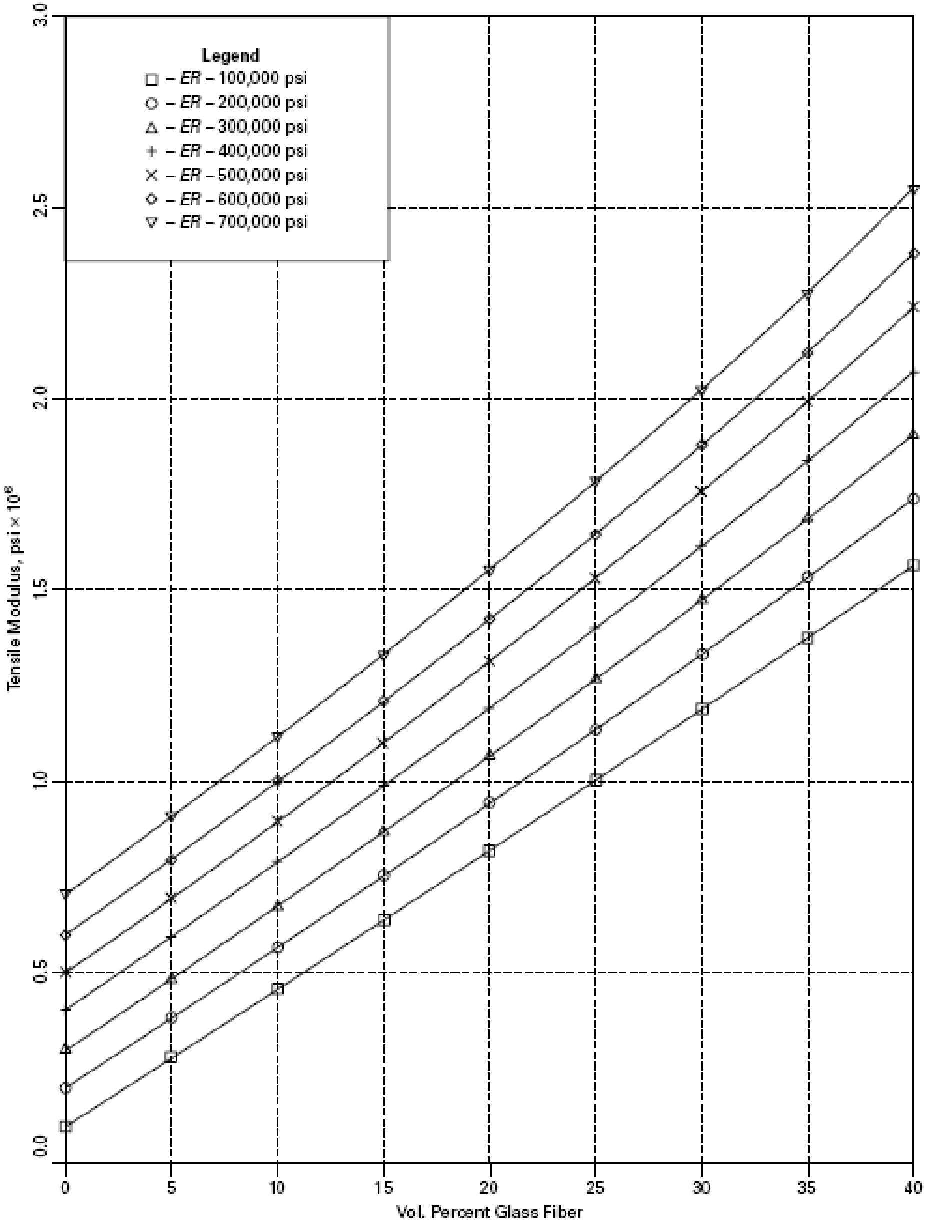


FIG. M3-1 RANDOM GLASS FIBER

Figure B

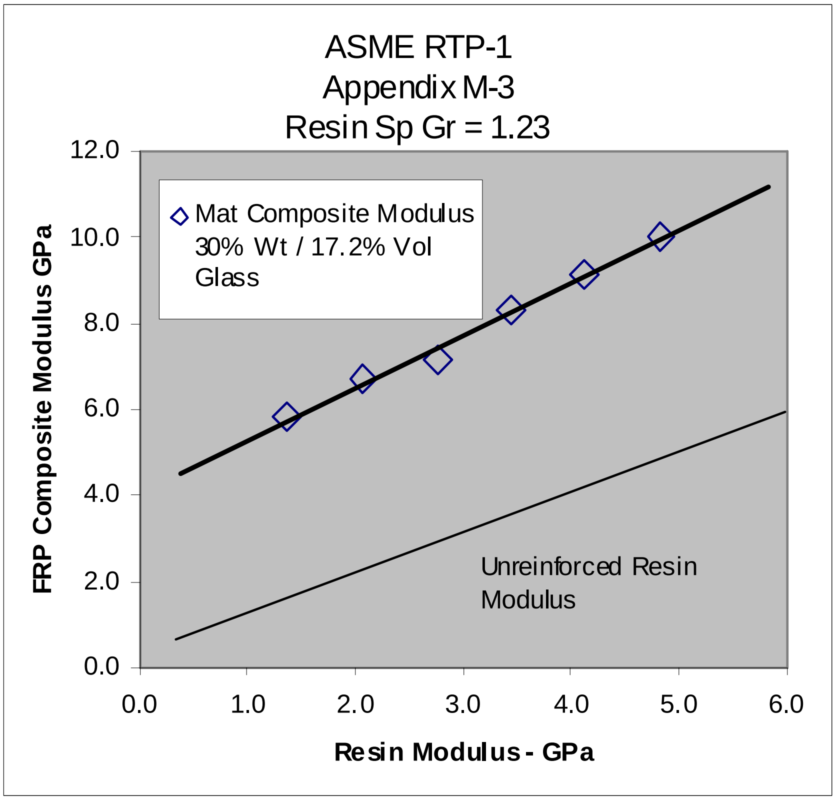


Figure C

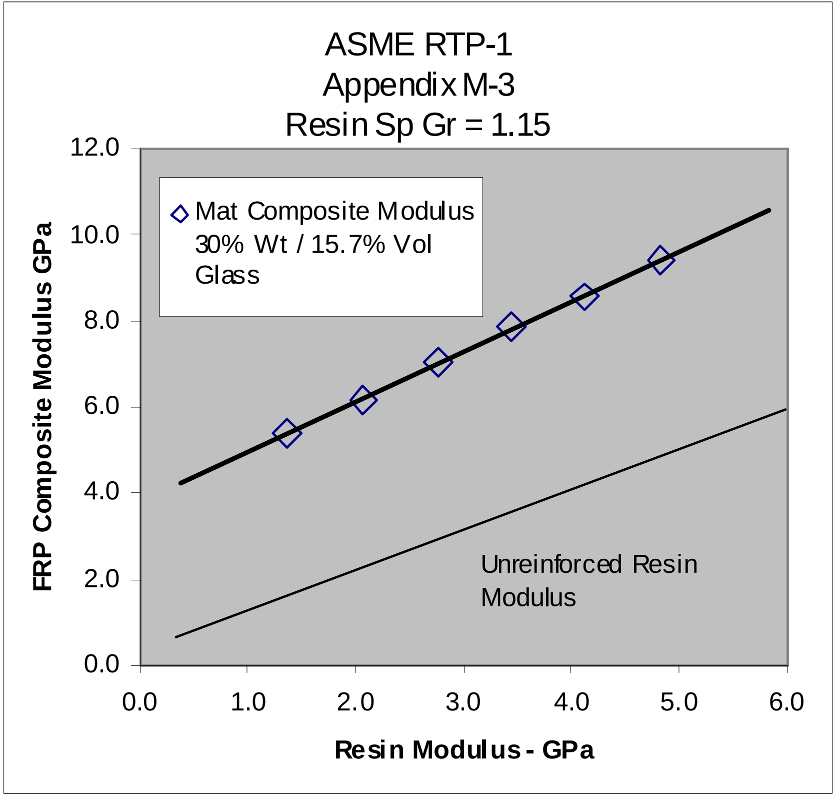


Table 1

Figure Code	Resin Type	Abbreviation	HDT		Casting Density	
			°C	°F	Gram/cm^3	Lbs/ft^3
D	F701-S polyester	LSIP	128	262	1.16	72.4
E	K022-CC Vinyl Ester	BEVE	112	234	1.23	76.8
F	F010 Vinyl Ester	BAEVE	120	248	1.12	69.9
G	K095 Vinyl Ester	BNVE	143	289	1.23	76.8
H	F085 Vinyl Ester	NVE	140	300	1.15	71.8
I	F086 Vinyl Ester	HTNVE	166	330	1.16	72.4

Figure D

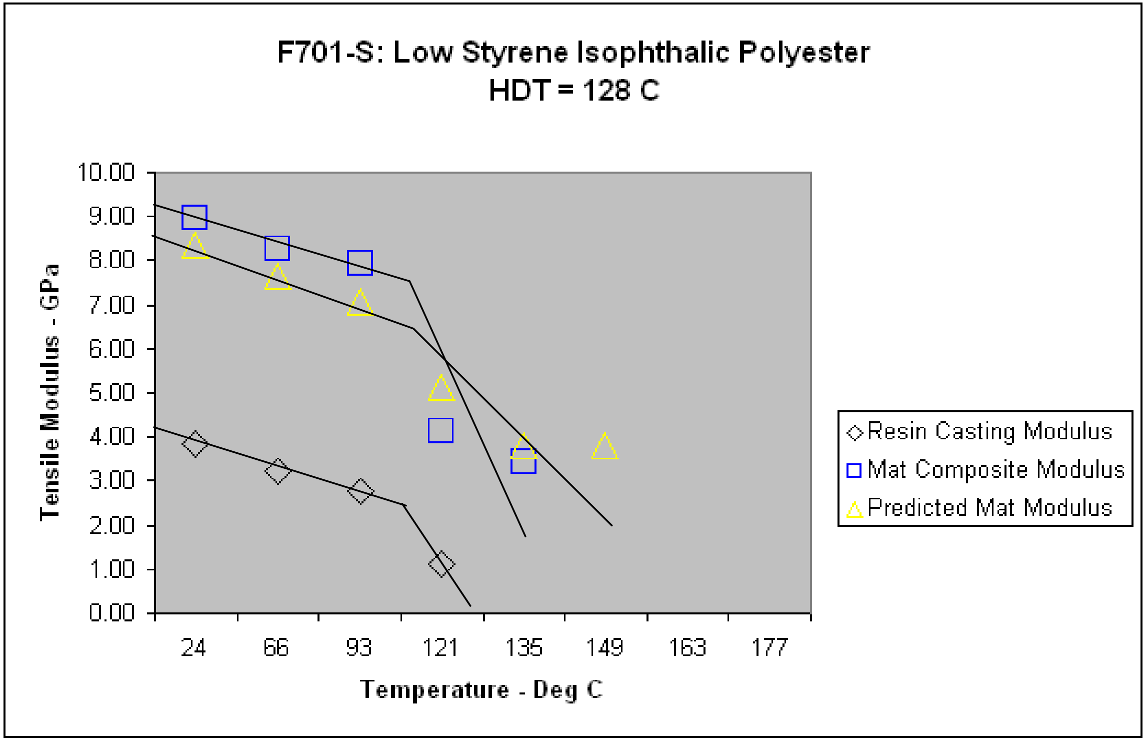


Figure E

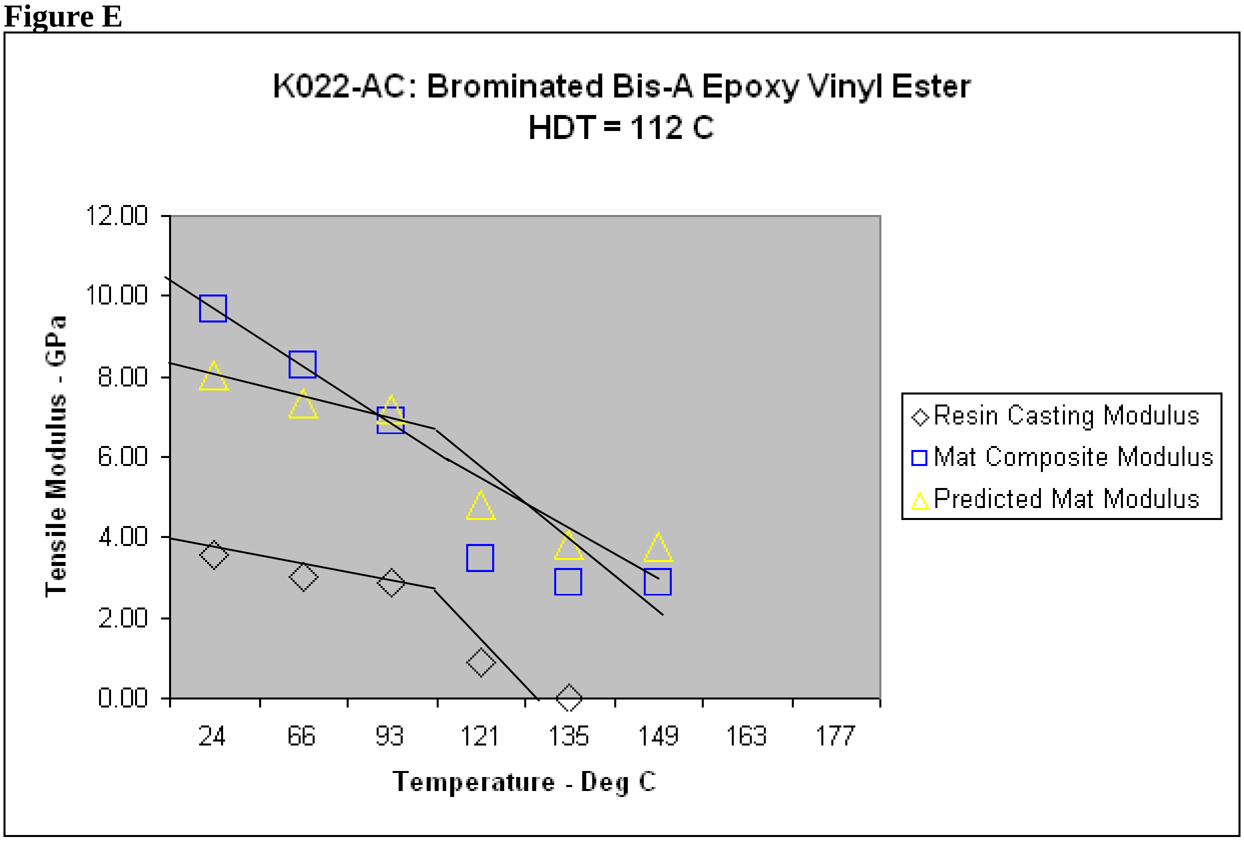


Figure F

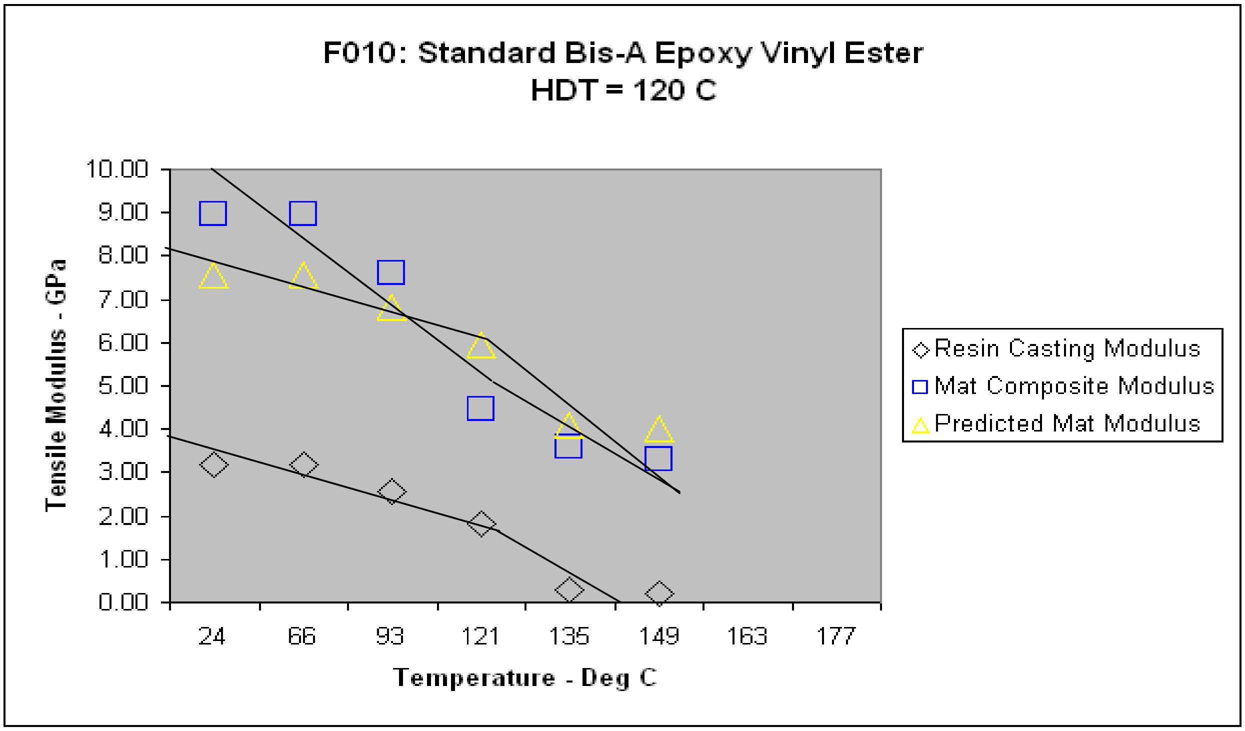


Figure G

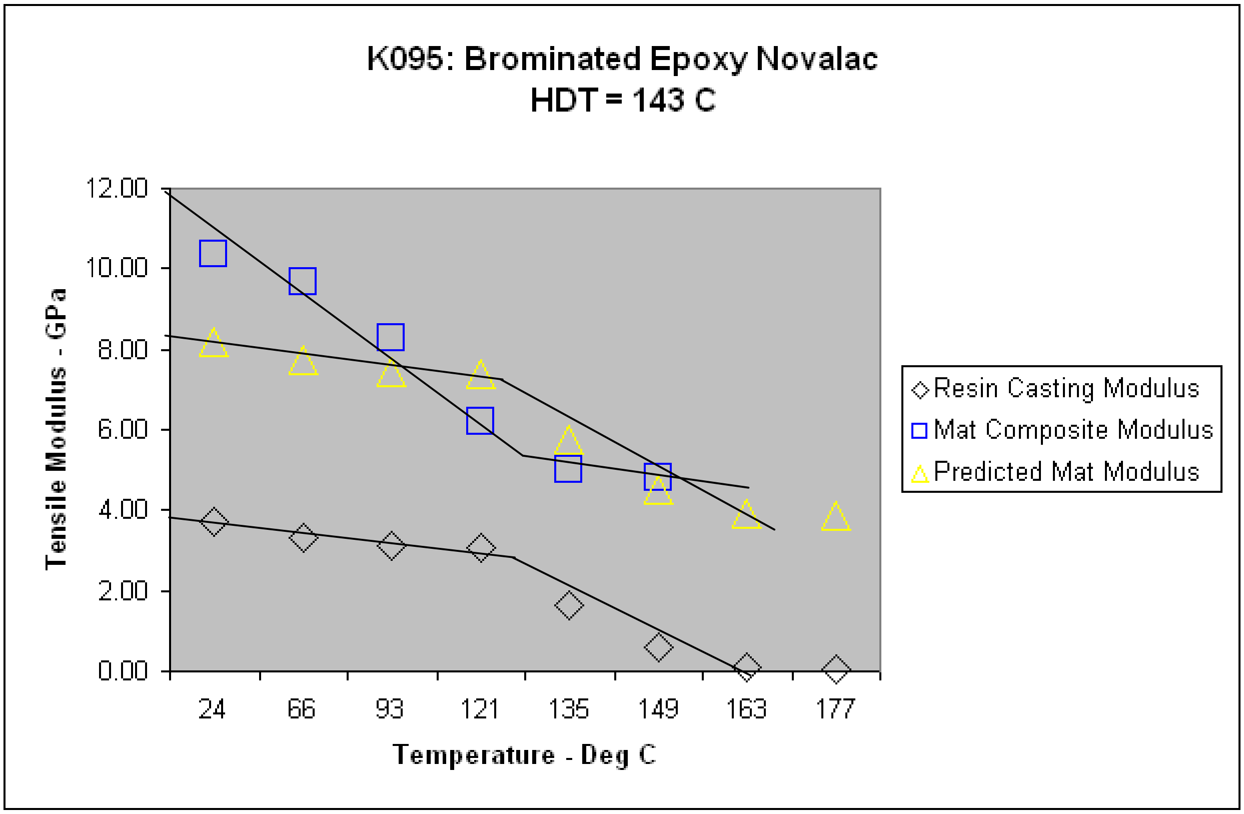


Figure H

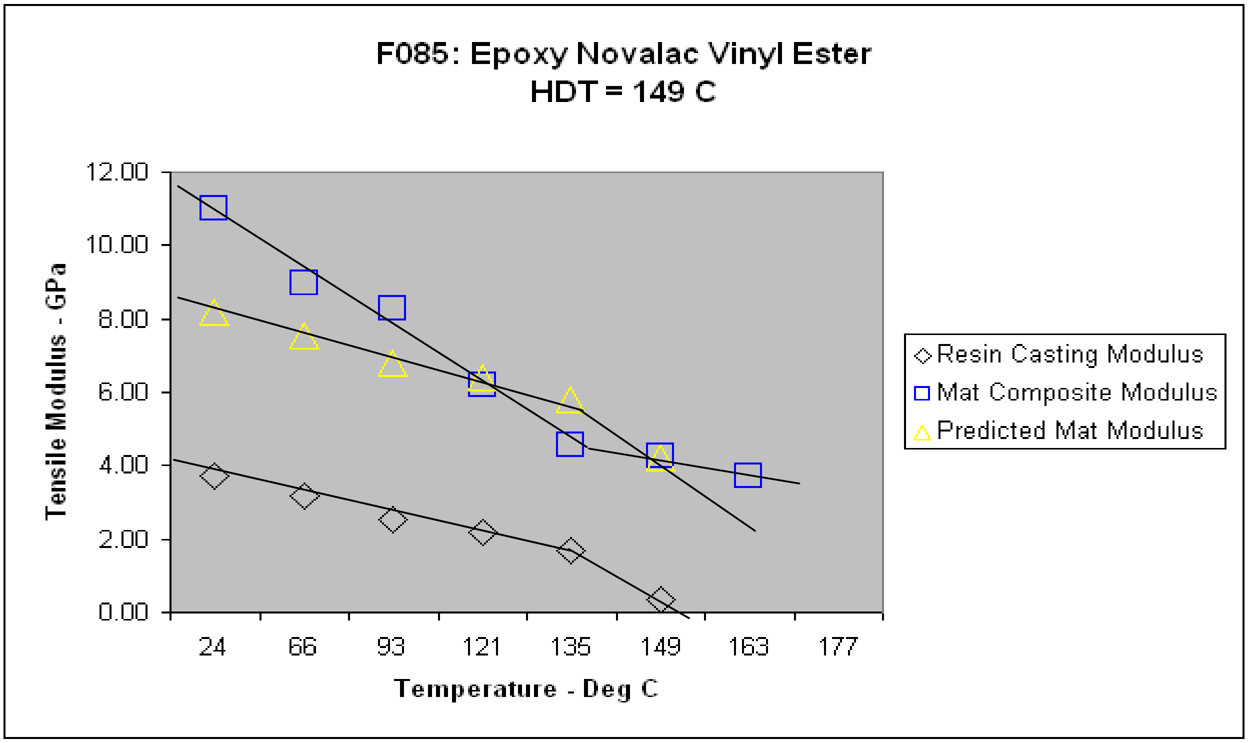
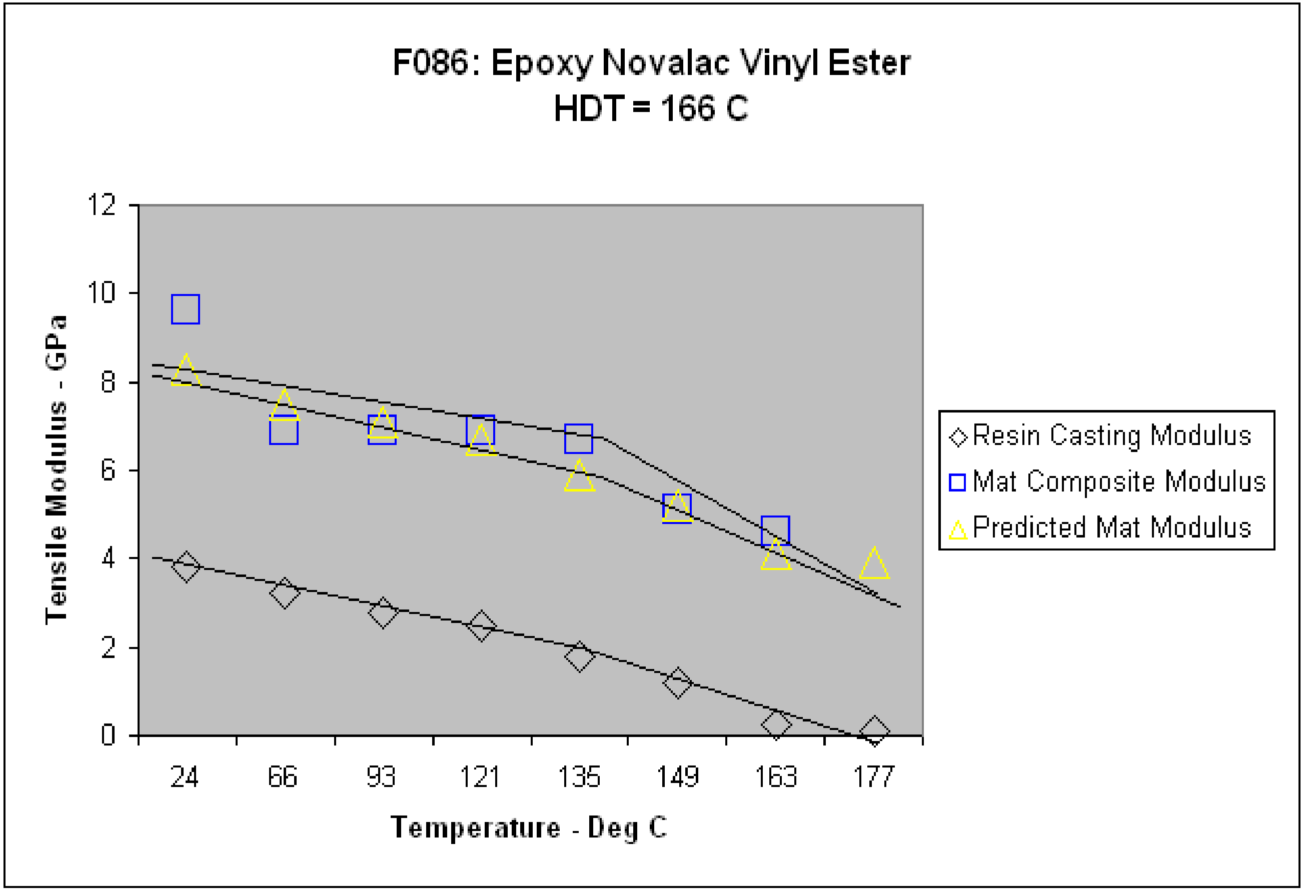


Figure I


F086: Epoxy Novalac Vinyl Ester
HDT = 166 C
Tensile Modulus - GPa
12
10
8
6
4
2
0
24
66
93
121
135
149
163
177
Temperature - Deg C
◇ Resin Casting Modulus
□ Mat Composite Modulus
△ Predicted Mat Modulus