

Effect of Temperature on the Mechanical Properties of Polymer Mortars

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This paper presents the results of an experimental program to investigate the effect of temperature on the performance of epoxy and unsaturated polyester polymer mortars (PM). PM is a composite material in which polymeric materials are used to bond the aggregates in a fashion similar to that used in the preparation of Portland cement concrete. For this purpose, prismatic and cylindrical specimens were prepared for flexural and compressive tests, respectively, at different temperatures. Measurements of the temperature-dependent elastic modulus and the compressive and flexural strength were conducted using a thermostatic chamber attached to a universal test machine for a range of temperatures varying from room temperature to 90 °C. The flexural and compressive strength decreases as temperature increases, especially after matrix HDT. Epoxy polymer mortars are more sensitive to temperature variation than unsaturated polyester ones.

Keywords: *polymer mortars, temperature dependency, material behavior*

1. Introduction

Recently, a considerable amount of research has been performed on the thermal degradation of polymer matrix composites because this is a major problem in the application of thermoset polymers in different types of environments that are subjected to temperature changes¹. The composite material behavior under different temperatures is an important parameter to be considered because it can, in many cases, determine the upper bound on the temperatures at which a material has suitable properties².

Polymeric composite materials are some of the youngest building materials, and they are continually appearing with new and optimized properties as new combinations and formulations are developed. Regardless of their significant advantages in comparison with conventional construction materials, the mechanical properties of polymer composites are highly susceptible to the type of resin and reinforcement (or aggregate) employed, as well as to the quantity of both components³⁻⁶.

However, the main problem with polymeric materials arises from the viscoelastic properties of the polymer, which result in creep and a high sensitivity to temperature⁷⁻¹⁰. The effects of temperature on the mechanical properties of polymers change considerably, especially within the heat distortion temperature range. The heat distortion takes place over a wide temperature range that, for many resins used in civil engineering, lies between 20 and 80 °C¹¹. This means that during the service lifetime of the material, glass transition can occur¹².

In this study, epoxy and unsaturated polyester polymer mortars are tested under different temperatures to evaluate their behavior when they are subjected to flexure and

compression. A polymer mortar (PM) is a composite material in which polymeric materials, thermoset resins, are used to bond the aggregates in a fashion similar to that of Portland cement that is used in the preparation of Portland cement concrete. PMs were first developed in the 1950s and then became widely popular in the 1970s. Today, PM is used very efficiently in precast components for buildings, bridge panels, hazardous waste containers, machine bases, and in various utility and transportation components.

2. Materials

Various PM formulations were prepared by mixing foundry sand with the thermoset resin binder. The epoxy resin system used was RR515 from SILAEX[®] based on a diglycidyl ether bisphenol A and an aliphatic amine hardener. It was processed with a maximum mix to hardener ratio of 5 : 1 with low viscosity. The unsaturated polyester resin used was POLYLITE[®] 10316 from REICHHOLD[®], pre-accelerated with 1.5% (in weight) catalyst. The resin systems properties provided by the manufacturers are presented in Table 1.

A quartz foundry sand with a rather uniform particles size was used; the particles had an average diameter of 245 µm. The sand specific gravity is 2.65 g.cm⁻³^[13] and fineness modulus of 2.5¹⁴. The aggregate sieve distribution is presented in Figure 1.

Resin content was 12% by weight; no filler was added, and 88% of the aggregates complete PM formulations. Previous studies conducted by the author⁶, considering an extensive experimental program, allowed for an optimization of the mortar formulations that are being used in the present work.

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The mixture was performed mechanically to achieve a more homogeneous material. With the above mix proportions, polymer mortar specimens were cast to prismatic ($40 \times 40 \times 160 \text{ mm}^3$) and cylindrical ($\phi 50 \times 100 \text{ mm}$) specimens according to RILEM TC113/PC-2¹³ specification. For each formulation five cylindrical and five prismatic specimens were cast. All specimens were allowed to cure for 7 days at room temperature, and then, the epoxy specimens were post-cured at 80 °C for 3 hours and the unsaturated polyester mortars were post-cured for 4 hours at 60 °C before being tested for flexural and compression at different temperatures ranging from room temperature to 90 °C.

3. Experimental

To determine the influence of temperature on the mechanical strength of the PM, flexural and compressive tests were performed at different temperature levels. The test temperatures range from room temperature to 90 °C. To perform this research, a universal testing machine with an attached thermostatic chamber was used. Tests were performed inside the chamber at specific temperatures.

Prismatic polymer mortar beams were tested in three-point bending up to failure at the loading rate of 1 mm/min with the span length of 100 mm, according to RILEM TC113/PCM-8¹⁴ specification. The specifications of this standard, in terms of specimen geometry and span length, are similar to those specified in ASTM C348-02, the standard test method for the flexural strength of hydraulic cement mortars¹⁵. In both of the mentioned standards, the shear effect is not taken into account in the flexural strength calculation procedure. Despite the very short span compared to the thickness, the shear effect is disregarded. Polymer

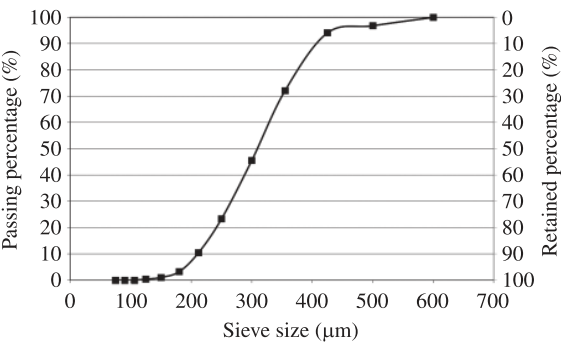


Figure 1. Aggregates sieve distribution.

Table 1. Properties of epoxy and polyester resins.

Property	Epoxy	Polyester
Viscosity at 25 °C μ (cP)	12000-13000	250-350
Density ρ (g.cm ⁻³)	1.16	1.09
Heat Distortion Temperature HDT (°C)	50	54
Modulus of elasticity E (GPa)	5.0	3.3
Flexural strength (MPa)	60	45
Tensile strength (MPa)	73	40
Maximum elongation (%)	4	1

mortar is considered to be an isotropic material, and the theory of plane cross-section is used. Damage in the flexure is assumed to be caused primarily by the axial tension and compression stresses.

Cylinder polymer mortar specimens were tested in compression at the loading rate of 1.25 mm/min, according to ASTM C39-05 standard¹⁶.

Both the flexural and compressive test set-ups are presented in Figure 2.

4. Results and Discussion

Flexural test results of the epoxy and unsaturated polymer mortars under different temperatures are presented in Table 2. The specimens were tested at 23 °C, 30 °C, 40 °C, 50 °C, 60 °C, 70 °C, 80 °C and 90 °C.

Figure 3 represents the loss of flexural strength in the epoxy and unsaturated polyester mortars over the entire range of test temperatures.

Upon increasing the test temperature, a significant loss in flexural strength is observed. Epoxy polymer mortars present a strong and marked temperature dependency. The decrease in the flexural strength is consistent, and a 91.8% loss is reported between room temperature tests and 90 °C.

In the analysis of the unsaturated polyester specimens, a lower temperature dependency was observed than that of the epoxy specimens; in addition, a smaller decrease is reported. Upon increasing the test temperature, a gradual decrease in flexural strength occurs; in fact, a decrease of 72.5% is reported when the temperature reaches 90 °C, as compared to the room temperature samples.



Figure 2. Flexural and compressive test set-up in the Universal Testing Machine.

Table 2. Epoxy and unsaturated polyester mortars flexural test results (Avg. \pm St.Dev.).

Test temperature (°C)	Epoxy (MPa)	Polyester (MPa)
23 (Room temperature)	16.62 \pm 1.28	9,01 \pm 0.73
30	14.82 \pm 0.74	7.97 \pm 0.32
40	13.34 \pm 1.05	6.98 \pm 0.11
50	10.23 \pm 0.71	6.11 \pm 0.58
60	9.04 \pm 0.88	5.31 \pm 0.48
70	5.63 \pm 0.13	4.31 \pm 0.66
80	3.07 \pm 0.55	3.69 \pm 0.40
90	1.37 \pm 0.86	2.50 \pm 0.26

The relationships between the test temperature and flexural strength of both formulations of polymer mortar are presented in Figures 4 and 5.

According to Figure 4, between room temperature and 50 °C, only a loss in the ultimate flexural strength is observed. When the temperature is elevated from 50 °C to 60 °C, reaching the HDT (Heat Distortion Temperature)

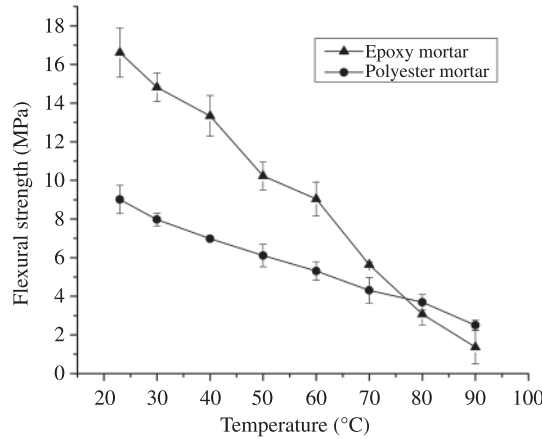


Figure 3. Flexural strength as function of test temperature for both polymer mortars.

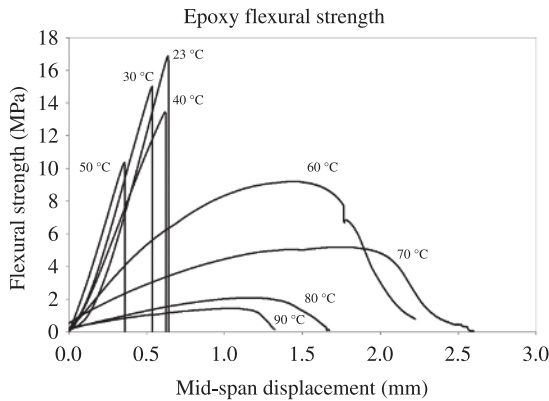


Figure 4. Typical flexural strength curves of epoxy mortar specimens at different test temperatures.

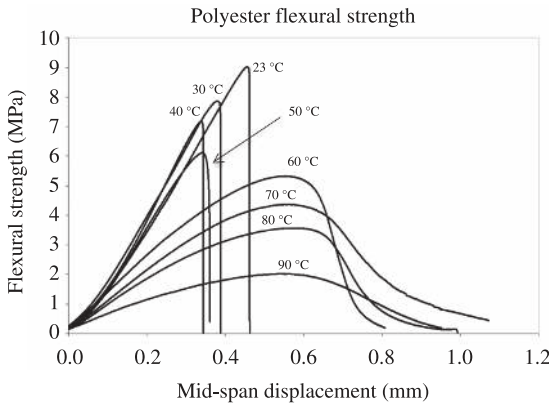


Figure 5. Typical flexural strength curves of unsaturated polyester mortar specimens at different test temperatures.

value of the epoxy resin, a change in the material behavior is observed. The epoxy mortar becomes less brittle, but no significant ultimate flexural strength change is reported. The HDT is the temperature at which a polymer sample deforms under a specified load. The HDT corresponds to the initial softening point and relates closely to the glass transition temperature of the polymer.

Upon continuing to raise the temperature, a ductile performance is observed followed by a decrease in the load bearing capacity, and at 90 °C, this value becomes almost insignificant.

Evaluating Figure 5, the same behavior reported for the epoxy mortars specimens is observed for the unsaturated polyester ones. Again, upon raising the test temperature to 50 °C, the brittle performance is reported; only a small decrease in the ultimate flexural strength is calculated. Also, the unsaturated polyester specimens become less brittle between 50 °C and 60 °C. Upon elevating the temperature to 90 °C, a lower loss in the flexural strength is observed than in the epoxy mortars. Specimens tested at 90 °C show a significant loss in the flexural strength.

As shown in Figures 4 and 5, for both formulations, the loss of load bearing capacity increases with temperature. This behavior is associated with a progressive loss of material stiffness, turning the brittle characteristics of the polymer mortar into ductility. The change in the polymer mortars behavior is related to the HDT values of the polymers used as binders. The indicated points are both located around 10 °C lower than the HDT of the resins used.

Table 3 presents the test results of the epoxy and unsaturated polyester mortars under compression at different temperatures.

Analysis of the results of the compressive tests reveals that the polymer mortars behavior is similar to that in the flexural tests. A decrease in the compressive strength for both the epoxy and unsaturated polyester mortars is reported. The loss computed in the epoxy specimens is, again, higher than the loss reported for the unsaturated polyester mortars. The decrease in the compressive strength values of the epoxy mortar specimens from room temperature to 90 °C is 87.2%. Considering the standard deviation of the test results, it can be assured that the epoxy mortars behave similarly in compression and in flexion when raising the temperature from room temperature to 90 °C. A lower compressive strength decrease is observed for the unsaturated polyester mortars. A decrease of 56.7% is calculated when the compressive strength at 90 °C is compared to the results

Table 3. Epoxy and unsaturated polyester mortars compression test results (Avg. \pm St.Dev.).

Test temperature (°C)	Epoxy (MPa)	Polyester (MPa)
23 (Room temperature)	38.73 \pm 2.32	26.60 \pm 2.21
30	35.94 \pm 3.10	24.20 \pm 1.93
40	30.02 \pm 2.77	22.51 \pm 2.87
50	23.80 \pm 1.30	20.06 \pm 1.45
60	16.77 \pm 0.93	16.91 \pm 0.77
70	10.36 \pm 1.34	13.12 \pm 0.94
80	7.28 \pm 1.69	12.46 \pm 1.45
90	4.96 \pm 0.74	11.50 \pm 1.23

at room temperature, making the unsaturated polyester polymer mortars stiffer in compression than in flexion.

The behavior of the compressive strength over the whole temperature range is shown in Figure 6.

As the test temperature increased, a trend in the increase of the ductile behavior can be seen. Again, the epoxy polymer mortars present a strong temperature dependency, and the rate of decrease in the unsaturated polyester mortars is lower than in the epoxy binder specimens.

Figures 7 and 8 compare the computed values for the epoxy and unsaturated polyester polymer mortars,

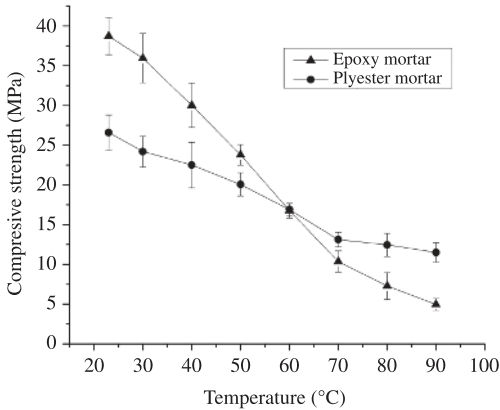


Figure 6. Compressive strength as function of test temperatures for both polymer mortars.

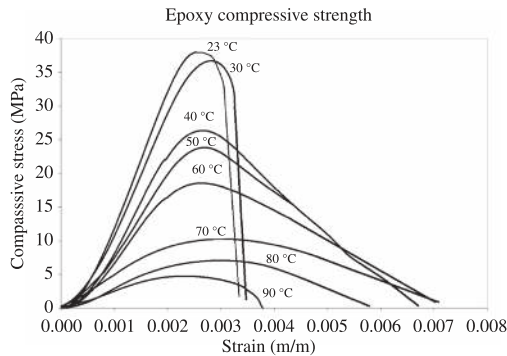


Figure 7. Typical compressive stress-strain curves of epoxy mortar specimens at different test temperatures.

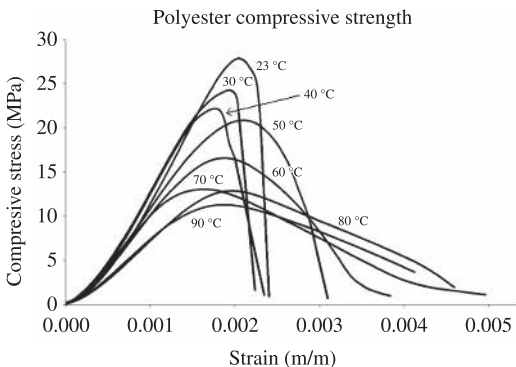


Figure 8. Typical compressive stress-strain curves of unsaturated polyester mortar specimens at different test temperatures.

respectively, under different test temperatures. They allow us to evaluate the compressive stress-strain behavior and to follow the phenomena that occur during temperature increase.

According to Figure 7, losses in the compressive stress of the epoxy mortar are reported from 40 °C to 90 °C. The values between 60 °C and 70 °C decrease drastically, and the compressive stress at 90 °C is the lowest reported. As the test temperature increases, the compressive elasticity modulus decreases, and failure becomes less brittle.

Unlike the behavior reported at 40 °C in the epoxy mortars specimens, the unsaturated polyester samples present a less brittle behavior starting at 50 °C. This is very similar to the results of the flexural tests. The decrease in the compressive stress present for temperatures between 70 °C and 80 °C is not significant; values are within the standard deviation range. The lowest strain is computed at 90 °C. As reported for flexure, the unsaturated polyester mortars exhibit ductile behavior as the test temperature increases.

As presented in Figures 7 and 8, for both formulations, a loss of brittleness capacity with an increase in temperature is observed. The change in the polymer mortars behavior within the temperature increment that is associated with the HDT values of the polymers used as binders occurs at lower steps. In compression, the epoxy specimens become ductile at 40 °C, and the unsaturated polyester mortars lose their brittleness at 50 °C. These values are lower than those observed in the flexural tests.

5. Conclusions

This work discusses the results of an experimental study of the influence of the temperature on two specific formulations of polymer mortars. Deformation and strength properties of epoxy and unsaturated polyester polymer mortars show the temperature dependency, including distinct inflection points where the dependency becomes dominant at the specific temperature in the respective properties. Except within a limited temperature range, from room temperature to 60 °C, flexural and compressive strength decreases drastically as temperature increases; a loss of more than 50% is reported.

The temperature dependency of the properties of polymer mortars is strongly correlated to that of the resins used. The epoxy mortars are more sensitive to temperature changes than the unsaturated polyester ones. The temperature dependency is related to the HDT of the resins used.

For the structural design of the epoxy and unsaturated polyester mortars applied in the temperature range above the HDT, the changes in the deformation and strength of the polymer mortars must be taken into account.

These results show the relevance of material knowledge when testing under different temperatures. The design of the polymer mortars must be approached carefully as properties can degrade significantly under certain conditions.

Acknowledgements

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