

EFFICIENT UTILIZATION OF MUNICIPAL SOLID WASTE FOR THE PRODUCTION OF PHENOLIC MATRIX COMPOSITE

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Abstract - This work is aimed to the production of a phenolic resin composite through the incorporation of fillers derived from municipal solid waste. To this purpose, a partially polymerized resin was fully cured after the addition of water, without applying pressure during the cure. Also, a defined quantity of municipal solid waste was added to the mixture and cured with the same conditions. The cure process was accurately set up by exploiting results from rheological analyses. Afterwards, cured samples, with and without fillers, were tested by flexural analyses, in order to evaluate the improvement in the mechanical response due to the addition of the waste.

Keywords - Phenolic Resins; Industrial Waste; Phenolic Composites; Waste Valorization;

I. INTRODUCTION

Phenolic resins were developed by Leo Hendrik Backeland in the first year of XX century¹. Starting from the first resinous product based on phenol and formaldehyde, obtained by A. Von Baeyer in 1872, Backeland was able to produce moldable formulation with economical routes.

Despite new resins with higher performances are nowadays available, phenolic resins are still being used because of some desirable features, such as good heat and solvent resistance, good dimensional stability and flame resistance².

Phenolic resins are often employed for the production of decorative laminates^{3, 4}. The manufacturing of these panels involves the impregnation with the resin and a high temperature and pressure step to obtain hard boards without voids⁵. Other applications of phenolic resins regard their usage as adhesives, binders, surface coatings and impregnants⁶.

Although phenolic are widespread diffused in the resin market, some issues lead to relevant drawbacks in terms of performances and quality of the final component. First, pressure is required during the cure, in order to reduce the voids generated from the volatiles. Also, the cure requires the addition of catalyst to lower the processing temperature. Finally, the chemical structure of the resin, characterized by the presence of the aromatic ring, is responsible of a high brittleness of the matrix.

The aim of this work is the development of a phenolic resin composite with a novel curing process which does not imply the use of high pressures and catalysts. The high void production was hindered by the addition of a particular filler, derived from municipal solid

waste. Besides a reduction of the porosity of the component, with a consequent improvement of its final properties, the use of this kind of additive allows improving the efficiency of the waste management and reducing its negative effects on the environment.

II. EXPERIMENTAL

A. SAMPLE PREPARATION

First, the phenolic resin (PR) was tested without the addition of water, in order to monitor the cure by increasing temperature. Afterwards, 30% of water was added to the powder and the cure process was optimized; once fixed the water amount, the phenolic resin was partially replaced by the municipal solid waste (MSW), then the effect of MSW on the polymerization of the resin was observed.

All the tested compositions are reported in Table 1. For sample preparation, the use of a mechanical stirrer, with a speed of 60 rpm and a time of 5 min, was required. Samples for flexural tests were obtained by a pressure-free process, by pouring the water suspension in silicon molds, followed by curing at different temperatures.

Table 1 Composition of samples

Code	PR (%wt)	MSW (%wt)	Water (%wt)
PR	100	-	-
PR_30w	70	-	30
PR-MSW30w	45	55	30

B. ANALYSIS METHODS

The cure process of the resin was first studied by rheological analyses with a Rheometric Scientific Ares instrument. Tests were carried out on PR_30w, with a parallel plate geometry, constant oscillatory amplitude (1%) and frequency (1 Hz), in the following conditions:

- dynamic temperature ramp test, from 20 °C to 200 °C, with a heating rate of 5 °C/min;
- dynamic test from 20°C with a heating rate of 5 °C/min, followed by an isothermal step at 110 °C and 120 °C.

Differential scanning calorimetry (DSC) analyses were then performed on cured samples, with a DSC 622 Mettler Toledo. Test consisted in a heating scan from room temperature to 250 °C, with a heating rate of 10 °C/min.

Finally, flexural tests were performed on samples produced with and without MSW addition, by using a Lloyd LR5K dynamometer, according to ASTM D 790 standard test method. Tests were performed on 100x10x3 mm samples, with a test speed of 2 mm/min.

III. RESULTS AND DISCUSSION

The complex viscosity of the phenolic resin with 30% of water was monitored by increasing temperature up to 200 °C.

The analysis of the evolution of the complex viscosity during heating provides information about the cure of the material, which involves an increase in molecular weight and, as a consequence, of the viscosity of the sample. As observed in Figure 1, the cure process started at 110 °C. After a sharp increase, the viscosity levelled off at 190 °C, thus meaning a complete polymerization of the sample.

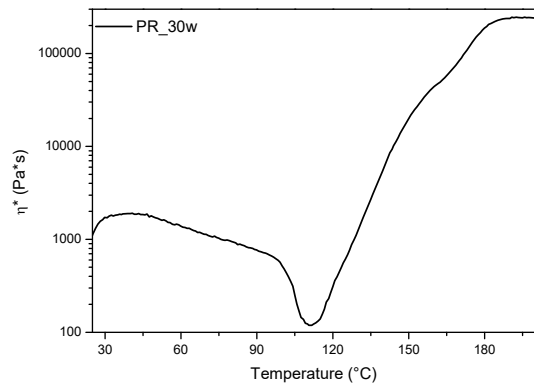


Figure 1: viscosity of phenolic resin in 30% water during a dynamic scan

The time necessary to complete the curing process in isothermal conditions was monitored with a temperature ramp test from room temperature, followed by an isothermal step at 110 °C and 120 °C. As shown in Figure 2, the increase in temperature caused a faster polymerization of the resin. In particular, the slope of both curves in two different ranges (1000-2000 s and 2000-3000 s) was calculated, in order to estimate the increase in the polymerization rate with increasing temperature. As shown in Table 2, an increase of 10 °C in temperature allowed doubling

the polymerization rate.

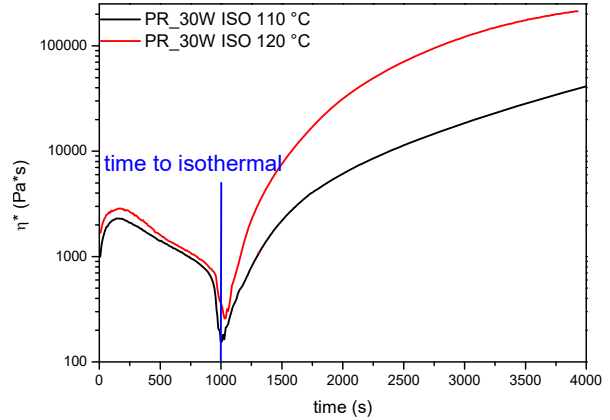


Figure 2: viscosity of phenolic resin in 30% water during a dynamic scan at different temperatures followed by isothermal step

Table 2: effect of temperature on the curing rate

	slope 1 (Pa)	slope 2 (Pa)
PR_30W ISO 110 °C	0.002	3.76E-4
PR_30W ISO 120 °C	0.004	7.95E-4

DSC curves when then carried out on PR samples obtained after polymerization at 120 °C. As shown in Figure 3, the addition of the filler involved an increase of about 10 °C of the glass transition temperature, whose values shifted from 142 °C for the phenolic resin to 152 °C for the PR_MS30w system. The same shift was reached with a polymerization temperature of 110 °C, thus meaning that the addition of the filler caused an increase in the glassy region regardless of the curing temperature.

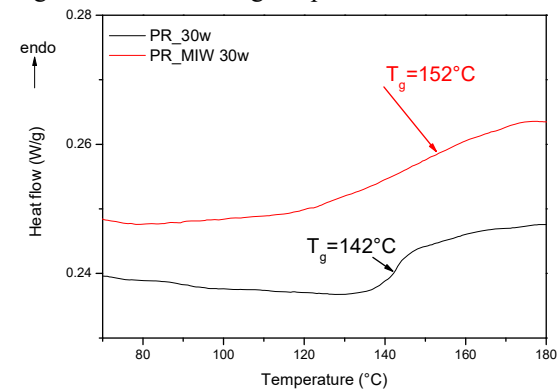


Figure 3: DSC curves for phenolic resin and phenolic resin with MSW addition

Flexural tests were finally performed on cured samples in order to evaluate the influence of the curing temperature and the addition of MSW on the mechanical response of the resin. Results in Figure 4 showed an increase in the flexural properties with the addition of the filler. For both samples, better mechanical properties were attained after curing at 110 °C, since an increase in the polymerization temperature involved a higher porosity caused by faster evaporation

of water during the process. This result was confirmed by the density values, also reported in Table 3; lower densities were found with higher polymerization temperatures; moreover, the presence of MSW caused a slowdown of the water evaporation, with resulting higher densities, lower void content and higher mechanical response. In addition, PR_MS W samples were found to be less affected by the increase in curing temperature.

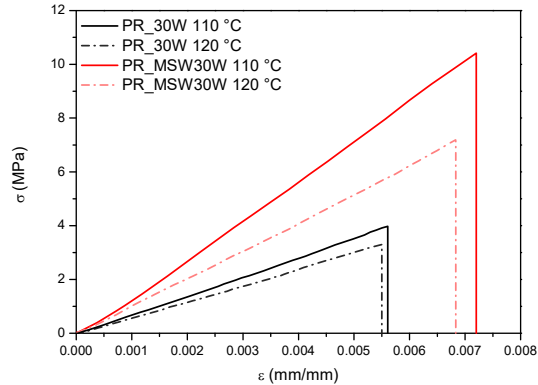


Figure 4: stress-strain curves for phenolic resin and phenolic resin with MSW addition cured at 110 °C and 120 °C

Table 3: mechanical and physical properties for phenolic resin and phenolic resin with MSW addition cured at 110 °C and 120 °C

Sample	σ_y (MPa)	ϵ_y	E (MPa)	ρ ($g\ cm^{-3}$)
PR_30W 110 °C	3.55 \pm 0.81	5.5E-3	6.0E2	0.70
PR_30W 120 °C	2.84 \pm 0.76	5.4E-3 \pm 1.2E-3	\pm 4.61E1 \pm 5.82E1	\pm 0.12 \pm 0.07
PR_MS W30W 110 °C	10.11 \pm 3.25	7.4E-3 \pm 1.5E-3	1.4E3 \pm 6.74E1	0.79 \pm 0.14
PR_MS W30W 120 °C	7.42 \pm 2.06	6.7E-3 \pm 1.1E-3	1.3E3 \pm 1.12E2	0.75 \pm 0.11

CONCLUSION

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This work was focused on the development of a composite phenolic material with the addition of municipal solid waste, through an innovative curing process performed with low pressures and without catalysts.

The analyses performed on the different systems allowed identifying two temperatures for the curing process. A higher polymerization temperature allowed strongly reducing the time necessary to complete the cure. On the other hand, lower curing temperatures allowed a higher control on the water evaporation during the process, which in turns means lower voids and higher mechanical performances. This effect is less emphasized with the presence of the filler, where good performances were also reached with higher curing temperatures.

The experimental results showed the potential of the developed approach for the production of PR samples characterized by higher stiffness and lower porosities. Moreover, the choice of using a municipal solidwaste as filler involved a cost reduction and an increase of the efficiency of waste management, with the reduction of

its negative effects on the environment and on population.

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