STRAIN RATE DEPENDENCY ANALYSIS OF POLYMER CONCRETE IN COMPRESSION TESTS

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Abstract. *Polymer concrete (PC) is a composite material consisted of mineral filler, foundry sand, and a polymer binder, unsaturated polyester resin. Understanding the behavior of this kind of composite at different strain rates is of critical importance in a range of applications. The present paper is focused on the study of the strain rate sensitivity of cylindrical polymer concrete specimens in monotonic and cyclic compression tests. Monotonic tests were performed at three different prescribed strain rates ($1.25x10^{-3}$ s^{-1}, $1.25x10^{-2}$ s^{-1} and $1.25x10^{-1}$ s^{-1}). The experimental results indicate an elasto-viscoplastic behaviour: the load-carrying capacity of the polymer concrete increases significantly with strain rate while the modulus of elasticity remains practically constant. The proportional limit increases 77% from the lower to the highest strain rate level and the ultimate compressive strength is 27% higher at a strain rate of $1.25x10^{-1}$ s^{-1} when compared to $1.25x10^{-3}$ s^{-1}.*

Keywords*: Polymer Mortar, Strain Rate, Experimental Results.*

1. INTRODUCTION

The development of new materials possessing increased strength, durability, excellent mechanical strength and a longer life cycle is a major requirement in this growing market. In the past decades, polymers have been used in the production of composite materials with those differentiated mechanical properties (Ohama, 1997, Fowler, 1999 and Gorninski *et al*, 2004). Polymer mortars (PM) are an example of a material with such high performance due not only to its high performance but also because of the reduction of the need for maintenance and frequent repairs required by conventional building materials. Those composites differ in terms of chemical composition from cementitious mortars by the replacement of the binder by a thermoset resin that will polymerize with the aid of additives, initiator and promoter (Novoa *et al*, 2004).

The PM compounds present large versatility in applications. In the United States applications are directed to floor covering, bridge coatings and the petrochemical industry (Lang *et al*, 2005). In Europe, applications are focused on prefabricated components for the building industry, piping and coatings for the chemical and food industries (Rebeiz, 1995a, 1995b). In Brazil, despite the need for strong and durable materials, PM has not received significant applications. This is possibly due to general unfamiliarity with the material's properties but compositions with reduced levels of resin can be dosed, making the material more competitive and with superior mechanical strength and durability.

Yet, experimental high-strain rate testing remains a difficult field and is full of complexities. Indeed, success with the high strain rate testing of polymer composites depends widely on the ability to isolate the inherent inertial disturbances attributed to the test system (Hsiao and Daniel, 1998, Fitoussi *et al*, 2005, Thiruppukuzhi, 2001, Daniel *et al*, 2010 and Zhou and Hao, 2008). High-speed mechanical testing of polymer composites gives rise to specific difficulties due to inertial effects, non-uniform stress/strain distributions and measurements repeatability. Previous researches have investigated fatigue performance of polymer mortars. Studies with different frequencies were performed (Bapokutty, 2006, Kwak and Kim, 1995, Stroeven, 2010 and Soudki *et al* 2007) and concluded that polymer mortars have a rate dependency and better performance than ordinary cement mortars.

The primary objective of the present work is to set up and optimize an experimental approach aimed at characterizing the mechanical behavior of polymer mortars subjected to rapid loadings. On the one hand, this study intended to quantify the strain-rate effects on the overall behavior in terms of elastic properties, damage and ultimate characteristics. On the other hand, it contributes to investigate local processes involving damage initiation and growth.

2. MATERIALS AND METHODS

PM formulations were prepared by mixing foundry sand with the thermoset resin as binder. 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 tab. 1.

Table 1. Properties of Polyester Resin

Property	Polyester
Viscosity at 250ºC μ (cP)	250-350
Density ρ (g/cm^3)	1.09
Heat Distortion Temperature HDT (ºC)	54
Modulus of Elasticity E (GPa)	3.3
Flexural Strength (MPa)	45
Tensile Strength (MPa)	40
Maximum Elongation (%)	1

Quartz foundry sand, of rather uniform particles size and average diameter of 245 μm, was used. The sand specific gravity is 2.65 g/cm^3 and with fineness modulus of 2.5. Resin content was 12% by weight; no filler was added and 88% of aggregates complete PM formulations. Previous studies carried out (Reis, 2009), considering an extensive experimental program, allowed an optimization of mortar formulations that are now being used in the present work. The mixture was performed mechanically, to achieve a more homogeneous material. With those mix proportions, polymer mortar specimens were cast to cylindrical specimens (ϕ50 x 100 mm) according to RILEM TC113/PC-2 (1995). All specimens were allowed to cure for 7 days at room temperature and then post-cured for 3 h at 60º C before being tested.

Compressive tests according to ASTM C39 (2005) were performed at 3 different strain rate. For each strain rate 3 specimens were tested. The strain rates used were $\dot{\varepsilon} = 1.25\times10^{-3}$ s^{-1}, $\dot{\varepsilon} = 1.25\times10^{-2}$ s^{-1} and $\dot{\varepsilon} = 1.25\times10^{-1}$ s^{-1}, respectively. Proportional stress was defined as that in which the curve above that value has an elastic behavior. It can be obtained from the intersection of the experimental stress-strain curve at the point $\varepsilon = 0.002$, see fig. 1.

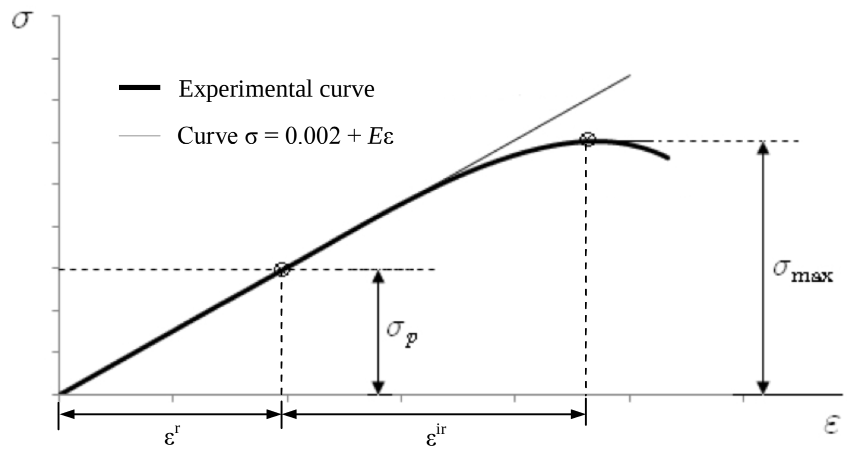

Figure 1 – Proportional stress identification

The definition of proportional stress allows us to decompose the strain variable into two. In tests with load lower than the proportional limit, the expression for calculation is the Hooke's law. For stresses higher than σ_p the stress-strain curve is not linear. Therefore, we can define Eq. (1) $\dot{\varepsilon}$

$$\varepsilon = (\varepsilon^r + \varepsilon^{ir}); \varepsilon^r = \sigma / E \longrightarrow \varepsilon^{ir} = \varepsilon - (\sigma / E) \tag{1}$$

Where ε^r and ε^{ir} are the reversible and irreversible strain respectively. It can be observed that $\varepsilon^r = 0$ when the load $\sigma = 0$. Besides that, $\varepsilon = \varepsilon^r$ when $\sigma < \sigma_p$.

3. RESULTS AND DISCUSSIONS

3.1. Strain-rate dependency

Table 2 presents the PM test results for all strain rates.

Table 2: PM test results

$\dot{\varepsilon} = 1.25\times10^{-3}$ s^{-1}			
Specimens	E (GPa)	σ_p (MPa)	σ_{max} (MPa)
1	3.23	14.31	26.77
2	3.90	15.58	27.66
3	3.56	14.96	26.08
Average	3.57	14.85	26.77
$\dot{\varepsilon} = 1.25\times10^{-2}$ s^{-1}			
Specimens	E (GPa)	σ_p (MPa)	σ_{max} (MPa)
1	3.89	21.47	30.16
2	3.91	22.82	30.66
3	3.62	22.56	29.82
Average	3.81	22.22	30.20
$\dot{\varepsilon} = 1.25\times10^{-1}$ s^{-1}			
Specimens	E (GPa)	σ_p (MPa)	σ_{max} (MPa)
1	3.70	24.08	33.31
2	3.72	28.08	34.45
3	4.22	27.08	35.19
Average	3.88	26.36	34.13

Analyzing table 2 we can observe that some properties are affected by strain-rate. As strain-rate increases, the modulus of elasticity, E, proportional stress, σ_p and maximum stress, σ_{max} also increase. Figure 2 displays the average curves of polymer mortars for each strain rate.

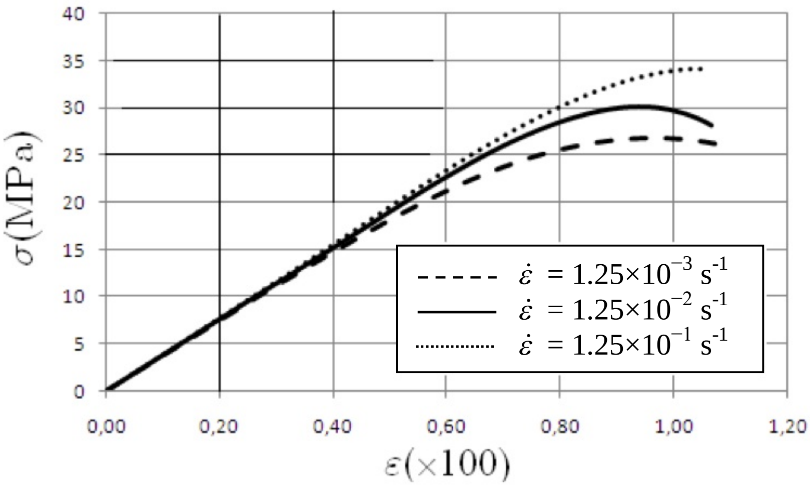

Figure 2 – Average stress-strain curves for all strain rate levels tested

It can be seen from fig. 2 that polyester polymer mortars are extremely strain-rate dependent. It is important to observe that for the lower strain-rate, $\dot{\varepsilon}$ = 1.25×10^{-3} s^{-1}, there is no variation in the stress-strain curve. Therefore, the average curve obtained at this strain-rate will be considered the limit curve, as it is similar to stress-strain curves for lower strain-rates. The initial behavior is linear, or proportional ($\sigma = E\varepsilon$). The modulus of elasticity has very small variation when strain-rates are increased, but this slope variation can be explained by the results variation. In this case, it is reasonable to consider that stress-strain behavior in the proportional phase is purely elastic; the viscoelastic behavior or strain-rate dependency can be neglected in the proportional phase. Otherwise, the proportional stress and maximum stress have a significant strain-rate dependency.

The curve σ x ε^{ir} can be obtained using equation 1. This curve allows us to obtain interesting information on the load speed effect (materials viscosity), eliminating the purely linear slope. In fig. 3 are presented the σ x ε^{ir} associated to average curves σ x ε, showed in fig. 2. For each average σ x ε, a corresponding σ x ε^{ir} was calculated until σ_{max} was reached.

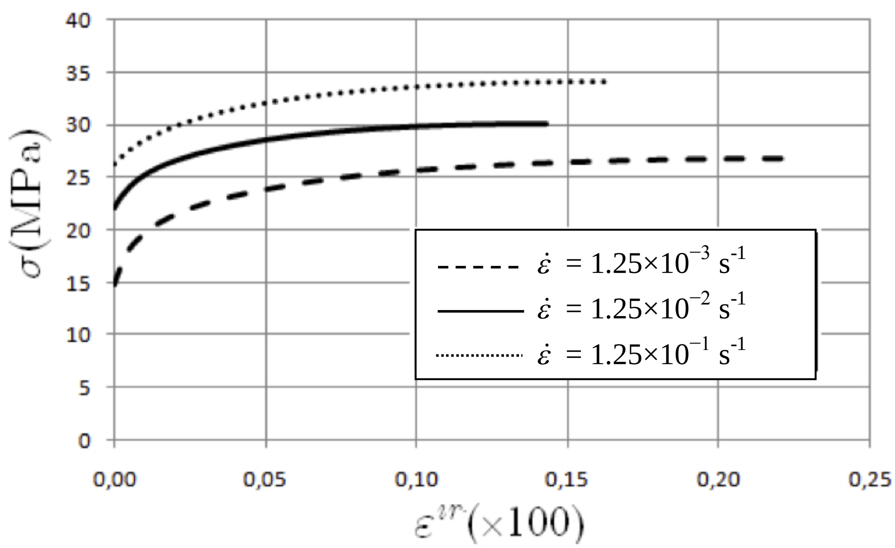

Figure 3 – σ x ε^{ir} curves for each strain rate tested

It is possible to observe from fig. 3 the effect of the strain rate in the test: the σ x ε^{ir} curves for strain rates $\dot{\varepsilon}$ = 1.25×10^{-2} s^{-1} and $\dot{\varepsilon}$ = 1.25×10^{-1} s^{-1} are similar to the curve for strain rate $\dot{\varepsilon}$ = 1.25×10^{-3} s^{-1} except for a vertical translation which is dependent of the applied strain rate.

4. CONCLUSIONS

From the experimental test results we can conclude that:

- The stress vs. strain curves varies for strain rates lower than $\dot{\varepsilon}$ = 1.25×10^{-3} s^{-1}
- Strain rate has no significant effect in the modulus of elasticity
- The influence of the strain rate in the maximum stress and proportional stress is significant.

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5. RESPONSIBILITY NOTICE

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