Rheological Behaviour of Lightweight Concrete with Embedded EPS Beads

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A rheological study was performed in order to appreciate the compatibility of the expanded polystyrene beads with the concrete matrix. In order to prepare homogeneous dispersions of the expanded polystyrene (EPS) in the cement paste, the EPS beads were first surface pre-treated with carboxymethylcellulose (CMC), intending to achieve the compatibility between the hydrophilic concrete matrix and the hydrophobic polystyrene beads. In this study, the mass fractions of aggregates, cement and water were maintained constantly for all the probes and it was checked the influence of two parameters: the EPS mass fraction and the CMC concentration. The study was performed with EPS mass fractions between 0.0028 – 0.0041 and with CMC – water solutions having concentrations between 0.5% - 2% (mass). The results showed that CMC can achieve the compatibility between concrete and EPS and that within a 2% CMC solution an important amount of EPS beads can be incorporated.

Keywords: lightweight concrete, expanded polystyrene, concrete rheology

The cement based composites [1-10] are an important class of building materials. These products are made of hydrated cement paste that binds together wood, particles or fibers for the pre cast concrete products. Wood and natural fibers are materials that contain different soluble organic compounds, like carbohydrates, glycosides and phenols. These compounds are well known as mortar retardants. Therefore, before using any admixture to obtain cement based composites, the compatibility between cement and aggregates must be established. In order to determine the compatibility, various methods based on different properties can be used, for example measuring the hydration properties of the cement – aggregate mixtures [11-16], comparing the mechanical properties of the mixtures and the visual evaluation of the micro structural properties [17-21].

Using limestone and slag (a ferrous metallurgy by-product) as fillers and keeping the same composition of cement as in a standard recipe, the mechanical resistance for medium and long time can be improved, fact that is favored by the hydro compounds forming as a result of the slag slowly hydration [8]. The cement composites filled with limestone and slag which contain a smaller quantity of cement are characterized by a slower set than the reference cement. Also the compression strengths of the cement composites with limestone and slag as fillers are smaller than the reference cement, as a consequence to the cement dilution [2].

A very interesting concrete composite for commercial application is the lightweight concrete based on expanded polystyrene (EPS) [4,7,17,22]. Expanded polystyrene, which is stable low density foam that consists of discrete air voids in a polymer matrix, has a series of excellent properties such as low density, high specific strength and low water adsorption. It has been used in building industry to produce lightweight concrete or mortars for thermal insulation [23-29]. Moreover, EPS has low electromagnetic parameters [30] and it can be used to adjust the parameters of the cement composite. When coated by a layer of cement, the EPS beads can scatter part of the incident wave on its surface, so the EPS filled cement composites can be looked as a kind of "porous" composite materials.

The lightweight concrete can be obtained by total or partial replacement of the standard aggregate with low molecular mass components and, preferable, having a low price. The interest is to reduce the volume of the components and, at the same time, to increase the thermal properties compared to the usual concrete [17,23,26]. A bright idea is to achieve the thermal insulation and the structure of resistance with the same material and this could suppress the thermal bridges that are present on the usual constructions.

Among different lightweight concrete types obtained in the previous years [4,22], the one obtained by mixing cement matrix with expanded polystyrene spheres is interesting for many reasons. First of all, the component's mixture can be prepared on the construction site. Another reason is that the concrete properties can be varied by choosing the size and the volume fraction of the EPS particles.

It is expected that the properties of the new concrete composite depends on the compatibility between the hydrophobic EPS beads and the hydrophilic inorganic concrete matrix. The present study intends to appreciate the compatibility of the expanded polystyrene beads with the concrete matrix by the rheological method, when a compatibility agent, namely carboxymethyl cellulose was used. The basic idea was that the rheology of a mixture is highly related with the system interactions and therefore with the compatibility.

Experimental part

The concrete matrix contains aggregates, cement and water. EPS beads have poor affinity with cement matrix and they have very low densities. When EPS beads are mixed with cement, the EPS beads will float at the surface

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No.	Mass fraction	Aggregates	Cement	Water	EPS	CMC
1	B1	0.612	0.204	0.184	0	0
2	B2	0.610	0.203	0.183	0.0037	0
3	B3	0.610	0.203	0.110	0.0037	0.073
4	B4	0.610	0.203	0.110	0.0037	0.073
5	B5	0.610	0.203	0.110	0.0037	0.073
6	B6	0.610	0.203	0.110	0.0037	0.073
7	B7	0.610	0.203	0.110	0.0041	0.073
8	B8	0.610	0.203	0.110	0.0033	0.073
9	B9	0.611	0.204	0.110	0.0028	0.073

Table 1
Used recipes

of the cement paste and so cause segregation. In order to make homogeneous dispersion of the EPS particles in the cement paste, the EPS beads were first surface pre-treated with carboxymethylcellulose (CMC) aqueous solutions. In this manner, it was intended to achieve the compatibility between the hydrophilic concrete matrix and the hydrophobic polystyrene beads.

The concrete matrix was separately prepared by mingling dry aggregates with cement. This dry mixture was then mingled with the wet polystyrene beads and only after that the water was added.

The mass fractions of aggregates, cement and water were maintained constantly for all probes and it was checked the influence of two parameters: EPS mass fraction and CMC concentration. EPS mass fractions ranged between 0.0028 – 0.0041 and CMC – water solutions had concentrations between 0.5 - 2% (mass percent).

The recipes for prepared composites are listed in table 1.

The rheological behaviour of the lightweight concrete was assessed on a Rheotest 2 device (Germany) having coaxial cylinders. We have to mention that all the rheograms were drawn based on the mean readings' values because for the heterogeneous mixtures the reading value oscillates in an interval.

Results and discussions

At the beginning, the rheological behaviour for two standards, named B1 and B2, were characterized. The first standard (B1) consisted in a concrete matrix without EPS, having only aggregates, cement and water in the proportions 3:1:0.9. The second standard (B2) contains the same concrete matrix as B1 and, additionally, an amount of EPS which, due to his small weight, does not modify the mass fractions of the main compounds. The B2 standard does not contain any CMC solution for compatibility.

From figure 1a it appears the pseudo plastic behaviour of the B1 standard. Increasing the shear rate and then decreasing it, the hysteresis phenomenon appears. The hysteresis loop is composed of two curves that appear for time dependent viscous fluids. When the time effect is reversible, then the phenomenon is called "elastic hysteresis". In figure 1b, as in all the following figures, hysteresis is not elastic. The hysteresis in figure 1b shows that the rheological behaviour of B1 standard is thixotropic. The thixotropic behavior can be explained by successive breakings, in time, of some structural bindings and creating of new ones, the fluid drifting to a new equilibrium, with respect to the new stress value.

It is worthy to note that the concrete paste appears to have a yield stress at 30 Pa, but the behaviour is not of a pseudoplastic thixotropic fluid, with yield stress, but of a "fake yield stress fluid", according to [34]. Some materials, known as fake fluids, present a yield stress smaller than the initial one when the shear rate is decreasing upto 0. These fluids need a much longer time to return at the initial yield stress.

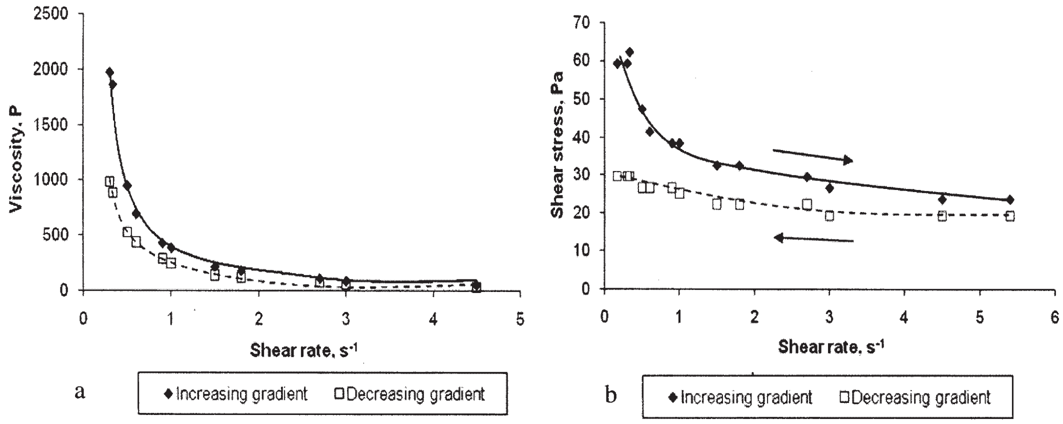

Fig. 1. Rheological behaviour for B1 sample (simple concrete)

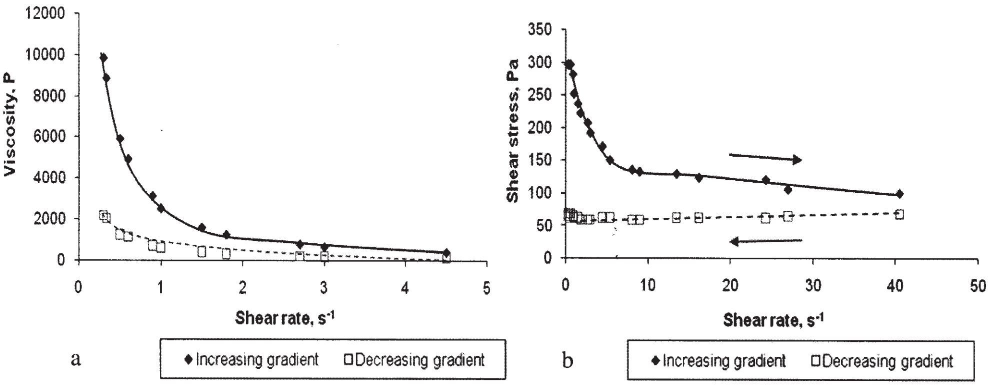

Fig. 2. Rheological behaviour for B2 sample (concrete with 0.0037 parts EPS, without compatibility agent)

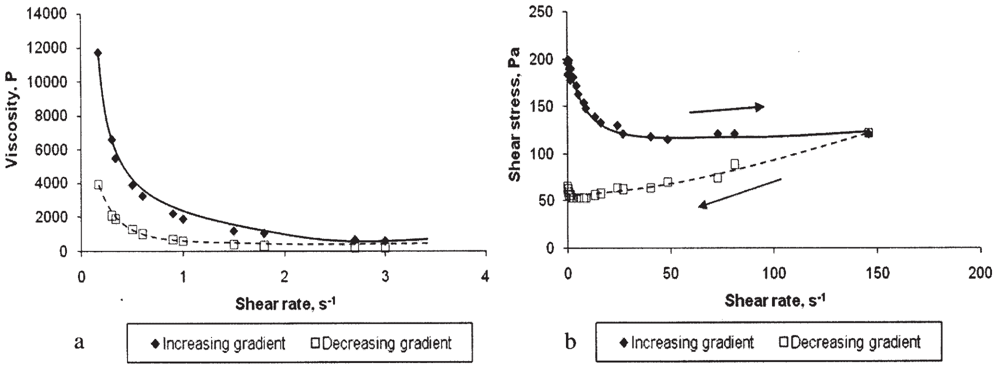

Fig. 3. Rheological behaviour for B3 sample (concrete containing 0.0037 parts EPS treated with 0.073 parts of 2 % CMC solution)

Figure 2 presents the rheological behaviour of B2 standard in the same conditions, at increasing and decreasing shear rate.

The first observation, when comparing figures 1a and 2a, is that in the small shear rates range, the EPS – concrete system (B2 standard) has a higher viscosity. This phenomenon is due to the polystyrene beads which could form conglomerates with the aggregates, cement and water. These conglomerates are ground at higher shear rates and generate an increase of viscosity. The viscosity increasing mechanism at big shear rates can be explained by the fact that the same solvent has to cover a bigger specific area as a result of vigorous mixing. Figure 2b relieves a bigger fake yield stress (close to 70 Pa, relative to 30 Pa for B1). Moreover, the initial flow stress is somewhere around 300 Pa for B2 standard and around 70 Pa for B1 standard. A higher flow stress means a higher initial viscosity.

Variation of CMC concentration

Keeping constantly the initial proportions between main compounds as in standard B2, the first checked parameter, namely the CMC concentration, was varied. Four CMC solutions with the following concentrations where used: 2, 1.5, 1 and 0.5%.

The rheological behaviour of an EPS – concrete sample (B3) with a 2% CMC solution is shown in figure 3. The B3 sample keeps the pseudoplastic thixotropic behaviour (fig. 3a), with fake flow stress (fig. 3b), as the previous samples (B1 and B2). The initial flow stress is around 200 Pa, value that places the viscosity of this sample between the B1 standard (simple concrete matrix) and B2 standard (concrete matrix + EPS). The conclusion is that the CMC solution for compatibility had created bonds between concrete and polystyrene, making this mixing to be more homogenous.

By treating the EPS beads with the 1.5% CMC solution (B4 sample), the figure 4 resulted. The pseudoplastic thixotropic behaviour of the lightweight concrete is maintained (fig. 4a), but the shear stress – shear rate dependence has modified (fig. 4b), suggesting that some changes in the mixture structure occurs. The viscosity of this sample is higher that the others.

B5 sample was obtained by impregnating EPS beads with 1% CMC, the rheological behaviour being represented in figure 5. The viscosity variation (fig. 5a) takes place on a wider shear rate range (2 – 8 s^{-1}), comparing to 0 – 1 s^{-1} for B4 sample, or 0 – 0.5 s^{-1} for B3 sample. The viscosity is smaller (2000 P), comparing to sample B4. The shear stress curves (fig. 5b) recover the aspect observed for B2 and B3 samples

B6 sample was obtained by impregnation of EPS beads with 0.5% CMC, the rheological behaviour being represented in figure 6a and figure 6b. The differences compared with the previous sample (B5 with 1% CMC) are insignificant, the rheological behaviour being almost identical.

By modifying the compatibility solution concentration in the range of 0 – 2%, some conclusions can be drawn regarding this parameter. The CMC concentration has important influences on viscosity and shear stress behavior through time and shear rate.

For small CMC concentrations of the compatibility agent solution (0.5% and 1%), the rheological behaviour is similar with the behaviour in the absence of the agent, making them uninteresting for practical applications.

By impregnation of EPS beads with 1.5% CMC, the pseudoplastic thixotropic behaviour of the lightweight concrete is maintained, but the mixture is very viscous, which makes it hard to mould and useless for practical applications.

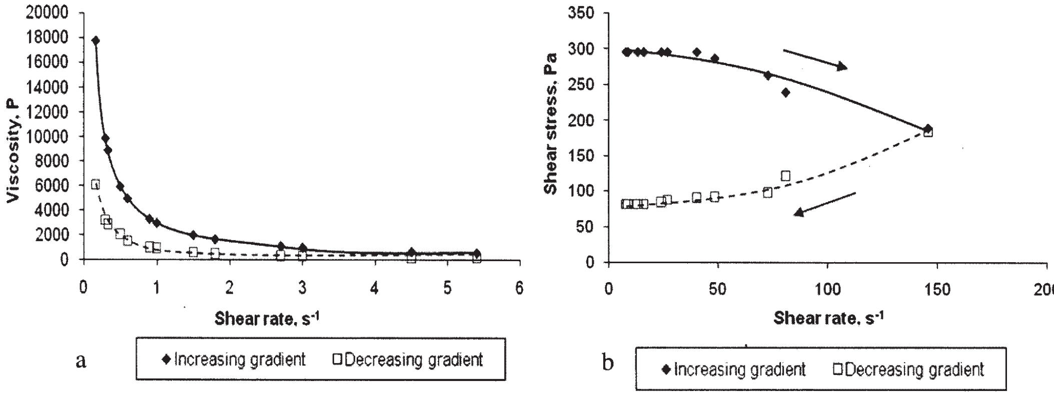

Fig. 4. Rheological behaviour for B4 sample (concrete containing 0.0037 parts EPS treated with 0.073 parts of 1.5 % CMC solution)

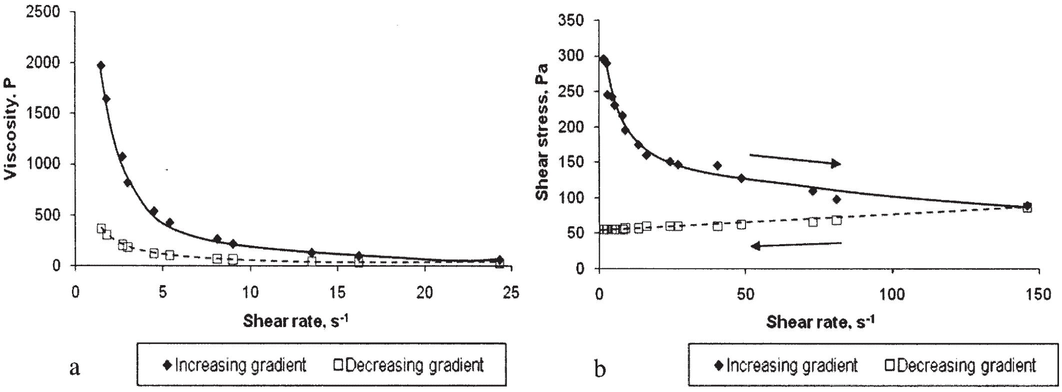

Fig. 5. Rheological behaviour for B5 sample (concrete containing 0.0037 parts EPS treated with 0.073 parts of 1 % CMC solution)

B3 sample (with 2% CMC concentration in solution) has a flow stress around 200 Pa, the viscosity is acceptable and can be recommended for practical applications.

The variation of the EPS fraction

B3 sample (fig. 3) had a polystyrene mass fraction of 0.0037, and the compatibility solution concentration was 2%. The samples B7, B8 and B9 kept the same 2% CMC concentration, but the EPS mass fraction was different.

The B7 sample contains the highest EPS fraction used in this study (0.0041) and the rheological behaviour is presented in figure 7. The range of variation for shear rate is 0 – 10 s^{-1}, after 10 s^{-1} the graphic becoming linear (quasi Newtonian) (fig. 7a). B7 sample has the maximum of variation for the viscosity between 1 and 3 s^{-1} comparing with the B3 sample's viscosity which decreases rapidly between 0 – 0.05 s^{-1}. The fake yield stress is 50 Pa (practically identical with B3) and the flowing stress is 300 Pa (fig. 7b) bigger than B3 (200 Pa).

B8 sample has an EPS fraction of 0.0033 and the rheological behaviour is presented in figure 8. The viscosity has the maximum of variation between 1 – 3 s^{-1}, decreasing rapidly from 1500 P until 400 P (fig. 8a). The fake yield stress is 50 Pa (practically identical with B3) and the flowing stress is 160 Pa (fig. 8b) smaller than B3 (200 Pa).

B9 sample has the smallest EPS fraction of 0.0028 and its rheological behaviour is presented in figure 9. The figure 9a shows that the pseudo plastic character lasts till about 15 s^{-1} and the fake yield stress is 56 Pa (practically identical with B3) and the flowing stress is 160 Pa (fig. 9b) smaller than B3 (200 Pa) and identical with the sample B8.

Comparing all these results, some conclusions could be drawn: the addition of EPS into the concrete matrix, even at the smallest mass fraction of EPS (B9 sample), produced an increasing of shear stress, the initial flow stress being at 160 Pa, relative to 60 Pa in the case of B1 standard – concrete matrix without EPS.

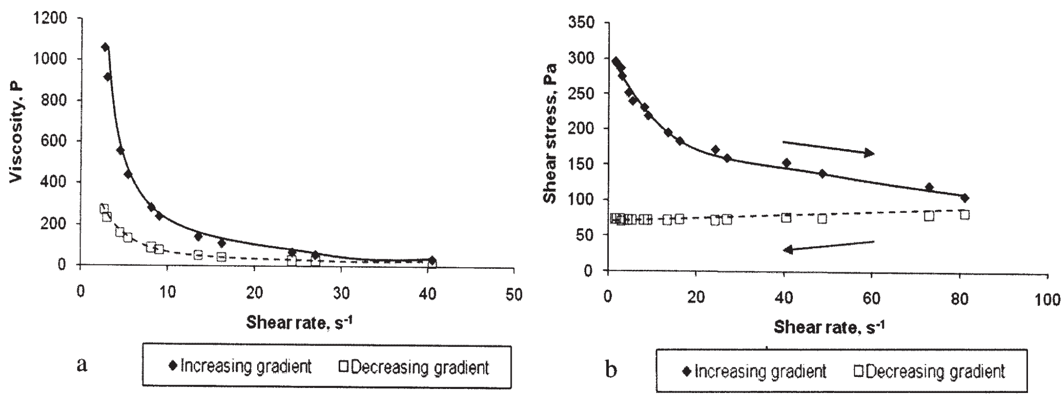

Fig. 6. Rheological behaviour for B6 sample (concrete containing 0.0037 parts EPS treated with 0.073 parts of 0.5 % CMC solution)

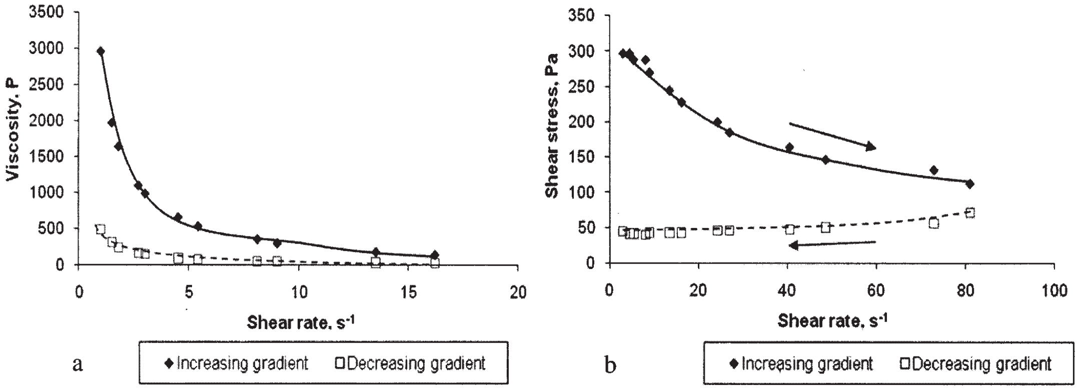

Fig. 7. Rheological behaviour for B7 sample (concrete containing 0.0041 parts EPS treated with 0.073 parts of 2 % CMC solution)

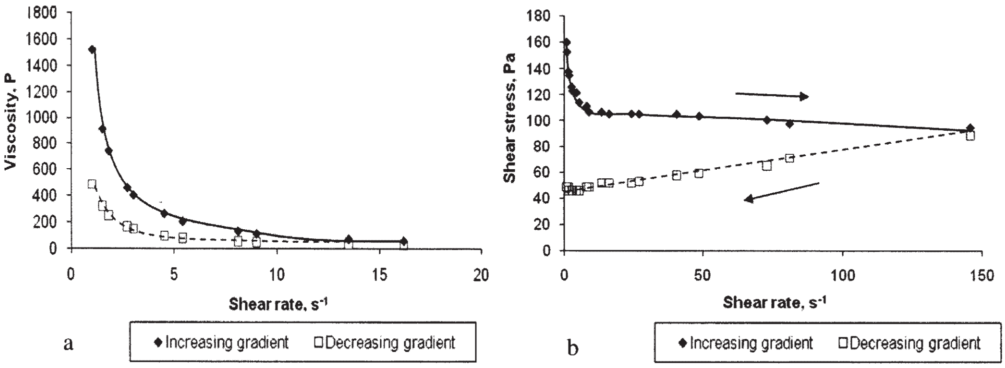

Fig. 8. Rheological behaviour for B8 sample (concrete containing 0.0033 parts EPS treated with 0.073 parts of 2 % CMC solution)

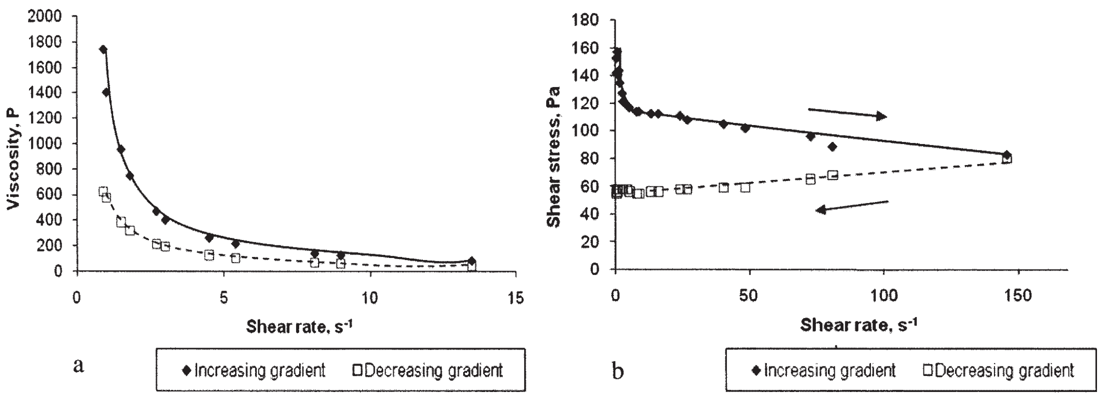

Fig. 9. Rheological behaviour for B9 sample (concrete containing 0.0028 parts EPS treated with 0.073 parts of 2 % CMC solution)

As the EPS fraction is increasing, the viscosity also increases and the flow stress grows to 200 Pa for B3 sample and 300 Pa for B7 sample.

Conclusions

The CMC concentration has important influences on viscosity and shear stress dependences function of time and shear rate. For small CMC concentrations of the compatibility agent solution (0.5 and 1%), the rheological behaviour is similar with the behaviour in the absence of the agent, making them uninteresting for practical applications.

The sample with 2% CMC concentration in solution has a flow stress around 200 Pa, the viscosity is acceptable and it can be recommended for practical applications.

The addition of EPS into the concrete matrix, even at the smallest mass fraction of EPS (B9 sample), produced an increasing of flow shear stress. As the EPS fraction is increasing, the viscosity also increases and the flow stress grows. The results showed that CMC can change the system interactions and in this manner could achieve the compatibility between concrete and EPS.

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