Mechanical properties of structural concrete containing very fine aggregates from marble extraction industry sludge

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Extended abstract

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1) Introduction

1.1) Preliminary remarks

The problems in the natural resources exploitation field are an emerging theme in the last decades and require increasing attention, with a growing number of organizations and countries that seek to draw awareness and alert the population to the problems originated by the uninterrupted exploitation of these resources. Every year large amounts of wastes are produced in the regions of Estremoz, Borba and Vila Viçosa, evaluated in 80-90% of the extracted rock. The construction sector is one of the largest consumers of natural resources, generating large amounts of waste. It is therefore increasingly important to seek solutions for the consumption of these wastes in order to satisfy their increasing extraction and to reduce the resulting environmental impacts. The use of the wastes originated from the marble dumps in the production of structural concrete is therefore justified. In order for this alternative to be validated in the construction sector it is necessary to ensure the quality and safety of concrete made with sludge from the marble extraction industry and to understand their behaviour and performance.

Regarding this problem there have been made several investigations that studied the behaviour of concrete made with added waste marble sludge as cement or sand replacement such as the ones by Hebhoub *et al.* (2011), Topçu *et al.* (2000), Almeida (2004) and Binici *et al.* (2007). These studies have shown that the use of sludge from the marble extraction industry (SME) in concrete proved to be an adequate method to reduce its increasing impact.

1.2) Scope and methodology of the investigation

Although a relatively extensive bibliography regarding this subject is available nowadays, the lack of experience in Portugal combined with the fact that little is known about the interaction between superplasticizers and SME have led to the present study. The objective is, therefore, to assess the use of SME in structural concrete by analyzing its mechanical properties, both in the fresh and hardened state. In the fresh state, workability and bulk density tests were made, while to evaluate the properties in the hardened state, compressive strength, splitting tensile strength, modulus of elasticity, ultrasonic pulse velocity and abrasion resistance tests were made. In order to carry out the experimental campaign, cubic and cylindrical specimens were prepared from twelve types of concrete, which can be grouped in three families, the first one with no adjuvant (B0), the second one with the incorporation of a current plasticizer (B1) and the third with the incorporation of a high-performance superplasticizer (B2). In all families, substitution ratios of 0%, 5%, 10% and 20% were used.

This investigation started with a bibliographical research on experimental programs with added waste marble sludge in concrete in order to summarize the most relevant properties of concrete with SME. The collected data indicated a constant decrease in the mechanical properties of concretes, as the replacement of cement with SME increased.

Afterwards, the experimental campaign was planned and carried out. Tests of the natural aggregates and SME were made. Concrete mixes without adjuvants, with a current plasticizer (SP1) and with a high-performance plasticizer (SP2) were produced and, for each type of adjuvants, four different substitution ratios, as shown previously. In order to have a coherent comparative basis, the tests performed in the concrete's fresh state sought to keep the workability constant in every specimen. After the curing period, tests were performed in the concrete's hardened state and were subsequently analysed in detail.

2) Experimental program

2.1) Materials

The natural aggregates used were river sand supplied by Grupo Soarvamil, and gravel supplied by Cimpor. The secondary aggregates were sludge from the marble extraction industry supplied by Solubema. The binder was CEM II 42.5R Portland, provided by SECIL cement works in Outão. Tap water was used.

2.2) Concrete design

According to Standard NP EN 206-1 (2007), the average compressive strength of concrete, tested in cubic samples, is approximately 37 MPa (C25/30). The workability class was set within the slump range 125 ± 10 mm. Table 1 gives the composition of all the concrete mixes produced.

Table 1 - Composition of the concrete mixes produced, per cubic meter

	BR	B0,5	B0,10	B0,20	B1,0	B1,5	B1,10	B1,20	B2,0	B2,5	B2,10	B2,20
Substitution rate (%)	0	5	10	20	0	5	10	20	0	5	10	20
Cement (kg)	350	332.5	315	280	350	332.5	315	280	350	332.5	315	280
Water (dm^3)	207.3	210.7	210.7	207.3	186.9	190.3	186.9	186.9	166.5	169.9	173.3	176.7
Fine sand (kg)	622.0	618.9	618.9	622.0	641.2	638.0	641.2	641.2	660.4	657.2	654.0	650.8
Coarse sand (kg)	326.4	324.7	324.7	326.4	336.5	334.8	336.5	336.5	346.6	344.9	343.2	341.5
Fine gravel (kg)	167.1	166.2	166.2	167.1	172.3	171.4	172.3	172.3	177.4	176.5	175.7	174.8
Gravel 1 (kg)	129.0	128.3	128.3	129.0	132.9	132.3	132.9	132.9	136.9	136.3	135.6	134.9
Gravel 2 (kg)	548.3	545.5	545.5	548.3	565.2	562.4	565.2	565.2	582.1	579.3	576.5	573.7
SME (kg)	0	15.4	30.7	61.4	0	15.4	30.7	61.4	0	15.4	30.7	61.4
Plasticizer (kg)	0	0	0	0	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
w/c ratio	0.54	0.55	0.55	0.54	0.48	0.49	0.48	0.48	0.42	0.43	0.44	0.45
Slump (cm)	12.5	12.6	12.3	12.3	11.8	13.1	12.5	12.3	13.7	12	12.5	12.7

2.3) Testing of aggregates

The aggregates were characterized according to the following tests and standards:

- Sieve analysis - NP EN 933-1 (2000) and NP EN 933-2 (1999);
- Bulk density and water absorption - NP EN 1097-6 (2003);
- Apparent bulk density - NP EN 1097-3 (2003);
- Shape index - NP EN 933-4 (2002) (coarse aggregates only);
- Los Angeles abrasion test - LNEC E237 (coarse aggregates only).

2.4) Testing of fresh concrete

The tests carried out in fresh concrete and the standards used were the following:

- Slump test (Abrams cone) - NP EN 12350-2 (2009);
- Bulk density - NP EN 12350-6 (2009).

2.5) Testing of hardened concrete

The following tests, and corresponding standards, were carried out in hardened concrete:

- Compressive strength at 7, 28 and 56 days – NP EN 12390-3 (2011);

- Splitting tensile strength at 28 days - NP EN 12390-6 (2011);
- Modulus of elasticity at 28 days - LNEC E-397 (1993);
- Ultrasonic pulse velocity - NP EN 12504-4 (2004);
- Abrasion resistance - DIN 52108 (2008).

3) Experimental results and discussion

This section contains the results and analysis obtained through the experimental program.

3.1) Properties of aggregates

3.1.1) Natural aggregates

The test results for natural aggregates are presented in Table 2. The table contains the results of water absorption (WA_{24}), particles bulk density (ρ_a), particles dry density (ρ_{rd}), particles saturated surface-dried density (ρ_{ssd}), apparent bulk density (ρ), Los Angeles coefficient (Δ LA) and particle shape index (SI).

Table 2 - Test results for natural aggregates

	WA_{24} (%)	ρ_a (kg/m^3)	ρ_{rd} (kg/m^3)	ρ_{ssd} (kg/m^3)	ρ (kg/m^3)	Δ LA (%)	SI (%)
Gravel 2	2.35	2715	2552	2612	1314.6	27.99	14
Gravel 1	2.06	2775	2625	2679	1297	27.83	17.1
Fine gravel	1.21	2749	2661	2693	1336.7	-	17.9
Coarse sand	0.97	2469	2411	2434	1591.5	-	-
Fine sand	0.09	2566	2560	2563	1619.2	-	-

3.1.2) Sludge from the marble extraction industry

The tests on sludge from the marble extraction industry (SME) were performed at the facilities of the Civil Engineering Nacional Laboratory (LNEC) because, due to their fineness, the characterization of these aggregates had to be performed in specialized laboratories, according to different standards. The tests performed and the corresponding standards were the following:

- Bulk density and Blaine specific surface - NP EN 196-6 (2010);
- Apparent bulk density - NP EN 1097-3 (2002);
- Sieve analysis - EN 933-10 (2009);
- Chemical composition - NP EN 196-2 (2006) and LNEC E 406 (1993);
- Mineralogical composition - LNEC E 403 (1993).

The results of these tests can be seen in Tables 3, 4 and 5.

Table 3 - Bulk density, Blaine surface and apparent bulk density of the SME

Bulk density (g/cm^3)	Blaine surface (cm^2/g)	Apparent bulk density (kg/m^3)
2.73	2150	1.1

Table 4 - Sieve analysis of the SME

Size grading (mm)	Cumulative passing material (%)
2.000	84.2
0.125	27.5
0.063	16.8

Table 5 - Chemical composition of the SME

L.O.I (%)	Ins. R (%)	SO_3 (%)	Cl^- (%)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	Na_2O (%)	K_2O (%)	CaO (%)	MgO (%)
42.6	1.8	< 0.1	< 0.01	1.39	0.32	0.14	< 0.04	< 0.06	54.2	0.64

In terms of the mineralogical composition, the predominant compound was calcite. Taking into account the results shown in Table 4, it is important to notice that the fineness of the SME is not the expected one, and this will have repercussions on the mechanical properties of concrete, since the void filling effect will not be as significant. However, this improves the innovative component of the present work.

3.2) Properties of fresh concrete

3.2.1) Workability

Table 6 shows the slump test results and the water/cement (w/c) ratio of each concrete mix produced.

Table 6 - Slump test results and water/cement ratio

	BR	B0,5	B0,10	B0,20	B1,0	B1,5	B1,10	B1,20	B2,0	B2,5	B2,10	B2,20
w/c ratio	0.54	0.55	0.55	0.54	0.48	0.49	0.48	0.48	0.42	0.43	0.44	0.45
Slump (cm)	12.5	12.6	12.3	12.3	11.8	13.1	12.5	12.3	13.7	12	12.5	12.7

Table 6 shows that, in terms of workability of concrete, there was no need to significantly change the w/c ratio as the ratio of SME as cement replacement increased, in order to maintain similar levels of workability. It can also be noticed that the w/c ratio was significantly reduced due to the addition of plasticizers and that reduction was increasingly bigger as the water reduction power of the plasticizers increased, as expected.

3.2.2) Bulk density

Figure 1 shows the bulk density of fresh concrete as a function of the aggregate substitution ratio. It also shows that the incorporation of SME in concrete has a small influence on the bulk density in the fresh state. The incorporation of plasticizers leads to an increase in bulk density. This occurs due to a decrease in concrete porosity, as a result of a reduction in the w/c ratio.

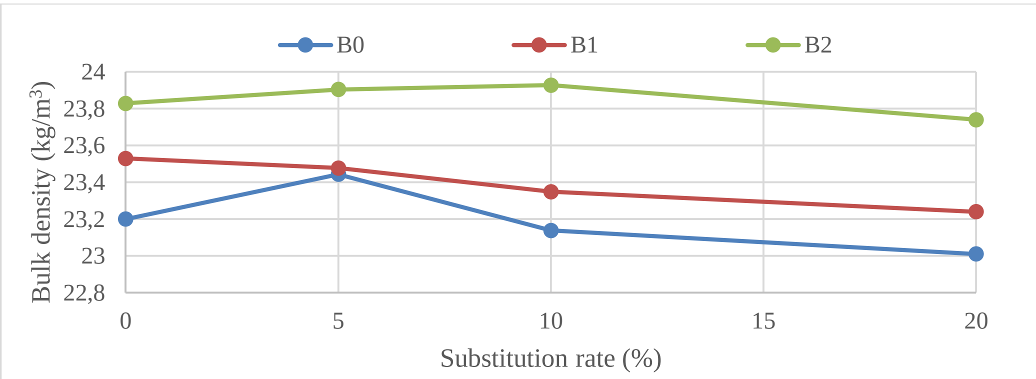

Figure 1 - Bulk density of fresh concrete

3.3) Properties of hardened concrete

3.4.1) Compressive strength

The results of the concrete compressive strength test at 28 days are shown in Figure 2. The control mixes (B0, B1,0 and B2,0) registered average values of 39.2 MPa, 47.1 MPa and 51.4 MPa, respectively.

The results show that the compressive strength has a decreasing trend with the increase of the substitution ratio. At 28 days, reductions of 28.6%, 26.8% and 29.2% were registered in concrete without adjuvant, with a current plasticizer and with a high-performance plasticizer, respectively.

It is also noticed that the use of plasticizers leads to an increase in compressive strength that is greater the higher the water reduction power of the adjuvants. Maximum increases of 26.7% and 39.10% were registered in concrete made with a current plasticizer and a high-performance plasticizer, respectively. Similar results were obtained by Aliabdo (2013) and Ergün (2009).

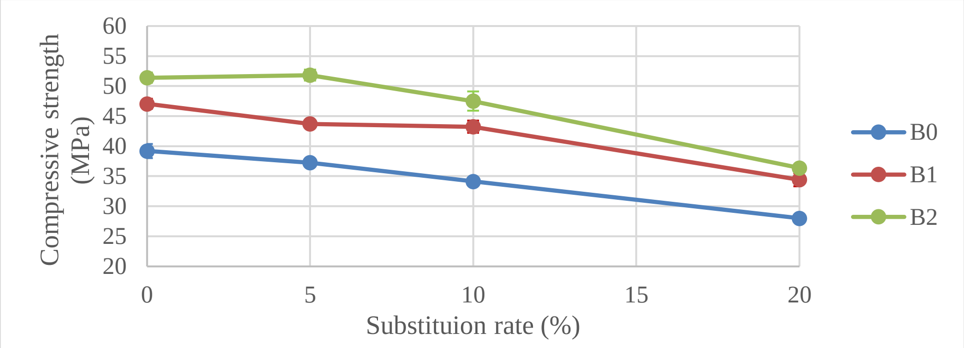

Figure 2 - Compressive strength (at 28 days)

The results also showed that mixes with SP2 had the higher variation of relative compressive strength followed by those made without plasticizer, which have similar values. The mixes with SP1 were the ones that registered the lowest relative loss in compressive strength.

Figure 3 shows that the evolution of the compressive strength of concrete with sludge from the marble extraction industry follows a similar trend to that of the conventional concrete. In both the increase in compressive strength is greater at earlier ages than later on, as expected.

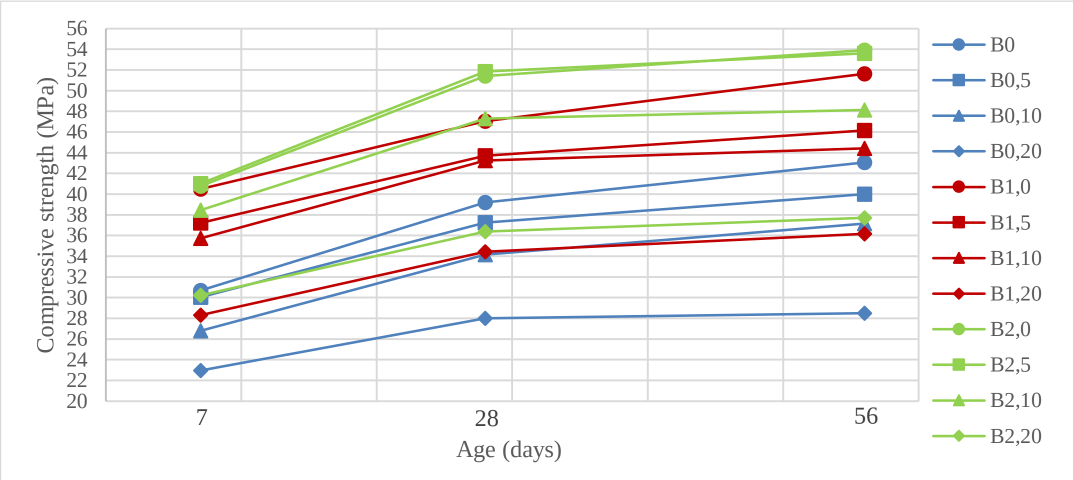

Figure 3 - Evolution of the compressive strength for the various mixes

3.4.2) Splitting tensile strength

The results of the splitting tensile strength, as a function of the SME content ratio, are presented in Figure 4. To make these results in absolute values, the values for the control mixes (B0, B1,0 and B2,0) are 3 MPa, 3.1 MPa and 3.6 MPa, respectively.

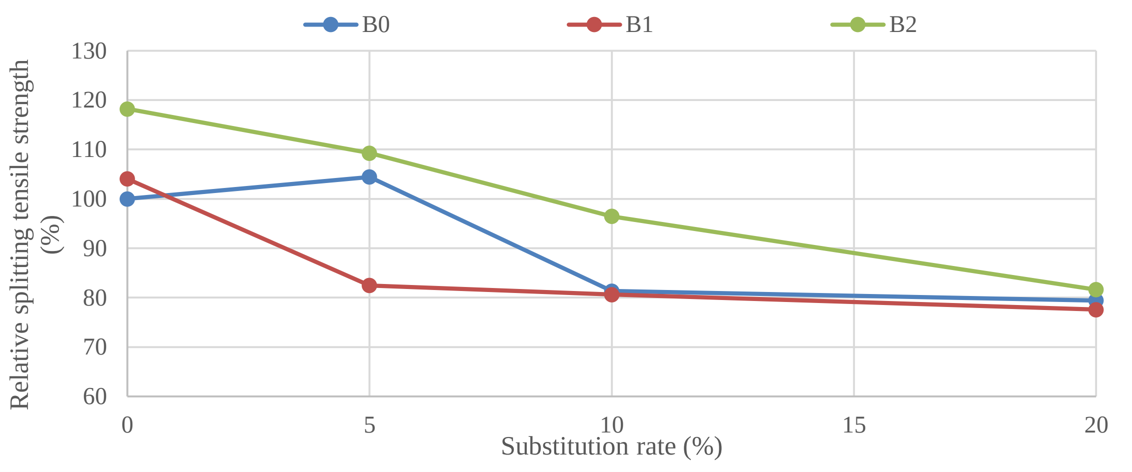

Figure 4 - Splitting tensile strength (at 28 days)

As Figure 4 shows, as the ratio of SME increases, splitting tensile strength decreases. At 28 days, reductions of 20.6%, 25.5% and 30.9% were registered in the B0, B1 and B2 mixes, respectively. The use of high-performance plasticizers allowed considerable increases of this parameter, topping at 18.6%, while the effect of SP1 plasticizers was not as noticeable. It was also seen that the splitting tensile strength test was the one that presented more variability. This can be explained by the fact that, in this test, the load was distributed along a given transversal section of the cylindrical specimen, which can have weaker zones, leading to a precocious rupture.

3.4.3) Elasticity modulus

Figure 5 shows the results of the elasticity modulus test. In order to determine the absolute values, the values for the B0, B1,0 and B2,0 mixes are 35.8 GPa, 38.8 GPa and 40.9 GPa, respectively. The elasticity modulus was not highly affected by the SME ratio. There were reductions of 8.1%, 10.3% and 7.0% for the B0, B1 and B2 mixes. It was also seen that the use of plasticizers allowed increases of this property, due to the reduction of the concrete porosity.

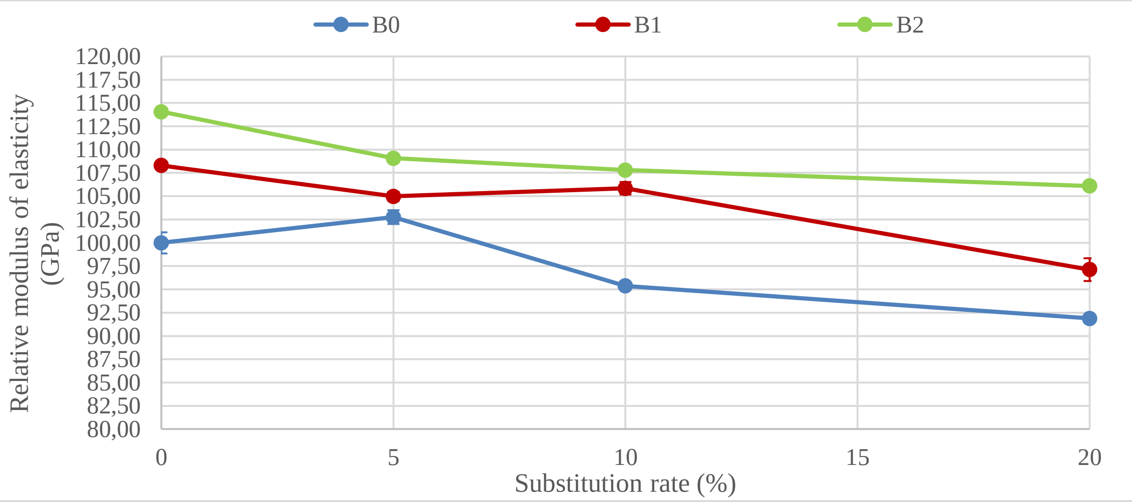

Figure 5 - Elasticity modulus (at 28 days)

3.4.4) Ultrasonic pulse velocity

Figure 6 shows the results of the ultrasonic pulse velocity (UPV) test. This figure shows that the use of SME as cement replacement leads to a decrease in the UPV. However, this decrease is minor. The decrease in this property is due to the fact that the SME are less fine and also have less effect in the promotion of hydraulic reactions when compared to the cement particles. It was also noticed that the UPV is hardly affected by the incorporation of plasticizers.

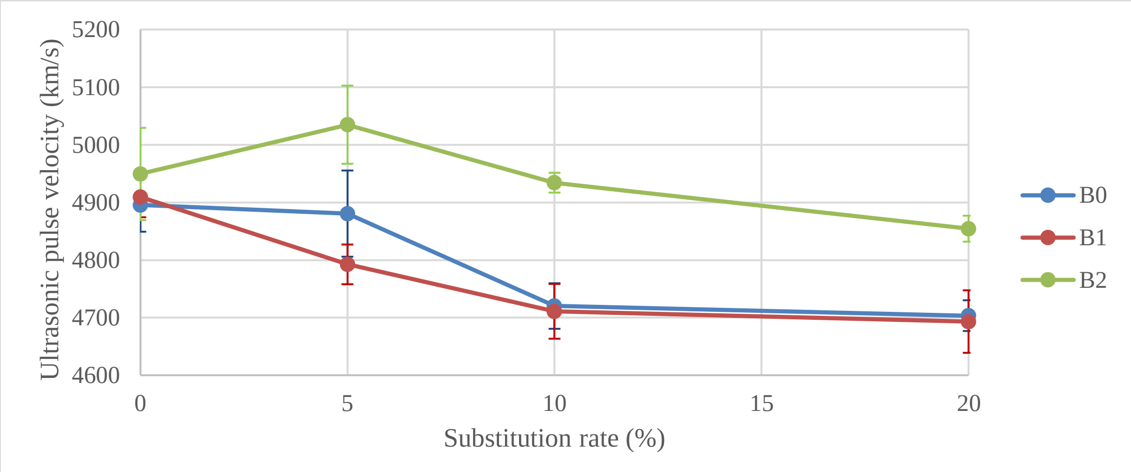

Figure 6 - Ultrasonic pulse velocity (at 28 days)

3.4.5) Abrasion resistance

The results regarding the abrasion resistance test are shown in Figure 7. It shows that the abrasion resistance decreases with the incorporation of sludge from the marble extraction industry, registering decreases of 61.1%, 47.08% and 42.53% for the B0, B1 and B2 mixes, respectively. However, it was also noticed that this loss in abrasion resistance was not substantial for substitution ratios up to 10%. The use of plasticizers leads to an increase in abrasion resistance allowing reductions of the wear depth by abrasion of 11.94% and 16.08% for SP1 and SP2 type plasticizers, respectively.

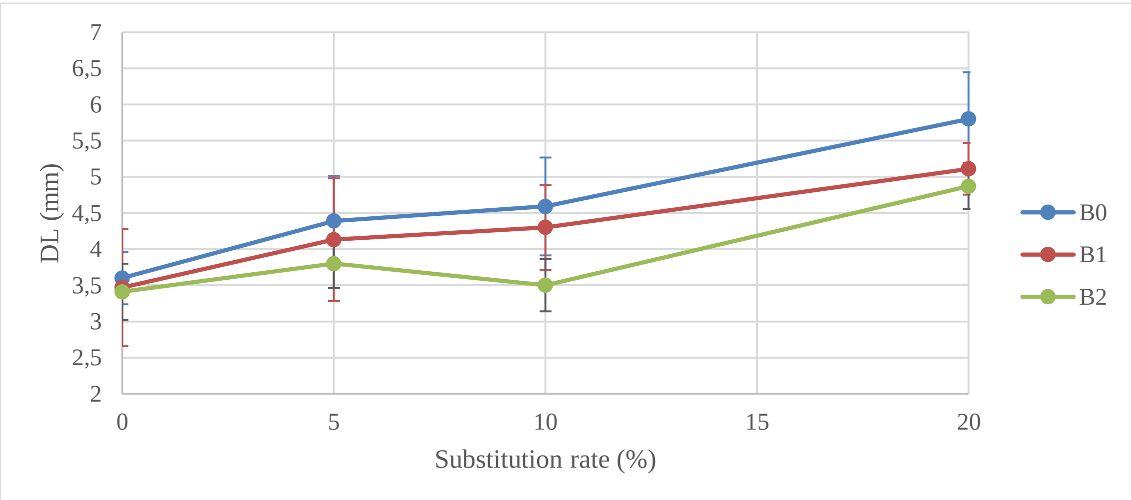

Figure 7 - Abrasion resistance

4) Conclusions

In general, concrete made with SME as cement replacement showed worse mechanical performances when compared to the control mixes. However, concrete with SME can be produced with sufficient quality for structural application with substitution ratios up to 10%. The following conclusions can be drawn:

- Compressive strength is affected by the incorporation of sludge from the marble extraction industry. As the substitution ratio increased a decrease in the compressive strength of concrete families was noticed. The use of plasticizers allowed an increase of the compressive strength of all concrete families;
- Splitting tensile strength shows similar results to those of compressive strength. An increase in SME leads to a decrease in splitting tensile strength. In this case, high-performance plasticizers allowed an increase in tensile strength whereas the effect of ordinary plasticizers was not noticed;
- Elasticity modulus is not considerably affected by the incorporation of SME, registering minor losses. Mixes with SP2 registered the best performance, followed by those with SP1. This is due to a reduction of the w/c ratio, which leads to a decrease in porosity;
- Ultrasonic pulse velocity decreases were registered with the incorporation of SME, due to the lack of capacity that these particles to promote hydraulic reactions, when compared with cement particles. However, these decreases were basically insignificant. Also, the use of SP2 and SP1 plasticizers did not lead to significant variations in UPV.
- Abrasion resistance showed a significant decrease with the incorporation of SME. However, this loss of abrasion resistance was not noticed for substitution ratios up to 10%. The use of SP2 and SP1 plasticizers allowed an increase in abrasion resistance, mostly due to their water reduction power.

From a general perspective, the incorporation of sludge from the marble extraction industry yielded good results. A slight decrease of the mechanical properties of concrete was observed, especially at high substitution ratios, but this does not compromise the use of this sludge in structural concrete. It was also seen that plasticizers can be used to offset the losses resulting from the incorporation of sludge from the marble cutting industry.

5) References

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