Utilization of Waste Marble Dust and Blast Furnace Slag in Steel Fiber Reinforced Self Compacting Concrete

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Abstract

Self-compacting concrete (SCC) is considered as a concrete which can be placed and compacted under its self weight with little or no vibration without segregation or bleeding. It is used to facilitate and ensure proper filling and good structural performance of restricted areas and heavily reinforced structural members. It has gained significant importance in recent years because of the advantages it offers. SCC was developed in Japan. Researchers have found that the use of mineral admixtures such as fly ash and blast furnace slag could increase the workability of the concrete mix without increasing its cost, while reducing the dosage of superplasticizer needed to obtain similar slump flow compared to concrete made with Portland cement only. The waste marble dusts obtain by different methods or cutting process of marble in marble manufacturing companies. However, some environmental problems occur during the uncontrolled spill of these waste materials in habitat. During sawing, shaping, and polishing process, about 25% of the processed marble turns into dust or powder form. Turkey has 40% of the total marble deposits in the world such that 7,000,000 tons of marble have been produced in Turkey annually and 75% of it has been processed in nearly 5000 processing plants. The other waste used in this study is ground garnaulated balast furnace slag (GBFS) which is the by-product of iron industry. Slag is a mineral admixture that has a chemical composition very close to the one of cement and relatively constant. In the world, there is about 250 million tonnes of slag generated per year. Out of which only 90 million tones are used in the production of concrete.

The use of any of these mineral admixtures could increase the fluidity of the concrete and may reduce the requirement of superplasticizer necessary to obtain a similar slump flow compared with the same concrete containing cement only. In this study the physical and mechanical properties of steel fiber reinforced SCC produced with marble dust and blast furnace slag was investigated. Utilization of marble dust and GBFS as mineral filler material in SCC mixtures increased the cohesiveness of the fresh concrete. Due to the pozzolanic effect of GBFS the strength properties of hardened composite specimens were increased with improved flowability.

Keywords: *Self compacting concrete; Steel fiber; Marble dust; Blast furnace slag*

INTRODUCTION

Self-compacting concrete (SCC) is considered as a concrete which can be placed and compacted under its self weight with little or no vibration without segregation or bleeding. It is used to facilitate and ensure proper filling and good structural performance of restricted areas and heavily reinforced structural members (Siddique 2013). After more than 20 years of development initiated in Japan in late 1980s, the use of SCC in building industry is quite common at present. The main benefits from using SCC in building structures consist in shortening the construction period and thus increasing productivity, assuring compaction in the structure (particularly in confined zones where it is difficult in general) and so enhancing the construction quality and eliminating noise due to vibration which leads to substantial improvement of the working environment on site (Vejmelková et al. 2011).

The most important two basic property of SCC are higher consistency due to the usage of fine powder materials with superplasticizer and high segregation resistance of the fresh concrete (Felekoğlu et al. 2006). The powder generally consists of a combination of Portland cement with one more additions such as limestone powder, pulverized fuel ash, ground granulated blast furnace slag (GBFS) and/or condensed silica fume (microsilica), therefore strength tends to be governed as much by the type and proportion of powder addition than by the water/powder ratio (Domone, 2007). Preliminary studies carried out as part of a major European research project on SCC suggested that fine limestone powder could be used effectively in SCC. The SCC mixes containing fine limestone powder showed good fresh properties, higher than expected

compressive strength and excellent surface finish. It is not certain, however, if different types and finenesses of $CaCO_3$ powders could offer similar benefits to SCC (Zhu & Gibbs 2005).

That large amounts of raw materials are required particularly in the construction industry, road construction, the construction of waste storage areas, and concrete manufacture makes recycling and the use of sustainable materials significant. For this purpose, utilizing industrial waste provides not only prevention of environmental pollution caused by waste but also contribution to the national economy by using industrial waste in the construction industry. Such industrial wastes as marble dust (MD), molding sand, fly ash, GBFS, phosphogypsum, glass dust and sewage sludge are wastes that are environmentally harmful but contribute to national economy if they are recycled. Because of increasing enterprises with the development of marble sector, utilizing marble wastes has been the agenda. MD is left to nature in the form of aqueous sludge at the end of cutting process. When MD is uncontrollably left to nature, it damages to the environment because of these causes that marble waste reduces water filtering capacity of the soil, prevents the development of vegetation, fills stream beds and contaminates water resources (Fig. 1).



Figure 1. Environmental pollution of MD

In this study, it is aimed that MD wastes will be able to provide benefits to the economy and the environment by using it for SCC production. According to Topçu et al. (2009) investigate the effect of MD as fine material on the fresh and hardened properties of SCC. In this study it is suggested that the optimum usage of MD in SCC mixture as 200 kg/m^3 content in order to obtain best performance for both of fresh and hardened properties of SCC. Gesoğlu et al. (2012) found that the increase in the amounts of MD and limestone filler increased the viscosity of the SCC mixtures. Uysal & Yılmaz (2012) suggested that incorporation of mineral admixtures reduced the cost per unit compressive strength of SCC mixtures, for all investigated cases. The reduction was approximately 0.1 \$/MPa/m^3 for MD used mixtures, which is the most economical mixture among the entire SCC series.

Steel fibers are widely used in concrete production. These fibers increase the flexural strength and toughness of the composite concrete. The fiber addition proved to be very effective in counteracting drying shrinkage of SCC, which is usually a great problem for this material, rich in powders and poor in the coarse aggregate fraction (Corinaldesi & Moriconi 2004). The addition of fibers into SCC may take advantage of its high performance in the fresh state to achieve a more uniform dispersion of fibers, which is critical for a wider and reliable structural use of fiber-reinforced cement composites (Ferrara et al. 2007). The addition of long steel fibers with crimped ends can however compromise the ability of the mix to flow smoothly through gaps in the reinforcement and to cause segregation of the fibers (Deeb et al. 2012). These facts must be considered before using steel fibers in SCC mixtures. In this study it is aimed to determine the fresh and hardened properties of SCC produced with MD, GBFS and steel fiber.

MATERIALS AND METHOD

The raw materials of SCC mixtures were obtained from different sources. A Portland cement cement, type CEM I 42.5 R was used as binder. Its Blaine fineness was 3641 cm^2/g and its density was 3.06 g/cm^3. The industrial by-products, FA and GBFS, were obtained from Kütahya Tunçbilek Thermal Power Plant and

Eregli Iron and Steel Factory, respectively. The MD was obtained from Bilecik marble manufacturing factories. The chemical composition of the powder materials are shown in Table 1. The MD and GBFS were sieved by 0.125 mm sieve before using in the SCC mixtures.

Table 1. Main oxide composition of powder materials

Oxide (%)	Material		
	Cement	GBFS	Marble Dust
SiO_2	19.96	41.61	0.62
Al_2O_3	5.03	11.84	-
Fe_2O_3	2.88	1.18	0.17
CaO	63.60	35.36	54.53
MgO	1.17	6.07	0.4111
Na_2O	0.27	0.81	0.6959
K_2O	0.80	0.56	0.0347
SO_3	2.79	0.12	0.0909
Cl^-	0.005	0.007	-

A polycarboxylate super plasticizer (Glenium C303) was used for improving the fluidity of the fresh SCC mixtures. Three different size of crushed limestone aggregates (0-5 mm and 5-12 mm) were used in reference and SCC mixtures. The gradation of the aggregate mixture can be seen in Fig. 2. The steel fiber in 0.55 mm diameter and 35 mm length were used in all concrete mixtures at constant 20 kg/m^3 dosage. In this study MD and GBFS were replaced in SCC mixtures at 10, 20, 30 % against the aggregate powder content below 0.125 mm sieve.

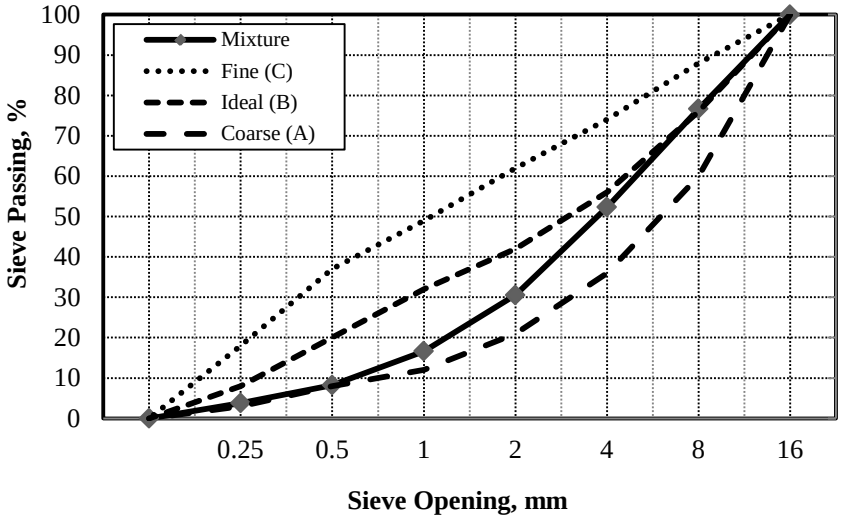


Figure 2. Gradation of the aggregate mixture

The mix proportions of the SCC mixtures were designed in accordance with the definitions in the EFNARC guidelines and TS EN 206. (Efnarc 2002; TS EN 206 2002). The mix designs of the SCC specimens are shown in Table 2. The SCC mixtures were labeled according to the type of mineral admixture and utilization ratio. The water cement (w/c) ratio of the SCC mixtures were used as 0.52. After mixing process of the SCC specimens the workability was determined by T_{50}, flow test, V-funnel, J-ring and concrete rheometer tests (Fig. 3). After fresh concrete tests the mechanical properties of the SCC specimens were determined by compressive strength and flexural strength tests on 15x15x15 cm and 10x10x50 cm specimens respectively. The hardened unit weight and ultrasound pulse velocity tests also carried out on these SCC specimens in order to determine the homogeneity of the composite.



Figure 3. Viscosity and T_{50} test of SCC mixtures

Table 2. Mix design of concrete specimens

Specimen Type	Amount, (kg/m^3)						
	Cement	Water	Sand	5-12mm Crushed Stone	Powder	Plasticizer	Steel Fiber
MD 10	380	200	888	850	62	7	20
MD 20	380	200	826	850	123	7	20
MD 30	380	200	770	850	180	7	20
GBFS 10	380	200	888	850	62	7	20
GBFS 20	380	200	826	850	123	7	20
GBFS 30	380	200	770	850	180	7	20

TEST RESULTS

Fresh Concrete Test Results

Consistency is an important property of SCC for achieving good workability. The superplasticizer is necessary for producing a highly fluid concrete mix, while the powder materials or viscosity agents are required to maintain sufficient stability/cohesion of the mix, hence reducing bleeding, segregation and settlement (Zhu & Gibbs 2005). The workability test procedure of SCC is different when compared with traditional concrete mixtures. Generally the test knowledge is based on flowing time from a specified cross section and flowing capability of the fresh mixture. The consistency test results of the fresh SCC mixtures are given in Table 3.

Table.3. Workability test results of SCC mixtures

Specimen Type	V-Funnel (sec)	T_{50} Time (sec)	J Ring		Flow Diameter (cm)
			Flow (cm)	Height (cm)	
MD 10	8	4	56	4	55
MD 20	11	5	59	3.5	59
MD 30	13	6	62	3.5	67
GBFS 10	8	4	60	3.8	58
GBFS 20	14	5	65	1.5	65
GBFS 30	22	5	67	1.3	70

According to V-funnel test results the flow time increased with the increase of MD and GBFS utilization ratio. The similar behavior can be seen from T_{50} flow time test results which are the elapsed time to gain the mean diameter of 50 cm. However, according to J-ring and flow table test the flow ability of the SCC mixtures increased with the increased MD and GBFS utilization ratios. The time reduction in GBFS used SCC mixtures reached 14 sec for GBFS 30 specimen. This behavior can be attributed to the fineness of the GBFS. The consistencies of the steel fiber reinforced SCC specimens were also determined by concrete rheometer test (Schleibinger Bt-2). Rheometer test results can be found in Fig. 4. According to test results it can be seen that the viscosity of the MD and GBFS used SCC mixtures reduced with the increase of the replacement ratio. It can be concluded that GBFS increase the fluidity of the fresh SCC than MD.

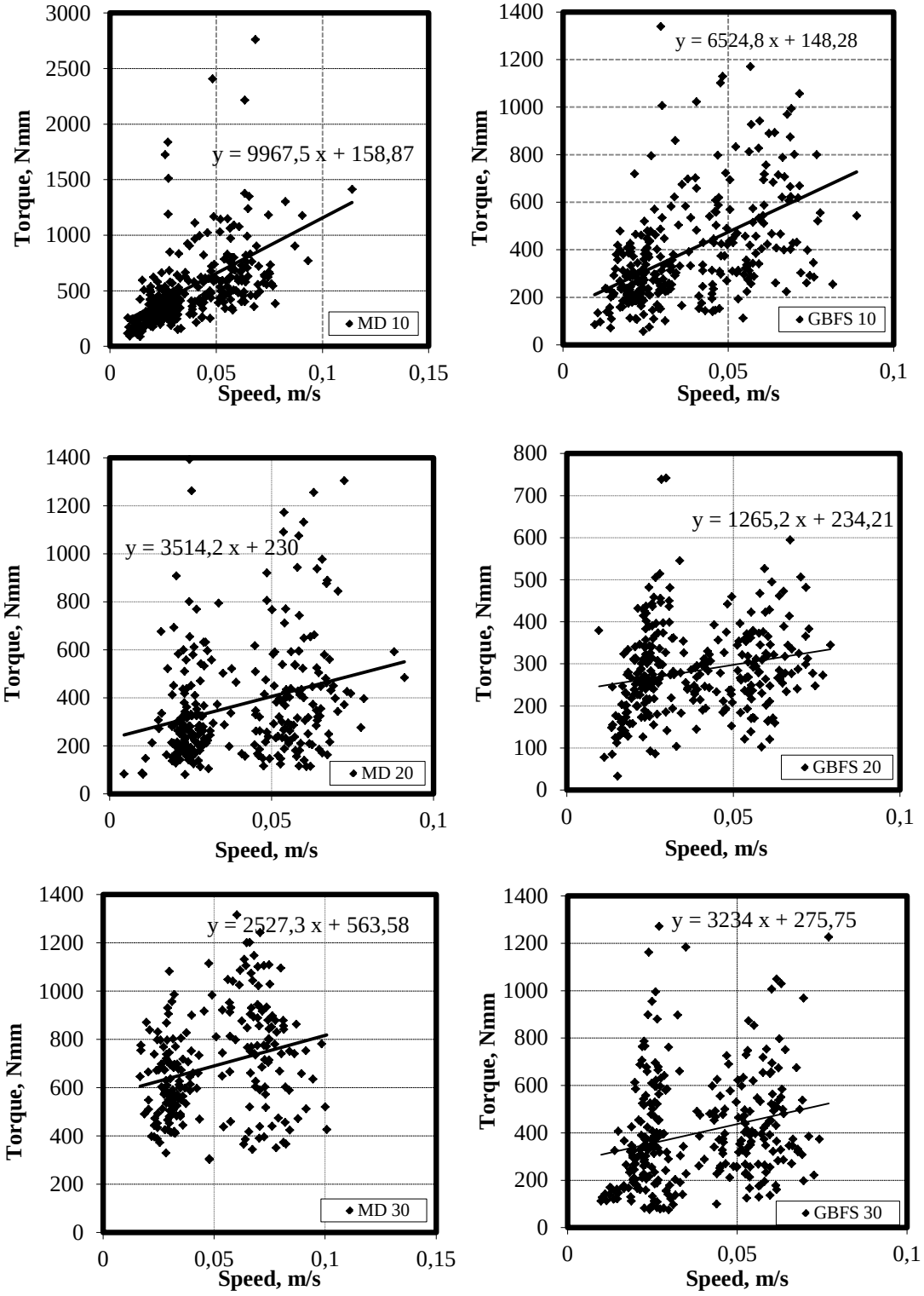


Figure 4. Rheometer test results of steel fiber reinforced fresh SCC

Hardened Concrete Test Results

The hardened unit weights of SCC test results are shown in Fig. 5. According to Fig. 4 the lowest unit weights were obtained from MD 10 specimens. The highest unit weights were seen on GBFS 10 specimens. This effect can be related with the higher density of GBFS when compared with MD. According to the results the unit weights were increased due to the increase of the MD and GBFS ratio. These results showed that the fine MD and GBFS filled the pores and the composite.

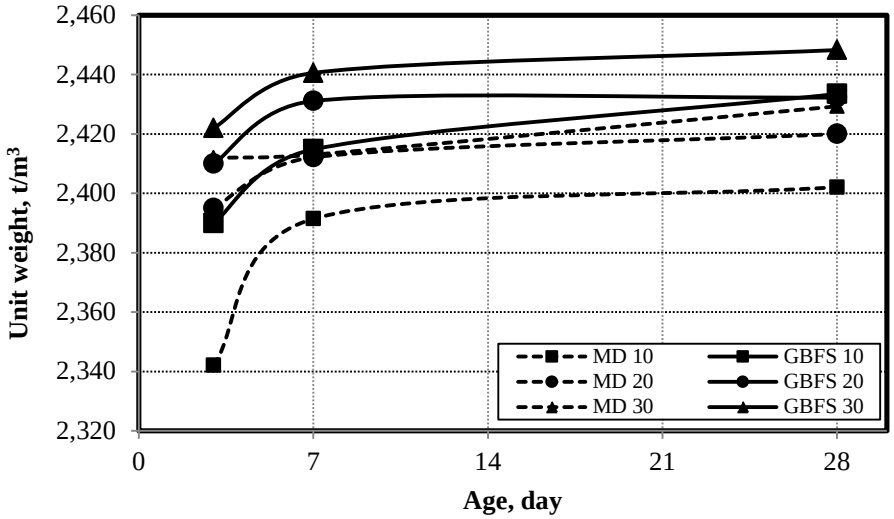


Figure 5. Unit weight test results of the hardened SCC specimen

The ultrasound pulse velocity (UPV) test results of the hardened SCC specimens are shown in Fig. 6. As seen from Fig.5 the UPV values showed similar results when compared with the unit weight results. All UPV values were increased with the increase of the SCC specimen age. The highest UPV values were obtained with the GBFS used SCC specimens. This behavior can be attributed to the increased compacity of the composite due to the pozolanic property of GBFS. The

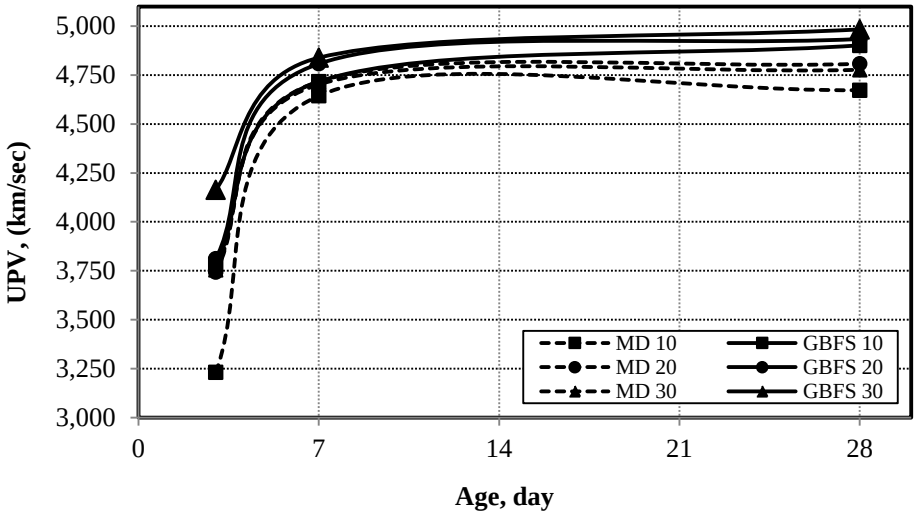


Figure 6. Ultrasound pulse velocity test results of the hardened SCC specimen

The mechanical properties of the SCC specimens were determined with compressive strength and flexural strength tests. Compressive strength test results of steel fiber reinforced SCC specimens are shown in Fig. 7. According to Fig. 6 compressive strength of the specimens are increased depending on the age of the SCC specimen. Early age strength development of both MD and GBFS specimens showed similar strength gaining behavior. The compressive strength of MD used SCC specimens test results varied between 45 to 50 MPa at 28 day. The strength results showed similar values with the increase of the MD ratio. These results showed that the increased replacement ratio of MD up to 30 % has no significant effect on the final compressive strength of the fiber reinforced SCC specimens. On the other hand, SCC specimens with GBFS

showed highest compressive strength values when compared with MD specimens. Especially GBFS 30 specimen's compressive strength reached 80 MPa at 28 day. According to these results GBFS has a beneficial effect on the final strength properties of fiber reinforced SCC. This behavior is related with the good pozolanic activity of the GBFS (Boukendakdji 2012; Karakurt & Topçu 2012).

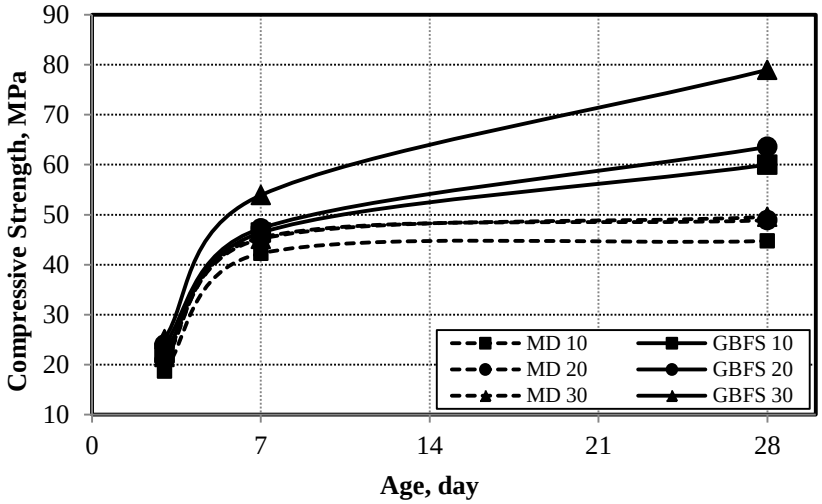


Figure 7. Compressive strength test results of the hardened SCC specimens

The flexural strength results of the SCC specimens are given in Fig. 8. Steel fiber is most effective on the bending and toughness properties of the concrete. Some studies mentioned that the addition of fibres has a slight decreasing effect on workability of SCC. It is also shown that the main influencing factor on workability is the geometry of long fibres rather than their strength (Akcay & Tasdemir 2012). According to Fig. 8 early age strength development of MD and GBFS specimens showed similar strength gaining behavior when compared with the compressive strength test results. The MD used flexural strength results of MD 10 and MD 20 specimens reached 7.5 MPa strength. Also these results are similar with GBFS flexural strength results. This effect can be related with the constant steel fiber utilization ratio in both types of mixtures. Flexural strength gaining of the specimens is primarily related with the steel fiber dosage in the composite. The highest flexural strength value (8.16MPa) was obtained with GBFS 30 like compressive strength results.

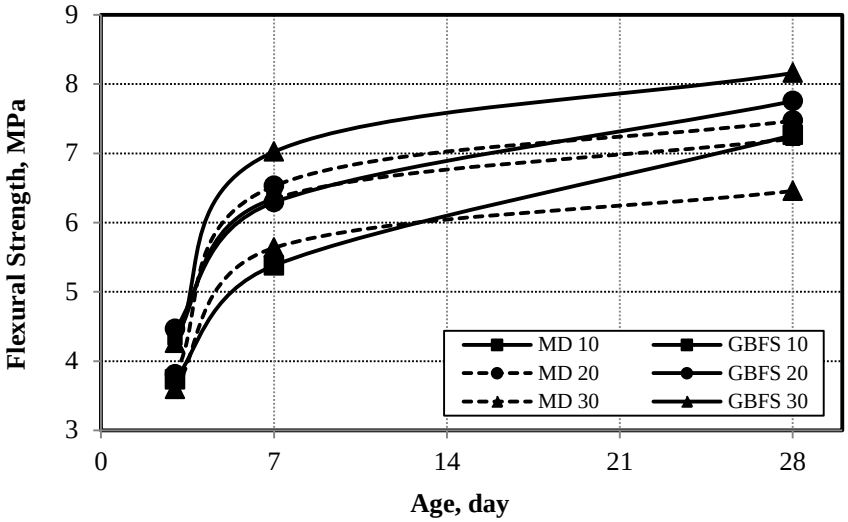


Figure 8. Flexural strength test results of the hardened SCC specimens

CONCLUSION

In this study 6 different types of fiber reinforced SCC mixtures were produced with the replacement of MD and GBFS against the filler content of the fine sand. The following conclusions can be drawn out depending on the presented test results of the study.

- According to the J ring and flow table test results. The flowability of the GBFS used SCC specimens is better than MD used mixtures. On the other hand, the rheometer test results showed that the viscosity reduction is higher in GBFS used SCC mixtures.
- The highest strength values were obtained with the MD 30 and GBFS 30 mixtures. This effect is related with the increased cohesion and compacity of the SCC composite.
- Utilization of steel fibers in SCC mixtures can reduce the workability of the mixture. This detrimental effect can be overcome by using MD and GBFS in steel fiber used SCC mixtures.
- Due to the fresh and hardened SCC test results, the performance of GBFS is better than MD in both cases. Especially the pozolanic property of GBFS increased the mechanical properties of the steel fiber reinforced SCC specimens.
- GBFS needs additional grinding process before utilization as mineral filler. This process increases the unit cost of this material. In addition GBFS becomes an economic material in the construction market. However, MD is not widely used and popular in the industry. Utilization of MD in construction industry as fiber reinforced SCC can be beneficial for waste management and environmental pollution which depends on this material.

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