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The Thermal Conductivity and Mechanical Properties of Waste Granulated Slag Aggregate Concrete

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Abstract

This study deals with the research of the use of the waste Ferrochromium slag as lightweight aggregate of concretes. These materials were examined whether they are used for lightweight aggregates instead of natural aggregates or not. Therefore, the granulated slag aggregate (GSA) was used to produce the waste lightweight aggregate concrete (WLC) in different rate instead of natural aggregate. To determine the effect of GSA ratio, different cement dosage on the some mechanical properties and thermal conductivities of concrete, 0%, 25%, 50%, 75% and 100% GSA ratios were used instead of normal aggregate by volume, 300, 400, 500 kg/m^3 cement dosages were used and 3±1cm slump was also used in this study. Some properties such as unit weights, thermal conductivities, compressive strengths and modulus of elasticity of these WLC obtained were compared to the some properties of the concrete by using sand. It was observed that the unit weights of the concretes produced by using the GSA were 17%-20% lower than those of the concretes by using normal aggregate (NA), being the thermal conductivity 1.95%-43.9% and the modules of elasticity as well as the compressive strengths were inversely changed with the increase of being used GSA ratio. The results indicated that the GSA can be safely used in the production of insulation concrete and semi lightweight concrete.

Keywords: Waste aggregate, Thermal conductivity, mechanical properties, granule slag aggregate, lightweight concrete

INTRODUCTION

Several generations of concrete aggregates have been developed with the aim of altering a wide range of plastic and hardened properties of concrete to achieve high-early-strength and high-performance concrete. Use of waste or artificial aggregates has allowed a dramatic reduction in the water-cementitious materials ratio (w/c) in the concrete mix, which in turn has resulted in sufficient strength, thermal conductivity and durable concrete. Significant research has also been done on the development and use of artificial and waste by-products aggregates, such as modified expanded polystyrene, granulated slag, and pumice, to replace or supplement the natural aggregate content in the concrete mixture. These materials have significantly improved the durability of concrete by reducing its permeability and unit weight.

The general class of lightweight aggregates encloses a wide range of products. From natural organic/mineral products (wood, cork, rice husk and products from volcanic source), to artificial products specially manufactured for the effect (expanded clay, shale or modified expanded polystyrene), as well as industrial sub-products and wastes (granulated slags and civil construction debris), a large spectrum of lightweight aggregates has been produced and/or applied in the last years for construction purposes. Lightweight aggregate is an important material in reducing the unit weight of concrete complying with special concrete structures of large high-rise buildings.

Industrial wastes, as a group, are probably the most widely reused of the waste materials generated. Granulated slag have been used as aggregates for base course, concrete, and asphalt; although only about one-half as many states have used it as have used GSA. These aggregates are used worldwide wherever they are readily available. Any applications other than in concrete require that the GSA be properly aged with water.

Non-ferrous slags are produced from the thermal processing of copper, lead, zinc, nickel, and phosphate ore. The majority of these smelters are in the eastern of the Turkey. Approximately 1.0 million tons of slag is produced each year, the majority of which is either iron or chrome slag. The slags are produced in either air-cooled or granulated form, and each contains some concentration of the metals from which they were produced.

Lightweight aggregate concretes are naturally utilized in structures in which major part of the total load is caused by the dead weight of concrete [1]. Obviously, it has economical and technical advantages over ordinary concrete, such as construction saving due to the reduction of dead weight, lower handling cost [1, 2]. Although structural LWAC is usually defined as a concrete with oven-dry density of no greater than 2000 kg/m^3, there are variations in certain parts of the world. For example, in the USA structural LWAC concrete is considered to be a concrete with on air-dry density of less than 1810 kg/m^3. In Japan, lightweight concretes do not specify any density values, and properties are only provided for concrete made with lightweight coarse and fine aggregates. In Europe, lightweight concrete is classified according to density [3].

A review of earlier investigation reveals that thermal conductivity of concrete increases with increasing cement content and type of aggregate [4,5,6]. Porosity and moisture content also have the maximum influence on the thermal conductivity. The thermal conductivity of rocks commonly used as aggregates in concrete, ranges from 1.163 to 8.6 W/mK [5, 6]. Mineralogical character of aggregate would greatly influence the thermal conductivity of concrete, because the thermal conductivity of rocks changes with its both composition and degree of crystallization. Basalt and dolerite have lowest thermal conductivity; granite genies, limestone and dolomite have intermediate, whilst quartzite and sandstone showed the highest thermal conductivity. This rock with crystalline structure show higher thermal conductivity than amorphous and vitreous rocks of the same composition [6, 7]. Thus, concrete made up of aggregate less thermal conductivity demonstrate less thermal conductivity whereas the more conductivity aggregate produces more conductive concrete [8, 9]. Aggregate type can cause nearly twice an increase in thermal conductivity of concrete, and concrete in moist state is 70% more than that of oven dried state [4, 8]. Since the thermal conductivity of crystalline silica is about 15 times that of amorphous [7], it is natural for the concretes with amorphous silica to have lower conductivity [10, 11]. The amorphous silica in the cement paste, which is the continuous phase in concrete taken as a composite, may also contribute to lower the thermal conductivity.

Taşdemir et al. [12] reported that blast furnace slag concretes tend to be weaker at early ages than ordinary Portland cement (PC) concretes, but at later ages they may have even or more strength than the ordinary PC ones. Reeves [13] have shown that in the use of blast furnace slag the heat of hydration is more slowly than ordinary PC. Thus, the rate of gain of strength is also more slowly than that of ordinary PC [14].

The main aim of this paper is to evaluate the possibilities of using this local source of waste slag as aggregate replacement normal aggregate (NA) in concrete by studying the effect of waste slag addition on compressive and splitting tensile strengths, modules of elasticity, thermal conductivity, unit weight and water absorption of WLC concrete produced from waste granule slag aggregate (GSA) which has different cement dosage. Very limited information is available about the effect of GSA on the thermal conductivity of concrete. There are some studies related to the effect of high volume lightweight aggregate on the mechanical properties of lightweight concrete, but the effect of high volume GSA on the thermal conductivity of concrete has not been reported previously. Thus, the effect of GSA on the thermal conductivity of concrete is also needs to be investigated.

MATERIALS and METHOD

GSA is a non-metallic material produced simultaneously with Ferrochrome in a blast furnace and which is then granulated by the rapid quenching process. It possesses latent hydraulic properties of its own which are activated by an alkaline material such as ordinary portland cement, thus producing additional cementitious materials.

In the production of concrete series, cement type of PC 32.5 was used. Waste granulated slag aggregate were obtained from Elazığ Ferrochromium Establishment and some physical properties were found out by primary tests. Natural aggregate were obtained from the Aras River in Erzurum, in Turkey. The natural sand was used 0-8 in size, specific gravity 2570, unit weight 1600 kg/m^3, fineness modulus 1.90 and water absorption in thirty minutes was 1%. The chemical composition and physical properties of the Portland cement and GSA used in this study are summarized in Table 1.

ASTM D75 and ASTM C 136 and C 29 were used for sampling, grading, unit weight and fineness modulus of aggregate. The compressive strength, splitting tensile strength and modulus of elasticity of the specimens determined in accordance with ASTM C 39, ASTM C 348 and ASTM C 469 at 28 day, respectively. To determine the effect of GSA ratio, different cement dosage on the some mechanical properties and thermal conductivities of concrete, (1) 0%, 25%, 50%, 75% and 100% GSA ratios were used instead of normal aggregate by volume, (2) 300, 400, 500 kg/m^3 cement dosages were used and (3) 3±1cm slump was also used in this study,(4) The water-cement ratio was kept constant as 0.55. GSA concrete mix proportion was given Table 2.

For each mixture, three samples of 150 mm diameter and 300 mm height cylinders and three samples of 250mm x 250mm x 50 mm prisms were prepared and stored in lime saturated water at 20 ±3 ^{0}C until the time of the testing. Specimens were removed from the moulds

Table 1. Chemical Analysis and Physical Properties of PC and GSA

Component		PC (%)	GSA (%)
SiO_2		17.69	20.43
Fe_2O_3		3.59	3.20
Al_2O_3		5.89	5.57
CaO		57.69	63.09
MgO		3.39	2.87
SO_3		2.57	2.38
K_2O		0.30	-
TiO_2		0.20	-
Sulphide (S^{-2})		0.17	-
Chloride (Cl^-)		0.04	-
Undetermined		0.42	0.73
Free CaO		0. 55	-
LOI		2.50	1.47
Specific gravity (g/cm^3)		3.08	2.40
Specific surface (cm^2/g)		3410	-
Remainder on 200-micron sieve (%)		0.10	-
Remainder on 90-micron sieve (%)		3.50	-
Compressive strength (MPa)	2 day	-	-
	7 day	21.6	-
	28 day	33.8	-

after 24 hours and they were kept in the curing tank for 28 days. With tests on hardened concrete unit weight, thermal conductivity, compressive and splitting strengths were determined. The prism specimens were dried at the age of 28 days in an oven at 110±10 ^{0}C and weighed at 24-h intervals until the loss in weight did not exceed 1% in a 24-h (ASTM C 332) for thermal conductivity. The specimens' surfaces were sandpapered before measuring their thermal conductivities. Cylinder specimens were tested for compressive strength in accordance with ASTM C 109 at 28 days curing period. For each curing period three samples were used to determine compressive strength. A Quick Thermal Conductivity Meter based on ASTM C 1113-90 Hot Wire Method was used to measure the thermal conductivity [15] The full details of the this method was given elsewhere [16,17,18].

RESULTS and DISCUSSIONS

After the experiments conducted on series of fresh and hardened concrete, properties for thermal conductivity and strength were determined. Changes in these properties were examined in relation with the

Table 2. Mix proportions of WLC

Mixtures	Dosage kg/m^3					Dosage kg/m^3					Dosage kg/m^3				
	300					400					500				
	GSA ratio (%)														
	0	25	50	75	100	0	25	50	75	100	0	25	50	75	100
w/c	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55	0.55
Water (kg/m^3)	164	165	166	166	167	218	220	220	222	223	272	274	275	276	277
Slump (cm)	2.5	2.5	3.0	2.5	2.0	3.5	3.5	3.0	2.5	2.5	2.5	3.0	3.5	3.5	3.0
GSA (kg/m^3)	-	235	502	748	968	-	202	481	758	955	-	166	414	716	869
Natural Aggregate (kg/m^3)	1585	1255	905	418	-	1460	1244	844	462	-	1360	1150	815	418	-

aggregate-volume ratio and the results were given in the figures below.

Dry unit weights

The variation of unit weight with the GSA ratio (at different dosage) of was presented in Fig. 1. It was observed that unit weights of the 28-day GSA concretes decreased with increasing GSA in the mixtures due to the lower specific gravity of GSA. The highest unit weight was 2112 kg/m^3 at specimens 0% GSA+100 % NA. The unit weights decreased with increasing GSA in the mixes. It was seen that the lowest oven unit weight value was 1396 kg/m^3 at 100%GSA+0%NA. A high amount of GSA as aggregate is known to decrease the concrete unit weight.

While the unit weight of concrete without GSA was 2110 kg/m^3, in consideration to the linear relation between GSA addition and unit weight, we observed a decline as much as 5-6% in unit weights. Such a difference was attributed to the fact that the specific gravity of GSA is much lower than that of natural aggregate.

Thermal conductivity

The relation between dry unit weight and thermal conductivity is shown in Fig. 2 and 3. These figures have showed the effects of oven dry unit weight and GSA (0%, 25%, 50%, 75% and 100% replacement of normal aggregate) on thermal conductivity. The following results were observed. GSA (replacement of NA) decreased thermal conductivity of GSA concretes. As can be seen in Fig. 2, thermal conductivity of GSA concretes increases with increasing unit weight and thermal conductivity of aggregate. GSA causes a decrease in the thermal conductivity. For 0%, 25%, 50%, 75% and 100% replacement of NA, dosage was 300 kg/m^3; the reductions were 1.95%, 5.10%, 18.89% and 21.44% compared to the corresponding control specimens, respectively. When dosage was 400 kg/m^3; the reductions were 15.76%, 24.73%, 24.86% and 25.54% compared to the corresponding control specimens, respectively. When dosage was 500 kg/m^3; the reductions were 32.5%, 42.76%, 43.67% and 43.9% compared to the corresponding control specimens, respectively (Fig. 3). This is because the density decreased with increasing GSA content. The low density of WLC by means of GSA is probably related to the higher air content [17, 19]. Additionally, Kan and Demirboğa [18], Gül et al. [20], Akman and Taşdemir [21] and Blanco et al. [22] also reported that the thermal conductivity, decreased due to the decreasing of concrete density. Sand increased thermal conductivity of concrete for 300, 400 and 500 kg/m^3 dosage and at 3±1cm constant slump. Chen et al. [23], reported that when they increased the volume fraction of nature sand from 30 to 50% in their study, the thermal conductivity of mixtures increased 16%.

Strength and water absorption

The evaluation of the mechanical and physical specification of WLC specimens for 0%, 25%, 50%, 75% and 100% GSA replacement of NA is shown in Table 3. Water absorption of concrete specimens increased 0.7%, 0.8%, 1.1%, 1.4% and 2.3% for 0%, 25%, 50%, 75% and 100% GSA replacement of NA, respectively. Thus, normal aggregate decreased water absorption of concrete specimens (see Table 3). Like other porous materials, water absorption of the GSA is usually higher than that of normal aggregates. To determine the strength of concretes with different aggregate ratios at the 28-day, compressive strength (Fig. 4), splitting tensile strength (Fig. 5) and elasticity modulus (Fig.6) of the specimens were measured. The compressive strength values were

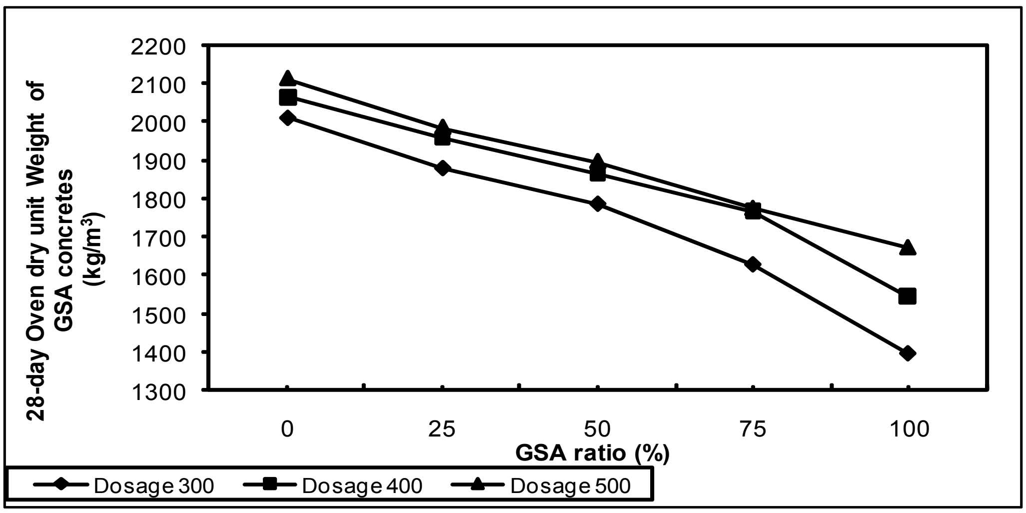

Figure 1. Relationship between GSA ratio and oven dry unit weight

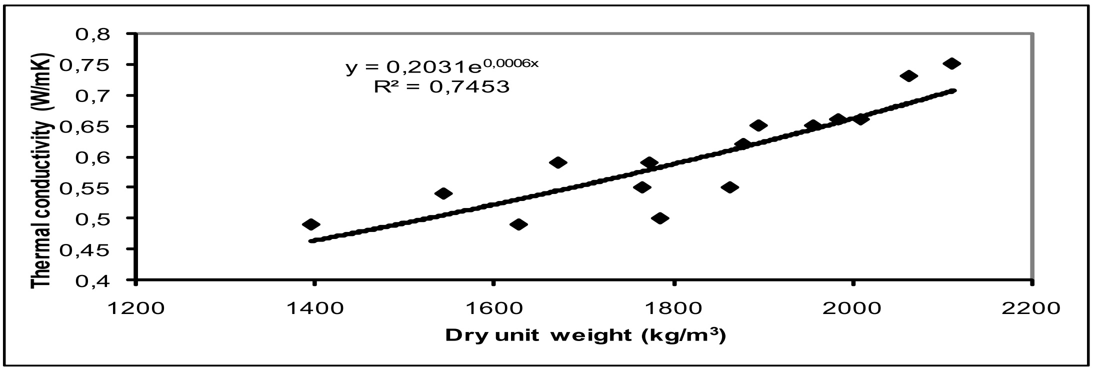

Figure 2. Relationship between oven dry unit weight of SGA concretes and thermal conductivity

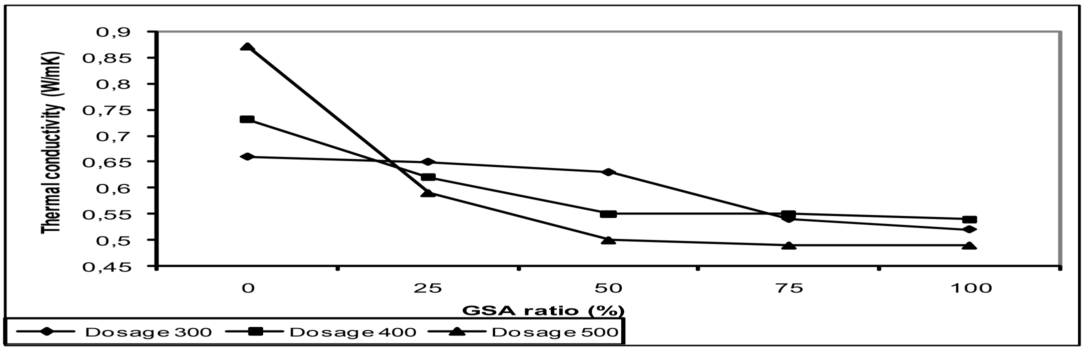

Figure 3. Relationship between GSA ratio and thermal conductivity of GSA concretes.

in the ranges of 34.5-5.2 MPa; the lowest value was belonging to the 100% GSA specimens which has 300 kg/m^3 dosage. The highest one was belonging to the 0% GSA control specimens which have 500 kg/m^3 dosages.

CONCLUSIONS

From the findings of the present work, the following conclusions can be drawn:

The density of concrete increased with the increase in cement dosage (keeping the slump constant at 3±1cm) and decreased with the increase in GSA ratios. Compressive strength, splitting tensile strength and elasticity module decreased with the addition GSA replacement of NA. GSA reduced compressive strength of concrete at all levels of replacement at 28-day. GSA decreased the density and thermal conductivity of the 28-day concrete specimens. The reduction in the thermal conductivity was between 1.95% and 43.9%. Natural sand also increased thermal conductivity of concrete specimens. The lowest thermal conductivity value was belonging to the 100% GSA specimens which has 500 kg/m^3 dosage. The highest thermal conductivity was belonging to the 0% GSA control specimens which have 500 kg/m^3 dosages.

Using GSA in concrete is an environmentally friendly process as it is too tough a material for nature to eliminate in an acceptable period of time.

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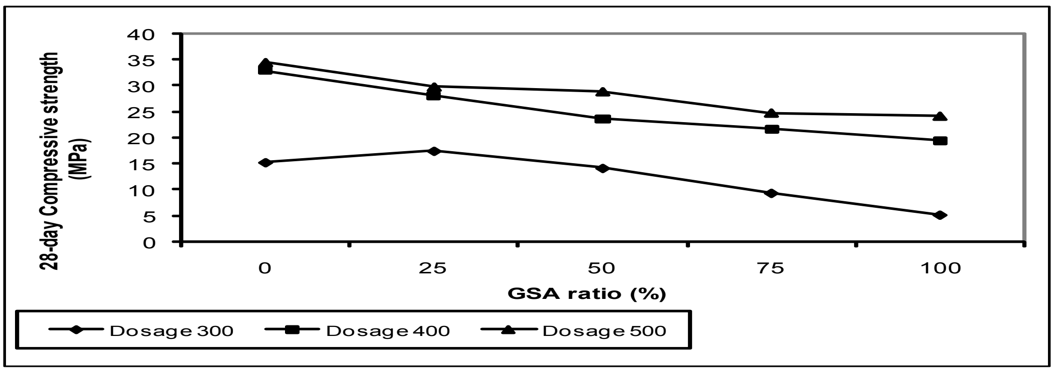

Figure 4. Relationship between GSA ratio and compressive strength of GSA concretes.

Table 3. Test results of all concrete groups

Mixtures	Dosage kg/m³					Dosage kg/m³					Dosage kg/m³				
	300					400					500				
	GSA ratio (%)														
	0	25	50	75	100	0	25	50	75	100	0	25	50	75	100
28-day Dry unit weight (kg/m³)	2010	1897	1786	1628	1396	2064	1957	1864	1766	1544	2112	1985	1896	1774	1672
Thermal conductivity (W/mK)	0.660	0.620	0.500	0.490	0.490	0.730	0.650	0.550	0.550	0.540	0.750	0.660	0.650	0.590	0.590
Water absorption (%)	0.7	0.8	1.1	1.4	2.3	0.5	0.5	0.6	0.8	0.7	0.3	0.4	0.6	0.6	0.8
28-day compressive strength (MPa)	15.3	17.5	14.2	9.4	5.2	33.0	28.2	23.8	21.8	19.6	34.5	29.8	28.9	24.8	24.2
28-day splitting tensile strength (MPa)	1.93	1.8	1.58	1.23	0.92	2.87	2.31	2.30	2.27	1.95	2.92	2.41	2.34	2.31	2.09
Elastisite modulus (MPa)x10²	222.0	222.5	170.6	125.2	97.50	317.2	295.1	214.5	198.6	169.9	339.7	314.4	242.6	226.5	188.7

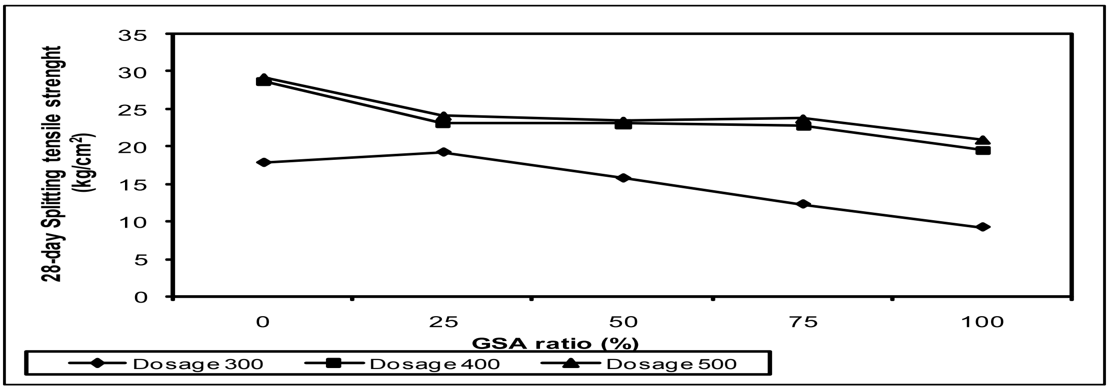

Figure 5. Relationship between GSA ratio and splitting tensile strength of GSA concretes.

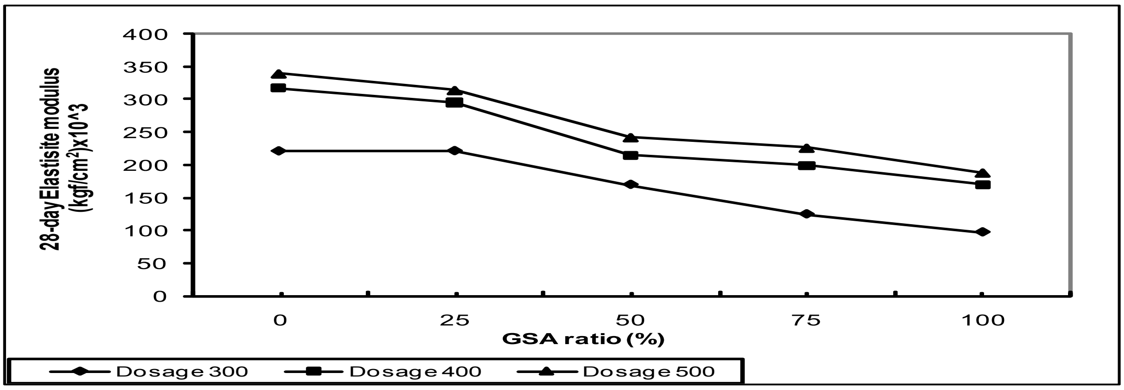

Figure 6. Relationship between GSA ratio and elasticity modulus of GSA concretes.

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