Study on Self Compacting Concrete using Industrial Waste Material (Steel Slag)

B. Lakshmi[1], Vinay Kumar Merugu[2], Vyas A[2], Krishna Solanki[2], Malika Katukam[2]

[1]Assistant Professor, [2]UG Student, [1,2]Department of Civil Engineering

[1,2]Kommuri Pratap Reddy Institute of Technology, Ghatkesar, Hyderabad, Telangana

ABSTRACT

This work aims to study the possibility of recycling floor steel slag as fine aggregate in the manufacturing of self-compacting concrete (SCC). For this; the sand is substituted with floor steel slag at different percentages (0, 5, 10, 15, 20 and 25). The slump flow diameter and T50, as well as compressive and split tensile strength in hardened state of the different SCC mixes, are determined, analyzed and compared with control concrete. The obtained results show that some physical and mechanical characteristics of SCC mixes with floor steel slag are better than those of conventional Self-compacting concrete. This study, as well, insures that reusing floor steel slag in SCC gives a positive approach to reduce the cost of materials and solve some environmental problems.

Key words: self-compacting concrete (SCC), slump flow, T50, compressive and split tensile strength.

1. INTRODUCTION

Nowadays, performance expectations from concrete structures are more demanding. As a result, concrete is required to have properties like high fluidity, self compactability, high strength, high durability, better serviceability and long service life. In order to address these requirements, self-compacting concrete (SCC) was developed in 1980s in Japan. Self-compacting concrete is a mix that can be compacted into every corner of formwork, by means of its own weight and without the need for vibrating compaction. Inspite of its high flowability, the coarse aggregate is not segregated. Thus, SCC eliminates the need of vibration either external or internal for compaction of concrete without compromising its engineering properties. Concrete is now no longer a material consisting of cement, aggregate, water and admixtures but it is an engineered material with several new constituents. The concrete today can take care of any specific requirements under most of different exposure conditions.

EFNARC has published specifications and guidelines for self compacting concrete (EFNARC 2002). Self-compacting concrete can be defined as the concrete that is able to flow in the interior of the formwork, passing through the reinforcement, filling it in a natural manner, consolidating under the action of its own weight. The filling ability, passing ability and stability can be considered as the main properties of fresh SCC. To make durable concrete structures, sufficient compaction by skilled workers is required. However, gradual reduction in the number of skilled workers in Japan„s construction industry has led to similar reduction in the quality of construction work. One solution for achievement of durable concrete is the employment of self compacting concrete. Self-compacting concrete as the name signifies should be able to compact itself without any additional vibrations or compaction. Self compacting concrete should compact itself by its self weight and under gravity. Self compacting concrete should be able to assume any complicated formwork shapes without cavities and entrapment of air. The reinforcement should be effectively covered and aggregates should be fully soaked in concrete matrix. To meet performance requirements the following three types of self compacting concretes are available i.e., powder type, viscosity agent type and combination type.

2. LITERATURE REVIEW

Fujii et al. (2007) examined a concrete that contained SFS as the aggregate and used combinations of cement, ground granulated blast furnace slag, and fly ash as the cementitious binder. The results indicated that the compressive strength can be similar to conventional concrete. The concrete produced typically failed before the freeze/thaw durability limit of 300 cycles. The results indicated that SFS aggregates with lower absorption capacity was more freeze/thaw durable compared with SFS aggregates with higher absorption capacity, especially if an air-entraining admixture was used. The authors theorized that the SFS aggregates leached calcium hydroxide, which reacted with the air-entraining agent, causing large bubbles to form and lowering the freeze/thaw durability of the concrete. The authors recommended the use of fly ash to reduce the calcium hydroxide content.

Lun et al. (2008) investigated various methods to reduce the free CaO content in BOF steel slag fine aggregate for use in concrete. The treatment methods were by steam for 8 and 12 hours and by autoclaving for 3 hours, all of which reduced the free CaO content. By soaking mortar bars in hot water, the steam-treated steel slag aggregates delayed the onset of, but did not prevent, deleterious expansion while the autoclave-treated steel slag did not undergo deleterious expansion. Initial results, without deleterious expansion, showed that the treated slag aggregate mortars had higher compressive and flexural strengths than the control with untreated slag aggregate. After the mortar was hot water cured and the aggregates expanded, the compressive and flexural strengths decreased, although the strengths were relatively consistent for the autoclaved slag aggregate mortar.

Qasrawi et al. (2009) investigated using 0, 15, 30, 50, and 100% fine aggregate replacements with low calcium (0.4% CaO) high iron (97% Fe2O3) steel slag aggregate. As the fine slag aggregate content increased, the concrete workability decreased and the unit weight increased. Particularly at later ages, the concrete compressive strength for mixtures with 15, 30, and 50% fine steel slag aggregate was higher than the control (0% slag aggregate) while the mix with 100% steel slag aggregate was lower than the control. The flexural strength was higher than the control for concretes with fine steel slag aggregates at all replacement levels, and the strength increased with increasing slag aggregate content up to 50%. However, when the steel slag aggregate was sieved to remove all material passing the 0.15 mm sieve, the compressive strength continued to increase as the fine steel slag aggregate content increased from 0% to 100%. The researchers concluded that a high amount of fines may adversely affect the concrete results because more cement is needed to effectively coat the particles. Netinger et al. (2010a) concluded that steel slag can be used as concrete aggregate. Such use would contribute to proper management of this type of waste and to preservation of aggregate normally taken from nature. Netinger et al. (2011a) reported that steel slag can be used as concrete aggregate in reinforced-concrete structures.

Maslehuddin et al. (2003) reported that the physical properties and durability characteristics of steel slag cement concrete were better than those of crushed lime stone aggregate concrete. Akinbinu (2010) reported that compressive strength of concrete mix containing steel slag have higher value when compared with laterite. Shih et al. (2004) studied that the characteristics of brick made from steel slag and revealed that it reduced the required firing temperature. Alizadeh et al. (2003) concluded that steel slag can be used as aggregate in concrete, however it has more advantages in high strength concrete than normal strength concrete. Wu et al. (2007) reported that the high temperature property of Stone Mastic Asphalt (SMA) mixture with steel slag is improved when compared with SMA mixture with basalt. The better physical properties of steel slag enhances the ability of resisting permanent deformation at high temperature.

Adegoloye et al. (2013) investigated the effects of EAF and stabilized argon oxygen decarburization (AOD) stainless steel slags as coarse aggregate replacements in concrete. Partial (50%) and full (100%) replacements of virgin coarse aggregate with the EAF and AOD slag aggregates increased the compressive strength and dynamic modulus relative to the control concrete. However, the concrete porosity and gas permeability were higher for concrete with stainless steel slags, although the permeability was still lower than the maximum recommended value for building construction. The concrete expansion was measured on prismatic samplesstored in water, and it was found that concrete with EAF slag had similar expansions to the control, but the AOD slag concrete expanded more, which was likely due to a higher MgO content. The expansion amounts for all concretes were still below the maximum allowable limit.

Anastasiou et al. (2014) tested mortar and concrete with combined coarse EAF slag aggregates, fine construction and demolition waste (CDW), and high calcium fly ash. With 100% coarse EAF aggregate, the compressive, split tensile, and flexural strengths and the modulus of elasticity increased relative to the control concrte. When CDW fine aggregates were used, the addition of coarse EAF slag aggregates did not significantly improve the properties. The high calcium fly ash further improved the hardened properties of the concrete with 100% coarse EAF slag aggregates, but only at later ages (>1 year). The use of coarse EAF slag aggregates did not appear to increase the water absorption, but the concrete porosity was slightly increased; the use of CDW with and without EAF slag aggregates increased the porosity and water absorption. Under pressure, the water penetration increased when EAF slag and/or CDW aggregates were used. The chloride penetration resistance slightly improved with EAF slag aggregates and decreased with CDW.

3. OBJECTIVE AND METHODOLOGY

3.1 Objective

The main objective of this study was to assess the steel slag properties and establish their potentiality as replacements of natural fine aggregates in M40 grade self-compacting concrete. Some specific objectives, among others were the analysis of the properties of steel slag, their potentials as artificial fine aggregates in concrete, and the establishment of optimum percentage of replacement of natural sand by steel slag in the new self-compacting concrete.

3.2 Methodology

- Collect waste iron slag from industry and dry it.
- Crushing of steel slag by using CTM to get fine powder form as like fine aggregates
- Sieve the sample by using 4.75mm IS Sieve, passed steel slag will be used for this study.
- Mixing of M40 based self-compacting concrete and test fresh and harden properties of ssc.
- Mixing of M40 based self-compacting concrete, fine aggregate replacement with steel slag and test fresh and harden properties of ssc.
- Compare the test results of conventional ssc and un conventional ssc(steel slag). Find out the optimum dosage of steel slagwaste with replacement of fine aggregate.

4. EXPERIMDENTAL WORK

This section describes about the materials used and their properties, experimental methods and setups in this investigation.

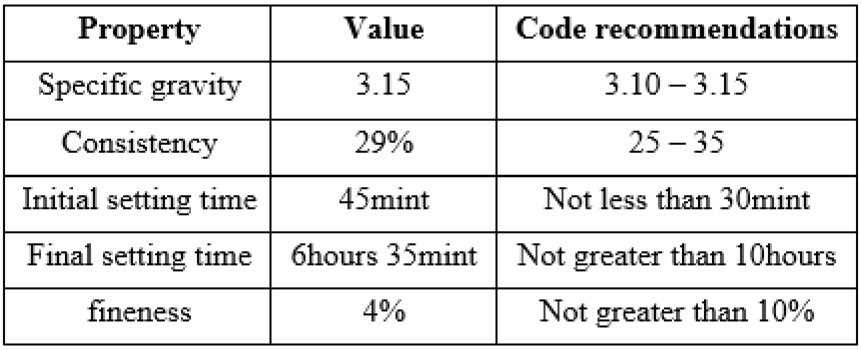
4.1 Materials used

Ordinary Portland Cement of 53 grade with specific gravity 3.15 available in local market, fine aggregate which is chemically inert, clean conforming to grade zone II with specific gravity 2.6 were used. Coarse aggregate of 20 mm size uniform quality with respect to shape and grading conforming to IS standards was used for control concrete and 10 to 12.5 mm size aggregates were used for SCC. GGBS obtained from Indian mart was used in this investigation to improve workability and durability of SCC. Steel slag obtained from 4.75mm IS Sieved passed aggregates are using for partial replacement of fine aggregates. Potable water available in the laboratory was used to cast concrete specimens and for curing.

4.2 PROPERTIES OF MATERIALS

Cement

In this investigation, 53 grade OPC conforming to IS 12269–1987 was used. The cement sample was tested as per the procedure given in IS 4031-1988 and 4032-1985. The physical properties satisfy the requirements of respective codes are listed in Table 4.1.



Property	Value	Code recommendations
Specific gravity	3.15	3.10 – 3.15
Consistency	29%	25 – 35
Initial setting time	45mint	Not less than 30mint
Final setting time	6hours 35mint	Not greater than 10hours
fineness	4%	Not greater than 10%

Fig. 1: Physical Properties of OPC 53 Grade Cement.

Fig. 2: Cement.

Fine Aggregate

Locally available river sand was used as fine aggregate conforming to grade zone II in this investigation. The sand was cleaned and screened at laboratory to remove deleterious materials and tested according to IS: 383-1970. The results of fine aggregate water absorption was 0.75% and specific gravity was 2.68.

Fig. 3: Fine aggregate.

Coarse Aggregate

The coarse aggregate occupies more than 85% of the volume of concrete and their impact on various properties of the concrete is predominant. The maximum size of the coarse aggregate was limited to 20 mm for control concrete and 12.5 mm for SCC. The results of coarse aggregate water absorption was 0.5% and specific gravity was 2.72.

Fig. 4: Coarse aggregate.

Steel slag

The results of steel slag fine aggregate water absorption was 0% and specific gravity was 2.2

Water

Water is an important ingredient of concrete as it actually participates in the chemical reaction with cement in concrete. Drinking water available in the laboratory conforming to IS 456-2000 was used to cast concrete specimens and for curing in this investigation.

GGBS

GGBS becomes the predominant pozzolan in use throughout the world due to performance and common factors. The results of GGBS specific gravity was 2.1 and fineness value was 2%.

Mix design

The concrete mix was designed for M40 grade concrete to study the various properties of the concrete as per IS 10262:2009.

4.3 Mix proportions for SCC

To produce SCC, the major work involves designing an appropriate mix proportion and evaluating the properties of the concrete thus obtained. In practice, SCC in its fresh state shows high fluidity, self-compacting ability and segregation resistance, all of which contribute to reducing the risk of honey combing of concrete. With these good properties, the SCC produced can greatly improve the reliability and durability of the reinforced concrete structures. In addition SCC shows good performance in compressive strength test and can fulfil other construction needs because its proportion has taken into consideration the requirements in the structural design. The mix proportion for self-compacting concrete is obtained by trial-and-error method. using EFNARC regulations. The mix proportion for 1 m3 of SCC is presented in Table 4.1.

Concrete	: GradeM40
Type of Cement	: OPC 53
Type of aggregate	: 20mm Sub rounded
Exposure Condition	: Severe
Specific Gravity of Cement	: 3.15
Specific Gravity Of Coarse Aggregate	: 2.7
Zone Provision	: Zone II
Workability	: 100 mm (slump)

Step 1: Calculation of Target Mean Strength

$\boldsymbol{f'_{ck}} = \boldsymbol{f_{ck}} + 1.65$ s

Where s = standard deviation

f_{ck} = Characteristic compressive strength at 28 days

f'_{ck} = Target mean compressive strength at 28 days

Standard deviation value for M30 grade concrete = 5.0 N/mm2

Therefore f'_{ck} = 40 + 1.65 x 5.0

= 48.25 N/mm2

Step 2: Selection of W/C Ratio

From IS 10262- 2019 Figure.1 for OPC 53 grade, f'_{ck} = 48.25 N/mm2 the W/C is 0.35 (0.35<0.50) Hence ok.

Step 3: Calculation of cement

Initially assume water content in between 180 – 210 kg/m3, Assuming 210kg/m3.

Then, cement content $= \frac{210}{0.35}$ = 600 kg/m3

The maximum cement content = 450 kg/m3

GGBS = 150 kg/m3

Step 5: Volume of fine aggregates and coarse aggregates

Assuming the coarse aggregate = 48%

And the fine aggregate = 52%

Step 6: Mix Calculations for Steel slag based SSC

Volume of Concrete = 1 m3

Volume of Cement $= \frac{\text{weight of cement}}{\text{specific gravity of cement}} \text{ x } \frac{1}{1000}$

$= \frac{450}{3.15} \text{ x } \frac{1}{1000}$

= 0.1428 m3

Volume of GGBS $= \frac{150}{2.85} \text{ x } \frac{1}{1000}$ = 0.068 m3

Volume of Water =0.210 m3

Volume of air voids = 0.01 m3

Total Volume of Aggregates = 1 - (0.1428-0.068-0.01-0.21)

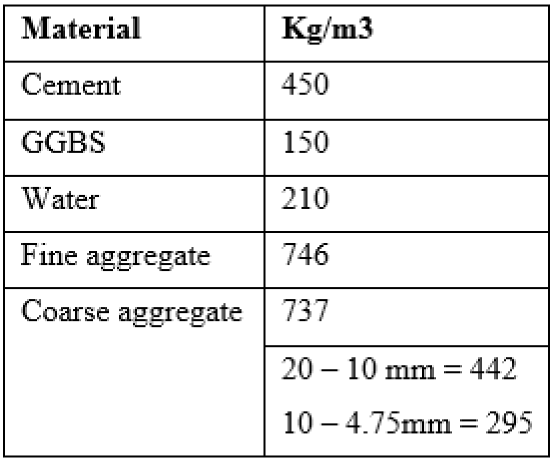
= 0.57m3

Mass of FA = 0.57 x 0.52 x 2.52 x 1000

= 746 kg/m3

Mass of CA = 0.57 x 0.48 x 2.7 x 1000

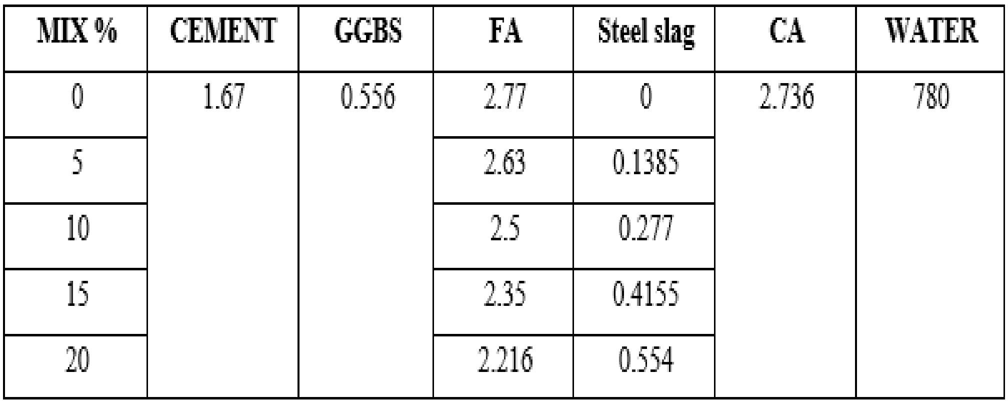
= 737 kg /m3



Material	Kg/m3
Cement	450
GGBS	150
Water	210
Fine aggregate	746
Coarse aggregate	737
	20 – 10 mm = 442 10 – 4.75mm = 295

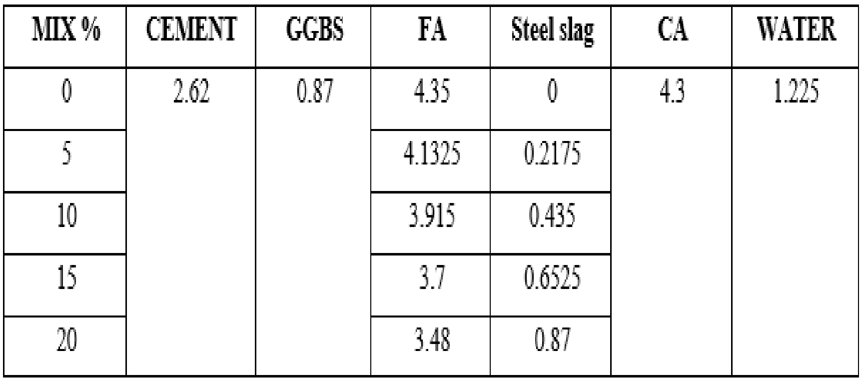
Fig. 5: Mix design.

- Volume of cube = (0.15)3 x 1.1 = 0.0037125
- Volume of cylinder = 1.1 X 5.3014 x 10-3 = 0.005831



MIX %	CEMENT	GGBS	FA	Steel slag	CA	WATER
0	1.67	0.556	2.77	0	2.736	780
5			2.63	0.1385		
10			2.5	0.277		
15			2.35	0.4155		
20			2.216	0.554		

Fig. 6: For single cube.



MIX %	CEMENT	GGBS	FA	Steel slag	CA	WATER
0	2.62	0.87	4.35	0	4.3	1.225
5			4.1325	0.2175		
10			3.915	0.435		
15			3.7	0.6525		
20			3.48	0.87		

Fig. 7: For single cylinders.

4.4 Fresh Properties of SSC

Slump flow test

The slump flow is used to assess the horizontal free flow SCC in the absence of obstruction. It was first developed in Japan for use in assessment of underwater concrete. The test method is based on the test method for determining the slump. The diameter of the concrete circle is a measure for the filling ability of the concrete.

This is simple, rapid test procedure, though two people are needed if the T50 time is to be measured. It can be used on site, though the size of the base plate is somewhat unwieldy and level ground is essential. It is most commonly used test, and gives a good assessment of filling ability. It gives no indication of the ability of the concrete to pass between reinforcement without blocking, but may give some indication of resistance to segregation. It can be argued that the completely free flow, unrestrained by any boundaries, is not representative of what happens in practice in concrete construction, but the test can be profitably be used to assess the consistency of supply of ready-mixed concrete to a site from load to load.

5. RESULTS AND DISCUSSION

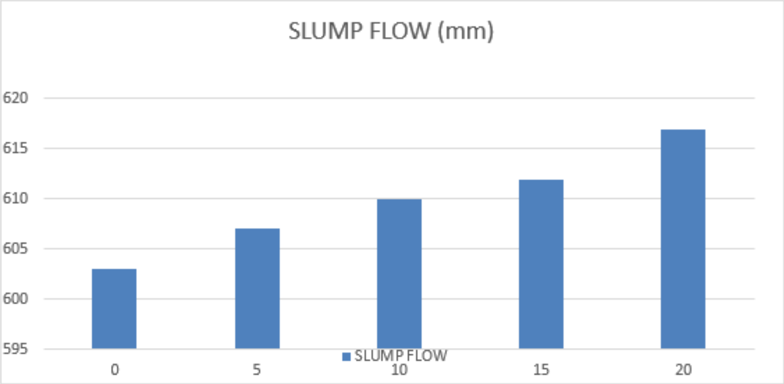


Fig. 8: Slump values graphs.

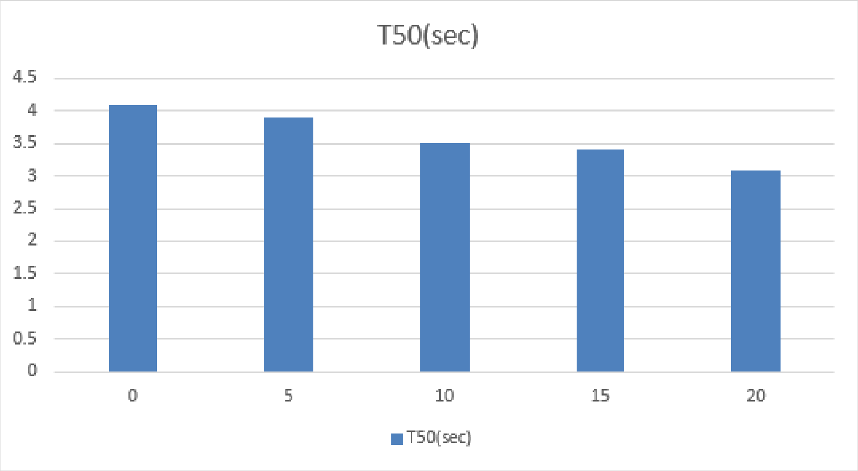


Fig. 9: T50 values graphs.

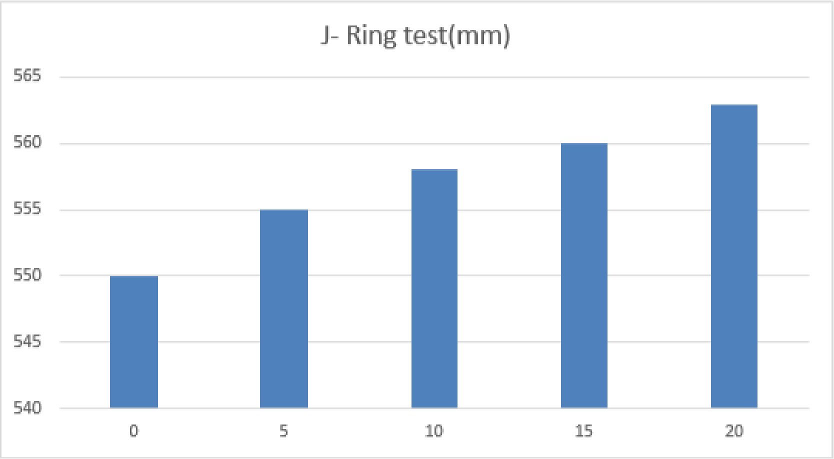


Fig. 10: j-ring test values graphs.

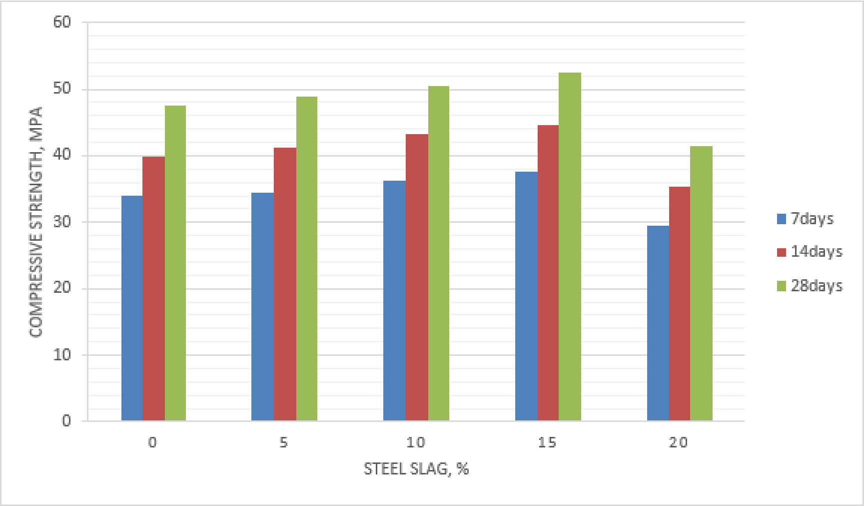


Fig. 11: Compressive strength test result graph for SCC.

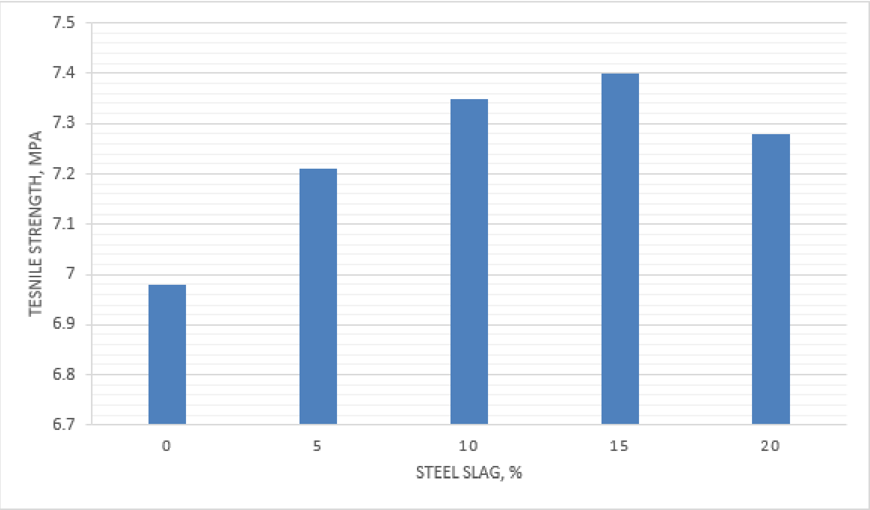


Fig. 12: Compressive strength test result graph for SCC.

6. CONCLUSIONS

This section study on the usage of waste construction materials is very important due to the material waste is gradually increasing with the increase in population and increasing of urban development. The reasons that many investigations and analysis had been made on steel slag aggregate are because tile aggregates are easy to obtain and their cost is cheaper than the natural aggregates.

- Based upon its properties steel slag aggregates are appropriate concrete material which is used as an alternative material to fine aggregates in concrete.
- This study was carried to obtain the results, test conducted on the Steel slag modified fine aggregate SSC concrete mix, in order to ascertain the influence of steel slag on the characteristic strength of SSC concrete. The higher compressive and tensile strength of SSC concrete, when the steel slag replacing of 15% in the fine aggregate content. The results show if around 10.9% of compressive and 6% of tensile strength as more than the conventional SSC.
- Use of steel slag aggregates is more economical than the conventional concrete. 10 percent money can be saved on total amount.

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