

## EFFECT OF USING STEEL SLAG AGGREGATE ON MECHANICAL PROPERTIES OF CONCRETE

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### ABSTRACT

This study presents an evaluation of the physical and mechanical properties and characteristics of steel slag aggregate concrete in comparison with the typical crushed limestone stone aggregate concrete. Hardened concrete consist of more than 70% aggregate due to the high demand in building construction and the increase of the amount of disposed waste material, suppliers and researchers are exploring the use of alternative materials which could preserve natural sources and save the environment. In this study, steel slag was used as an aggregate replacement in conventional concrete mixes. Steel slag which is mainly consists of calcium carbonate is produced as a by-product during the oxidation process in steel industry. Steel slag was selected due to its characteristics, which are almost similar to conventional aggregates and the fact that it is easily obtainable as a by-product of the steel industry. As a result, utilization of steel slag will save natural resources and clean environment. Furthermore, results have shown that slag aggregate has better abrasion factor and impact value than conventional aggregate. Thorough investigation of the results have indicated that the amount of increase in compressive strength at age of 7 days are much more than that of age 28 days for all types of aggregate replacement. This indicates that the added slag could work as accelerator at early age while at 28 days age, the effect is reduced. The fine slag replacement scores the highest effect.

**Keywords:** Aggregate, Concrete Strength, Hardened Concrete, Mechanical Properties, Steel Slag

### 1. INTRODUCTION

The aggregates typically account about 75% of the concrete volume and play a substantial role in different concrete properties such as workability, strength, dimensional stability and durability. Conventional concrete consists of sand as fine aggregate and gravel, limestone or granite in various sizes and shapes as coarse aggregate. There is a growing interest in using waste materials as alternative aggregate materials and significant research is made on the use of many different materials as aggregate substitutes such as coal ash, blast furnace slag, steel slag aggregate. This type of use of a waste material can solve problems of lack of aggregate in various construction sites and reduce environmental problems related to aggregate mining and waste disposal (Asi *et al.*,

2007). The use of waste aggregates can also reduce the cost of the concrete production (Kalyoncu, 2001; Farrand and Emery, 1995).

As the aggregates can significantly control the properties of concrete, the properties of the aggregates have a great importance (Beshr *et al.*, 2003). Maslehuddin *et al.* (2002) have indicated that the durability of steel slag cement concrete is better than the same for crushed limestone aggregate. Therefore, a thorough evaluation is necessary before using any waste material as aggregate in concrete.

In general, several factors are affecting physical and chemical properties of steel slag. These factors include: Type of steel furnace, steel making plant and steel slag processing.

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**Table 1.** Chemical analysis of steel slag

Compound	Mass%	Compound	Mass%
CaO	50-57	Fe	15-19
Fe <sub>2</sub> O <sub>3</sub>	10-13	SiO <sub>2</sub>	9-11
MnO	4-5	P <sub>2</sub> O <sub>5</sub>	3.2-2.3
MgO	1-2	Al <sub>2</sub> O <sub>3</sub>	1.4-0.7
S	0.12-0.1	K <sub>2</sub> O	0.04-0.01
Na <sub>2</sub> O	0.04-0.02		

Composite materials are multiphase materials obtained through the artificial combination of different materials in order to attain properties that the individual components by themselves cannot attain.

During the process of reducing iron ore, it is necessary to remove the silica, alumina and other components contained in iron ore, the added limestone fuses with these components and lower their melting point. The basis of steel slag is limestone used as auxiliary material in production of iron and steel. Making it easier to separate them from the iron and recover them. The recovered substance is slag. Chemical composition of iron and steel slag.

The primary components of iron and steel slag are limestone (CaO) and silica; other components of blast furnace slag include Alumina (Al<sub>2</sub> O<sub>3</sub>) and magnesium Oxide (MgO) as well as a small amount of Sulfur (S) while steel making slag contains iron oxide (FeO) (Hansen, 1966).

In the case of steel making slag, the slag contains metallic elements such as iron in oxide form; however, because refining time is short and the amount of limestone contained is large, a portion of the limestone auxiliary material may remain un-dissolved as free CaO.

**Table 1** shows the chemical analysis of typical steel slag. The masses indicated in the table are the average of chemical analysis during several intervals.

Several advantages of using slag aggregates are gained such as (Kim, 1999; Al-Negheismish *et al.*, 1996):

- Reliable Quality
- Does Not Contain Materials such as Chlorides Organic Impurities, Clay and Shells
- Increased Strength as Materials Age
- Does Not Generate Alkali-aggregate Reactions
- Blast furnace slag fine aggregate does not contain materials that may affect the strength and durability of concrete, such as chlorides, organic impurities clay and shells

## 1.1. Slag Waste in Jordan

Slag waste is a material resulting from the melting process of iron scrap or iron ore. The slag produced from iron ore is much less than that produced from melting steel scrap.

In Jordan, there are two types of factories that manufacture carbon steel bars which are used as reinforcement bars. The first type consists of imported semi processed iron in the form of plates to be melted later and processed to form reinforced bars. The other type melts the iron scrap to form a semi processed plates and then to be processed to form reinforced bars.

## 1.2. Steel Rolling Mills; There Are Four Working Factories

- Jordan Steel
- The global steel industry area distinguished
- General Company for the manufacture of iron Specialist
- Petra iron industry

## 1.3. Melting and Rolling Mills, There are Four Working Factories

- Jordanian Coalition, Zarqa city produces between 10000-20000 tons annually
- United Company for the manufacture of iron and steel, Amman produces 10000-20000 tons of slag annually
- Jordan iron smelting company, Zarqa produces 3000-4000 tons annually
- Ramallah New factory (currently under testing), Zarqa, expected production 15000-20000 tons annually

## 2. PROBLEM STATEMENT AND STUDY OBJECTIVE

Extensive researches have been conducted for the application of steel slag in broad areas of construction. Thus, an important need exists to quantify the benefits of using such cheap material in concrete technology, concrete asphalt pavement (Beshr *et al.*, 2003; Maslehuddin *et al.*, 2002; Moon and Yaoo, 1999; Sherwood, 1995; Asi *et al.*, 2007; Al-Negheismish *et al.*, 1996; Manso *et al.*, 2004).

Thus, the main objective of this research is to study the effect of using steel slag that combined with limestone aggregates by different ratios on improving the mechanical properties of hardened concrete.

There are several tests that were conducted to evaluate the mechanical properties of aggregate and slag according to (ASTM C 33, 2003; ASTM C 138/C 138M, 2001; ASTM C 150, 2005). The abrasion test and the impact value for both natural aggregate and slag aggregate are shown in **Table 2**.

The base case of crushed limestone batch design mix that was used for comparison is shown in **Table 3**. All ingredients are in Kg/m<sup>3</sup>.

In this study, several experiments have been conducted to study the effect of adding (replacing) steel making slag to concrete composite and measuring the effect of slag content on the mechanical behavior of hardened concrete. The steel making slag was used in three main phases: (a) as a replacement of sand, (b) as a replacement of fine aggregate and (c) as a replacement of coarse aggregate. The percentages of replacement in the concrete mix were ranging from 0 to 100%. The following ratio are reported in this study: 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100% by weight.

**Table 2.** Abrasion value and impact value of used aggregate

Type of coarse aggregate	Abrasion value	Impact value (%)
Natural aggregate	23.06	23.13
Steel making slag	20.26	6.31

### 3. RESULTS AND DISCUSSION

About 150×150×150 mm standard cube samples were prepared to run a compressive strength test. Compressive strength at both (7 days) and (28 days) were recorded as well as the unit weight of the concrete cube.

The results are shown on **Fig. 1 and 2**.

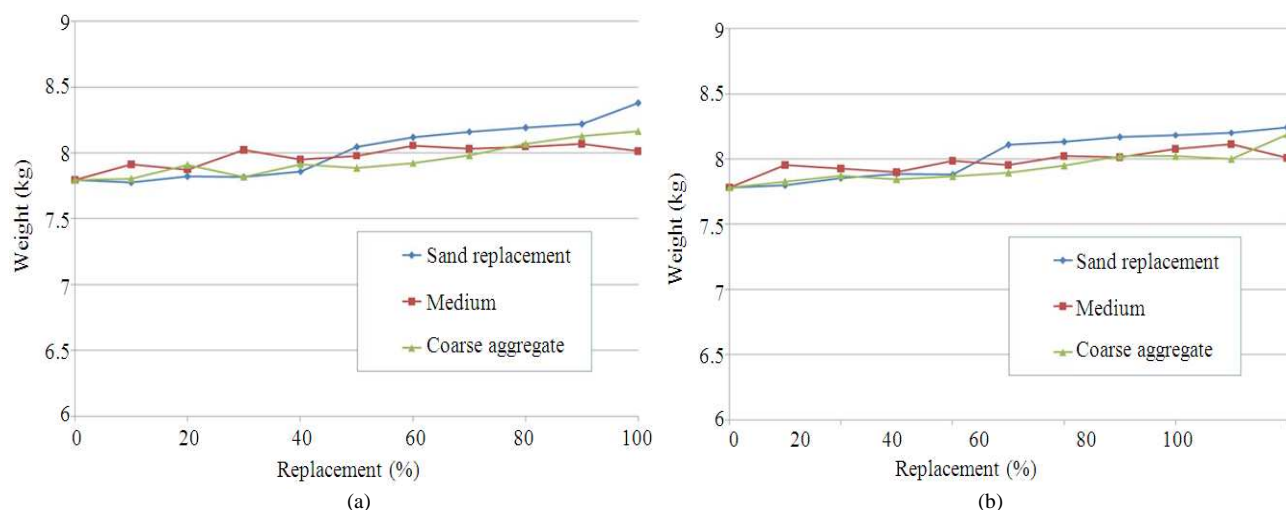
**Figure 3** shows the effect of partially replacement of sand by slag on compressive strength at both 7 days and 28 days.

**Figure 4** shows the effect of partially replacement of medium aggregate by slag on compressive strength at both 7 days and 28 days.

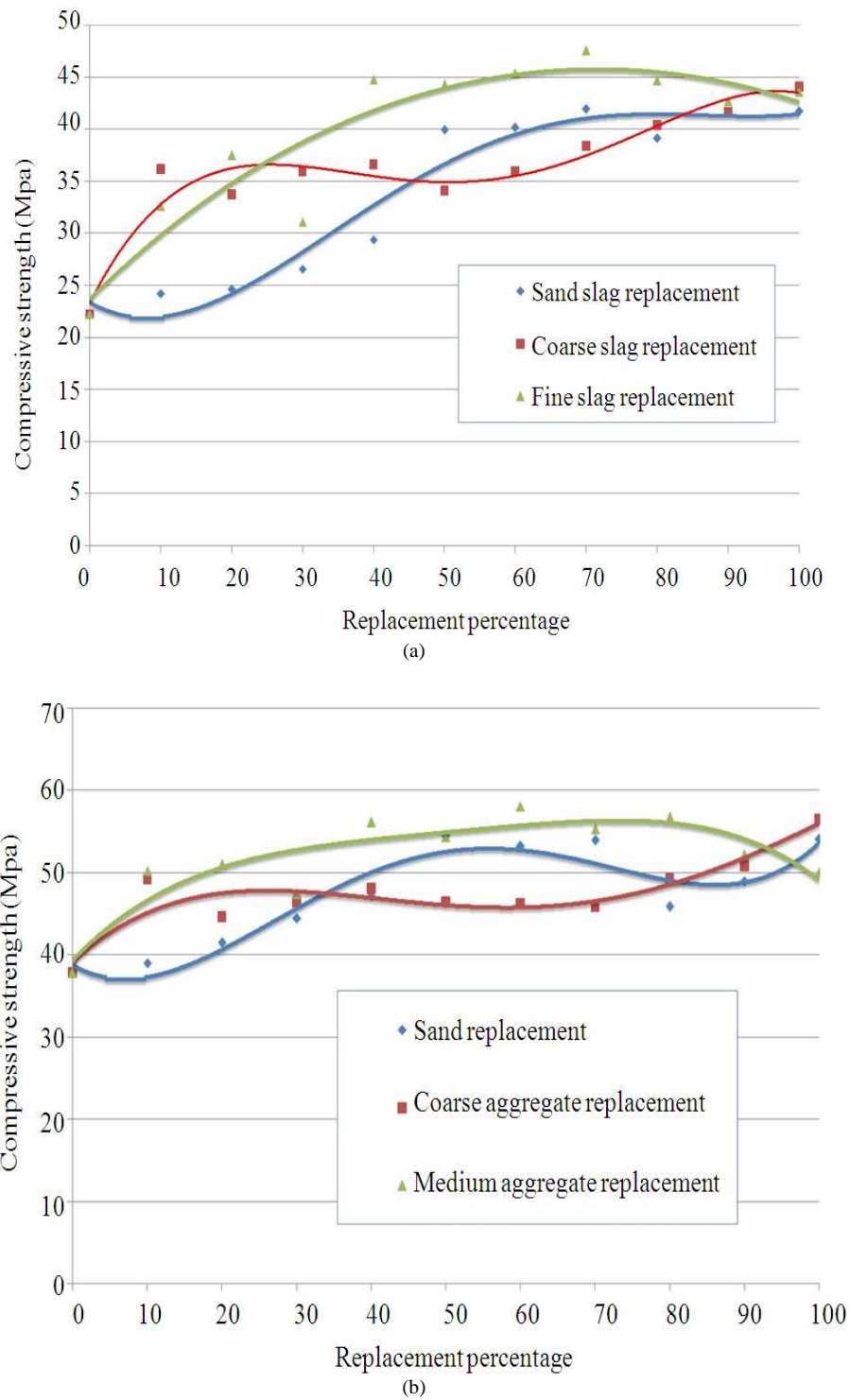
**Figure 5** shows the effect of partially replacement of coarse aggregate by slag on compressive strength at both 7 days and 28 days. Previous research has indicated that using steel slag as a replacement of coarse aggregate will improve the compressive strength of concrete (Al-Negheismish *et al.*, 1996).

**Table 3.** Base case batch mix ingredients

Ingredient	Weight (Kg/m <sup>3</sup> )
Cement	408
Water	163
Mixed aggregate	1038
Sand	767



**Fig. 1.** Effect of slag replacement on unit wight (a) At age of 7 days (b) At age of 28 days



**Fig. 2.** Effect of slag replacement on compressive strength (a) At cube age of 7 days (b) At cube age of 28 days

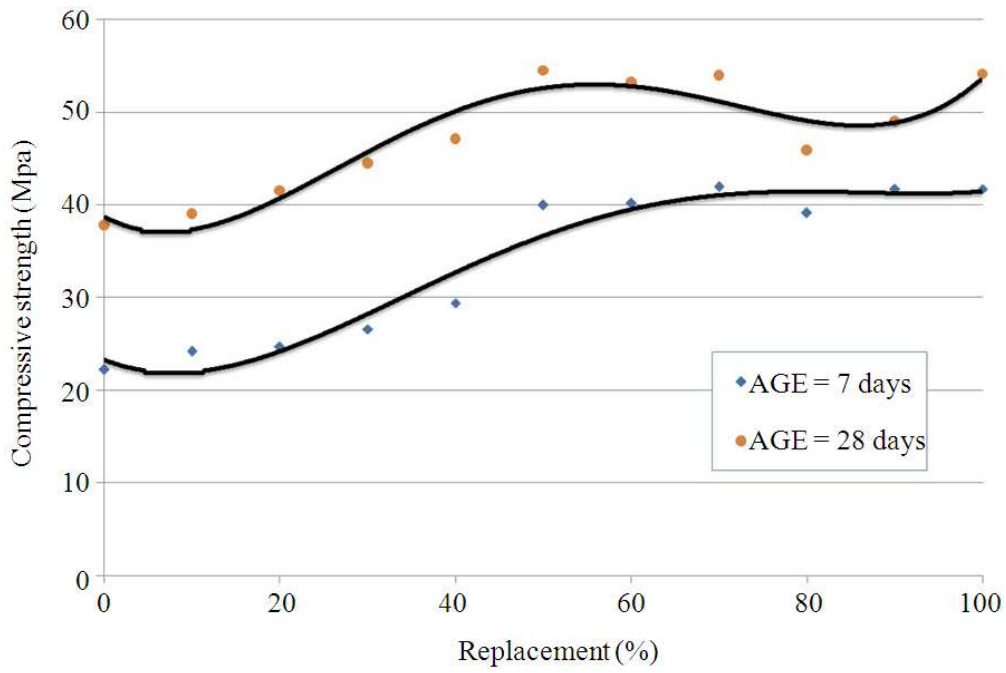


Fig. 3. Effect of Slag replacement on compressive strength: Fine sand only

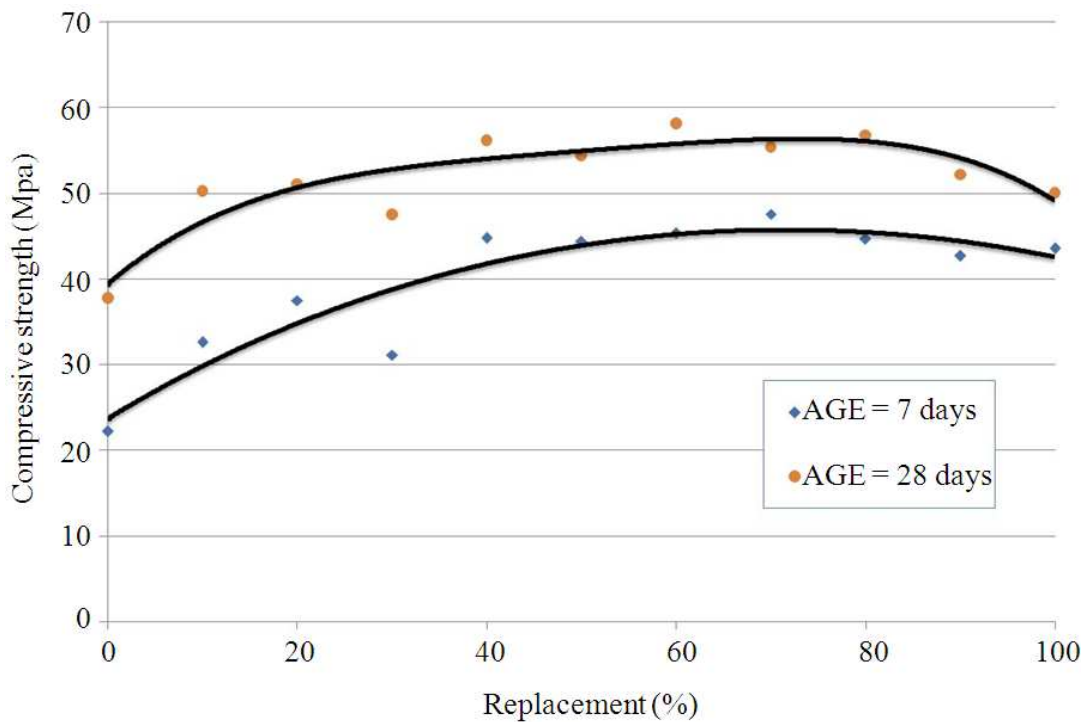


Fig. 4. Effect of slag replacement on compressive strength

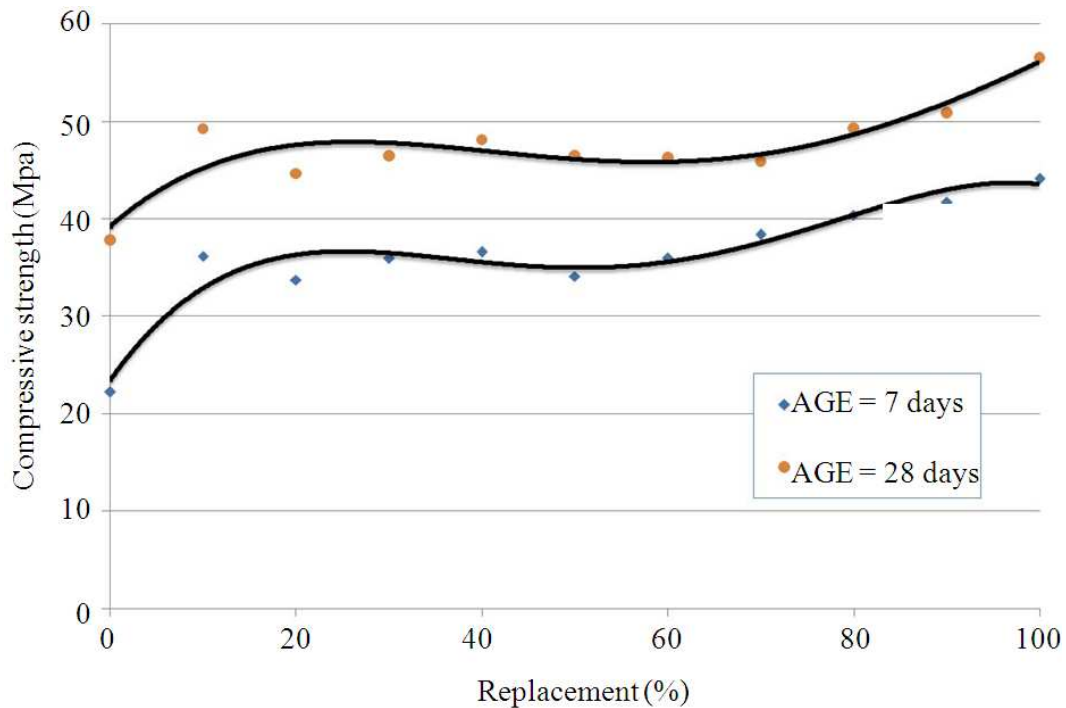


Fig. 5. Effect of slag replacement on compressive strength: Coarse aggregate only

#### 4. CONCLUSION

The influence of steel slag was evaluated in concrete in this study and the following findings are concluded:

- The aggregate produced from cooled steel slag meets criteria for the use in concrete mixes
- Furthermore, According to ASTM D5106 experiments, steel slag meets the requirements to be used in concrete mixes, whether partly or totally
- In all replacement ratios, the flexural strength increases by the increase in slag ratio
- Results have indicated that there is a high potential of using steel slag as aggregate replacement (Maslehuddin *et al.*, 2020; Al-Negheimish *et al.*, 1996). The use of such waste material in concrete industry will have significant impact on environment and reducing or eliminating waste materials produced by steel furnace industry. As a result this seems more economical and ecological specially, in regions with lack of natural aggregate resources and great amount of slag disposal. The finding of our research goes inline with the results of previous research conducted by Asi *et al.* (2007)
- As raw materials, results have shown that slag aggregate has better abrasion factor and impact value than natural aggregate which are used in this study
- Thorough investigation of results have indicated that the amount of increase in compressive strength at age of 7 days are much more than that of age 28 days for all types of aggregate replacement. This indicates that the added slag could work as accelerator at early age while at 28 days age, the effect is reduced. Furthermore, the fine slag replacement scores the highest effect
- Due to the fact that, sand amount is not significant compared to other aggregate types, the effect of sand replacement on enhancing compressive strength is minimum
- Further research on the role of slag as an accelerator should be conducted. The going research was on Normal Portland Cement (Type I). Further research on the effect of slag on other types of cement should be investigated

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