Jozef Junak, Nadezda Stevulova
Technical university of Kosice,
Institute of Environmental Engineering

NATURAL AGGREGATE REPLACEMENT BY RECYCLED MATERIALS IN CONCRETE PRODUCTION

In this contribution is presented overview of aggregate from recycled concrete and steel making slag treatment in civil engineering industry. The goal of experiments is utilization of these wastes as the partial or complete replacement of natural aggregates fraction 4-8 and 8-16 mm in concrete. Partial replacement was carried out from 20 to 80 %.

Key words: recycled concrete aggregate, steelmaking slag, concrete, compressive strength.

Зроблено огляд наповнювача з перероблeного бетону і сталеплавильного шлаку в будівельній галузі. Метою експериментів є використання цих відходів як часткової або повної заміни в бетоні природного заповнювача фракцій 4-8 і 8-16 мм. Часткова заміна проводилася у розмірі від 20 до 80 %.

Ключові слова: заповнювач до бетону, сталеплавильний шлак, бетон, міцність на стиск.

Introduction

Following a normal growth in population, the amount and type of waste materials have increased accordingly. Many of the non-decaying waste materials will remain in the environment for hundreds, perhaps thousands of years. The non-decaying waste materials cause a waste disposal crisis, thereby contributing to the environmental problems. The problem of waste accumulation exists worldwide, specifically in the densely populated areas. Most of these materials are left as stockpiles, landfill material or illegally dumped in selected areas [1].

In the world is increasing demand and interest in aggregates from non-traditional sources such as from industrial by-products and recycled construction and demolition wastes. The American Concrete Institute (ACI) focuses on the removal and reuse of hardened concrete whereas the Department of the Environment and Water Resources in Australia and CSIRO have developed a guide on the use of recycled concrete and masonry materials.

The Waste & Resources Action Programme (WRAP) in the UK classified aggregates from primary, recycled and secondary material resources. Recycled aggregates encompass industrial by-products and reused construction products, all of which were once considered wastes and dumped in landfill. The recently introduced European Standards for aggregates do not discriminate between different sources, and are for ‘aggregates from natural, recycled and manufactured materials’ [2].

Classification of aggregates [2]:

1. Natural aggregate

Construction aggregates produced from natural sources such as gravel and sand, and extractive products such as crushed rock.

2. Manufactured aggregate

Aggregates manufactured from selected naturally occurring materials, by-products of industrial processes or a combination of these.

3. Recycled aggregate

Aggregates derived from the processing of materials previously used in a product and/or in construction.

4. Reused by-product

Aggregates produced from by-products of industrial processes.

Recycled concrete aggregate (RCA) is generally produced by two-stage crushing of demolished concrete, and screening and removal of contaminants such as reinforcement, paper, wood, plastics and gypsum. Concrete made with such recycled concrete aggregate is called recycled aggregate concrete (RAC).

When demolished concrete is crushed, a certain amount of mortar and cement paste from the original concrete remains attached to stone particles in recycled aggregate. This attached mortar is the main reason for the lower quality of RCA compared to natural aggregate.

Technology of RAC production is different from the production procedure for concrete with natural aggregate. Because of the attached mortar, recycled aggregate has significantly higher water absorption than natural aggregate. Therefore, to obtain the desired workability of RAC it is necessary to add a certain amount of water to saturate recycled aggregate before or during mixing, if no water-reducing admixture is applied. One option is to first saturate recycled aggregate to the condition ―water saturated surface dry, and the other is to use dried recycled aggregate and to add the additional water quantity during mixing. The additional water quantity is calculated on the basis of recycled aggregate water absorption in prescribed time [3].

Steelmaking slag is an environmentally safe product with a wide range of valuable uses. Steelmaking slag includes blast furnace (“BF") iron slag, and basic oxygen furnace ("BOF") and electric arc furnace ("EAF") steel slag types.

Producing BF, BOF, and EAF slags is an important step in the iron/steel making process. During this process, substances that are incompatible with iron and steel are removed by forming complex metallic and non-metallic oxides. Chemically, steelmaking slag is a complex matrix structure consisting primarily of oxides of calcium, iron, silicon, aluminium, magnesium, and manganese in complexes of calcium silicates, aluminosilicates and aluminoferite. These compounds are generally similar to those found in the natural environment. At lower temperature, these individual oxidized components would not be fusible, but at a typical operating temperature of about 1600°C in the furnace, these materials are easily fused and captured in the slag. The matrix tightly binds metals found in steelmaking slag, and these metals are not readily liberated from the slag particles. Consequently, the metals in slag are not easily leached into the environment and therefore, are not readily available for uptake by humans, other animals or plants.

Steelmaking slag has been used commercially since at least the mid-19th century. It is currently used in all industrialized countries, wherever steel is produced. Beginning in the 20th century, many new uses for steelmaking slag were developed in a variety of industries.

These properties make steelmaking slag a superior material for use as a construction aggregate, currently the major use of steelmaking slag. Natural aggregates, such as limestone, sand, and gravel products, competes with slag for use as a construction aggregate. Because slag is a renewable mineral resource, its use reduces the consumption of natural resources by the construction industry.

Examples of construction applications of slag in the Europe include: aggregate in asphaltic concrete; fill; unconfined bases; shoulder stabilization; berm construction; railroad sub- base; base for walkways; and rock wool insulation. Slag also is used for agricultural purposes in the Europe; principally as a pH supplement/liming agent, soil conditioner, fertilizer, and remineralisation agent [4, 5].

Many research efforts were devoted to providing solutions in using of waste for natural aggregate replacement because aggregates represent about 60-70% per volume of concrete mixture. In our study of strength properties of concrete based on natural aggregate compensation by selected fractions of recycled concrete and steelmaking slag were investigated.

Materials and methods

In our study, Portland cement CEM II 32.2, recycled concrete aggregate, steelmaking slag and natural aggregate were used as raw materials.

Used recycled concrete aggregate (Fig. 1.) was created as a crushed and sorted waste from demolition building and roads. This material was obtained from recycling plant Rail and Transport Buildings, Ltd. Kosice, Slovakia. This material, fraction 4/8 and 8/16 mm was used as natural aggregate replacement in concrete mixtures.

Fig. 1. Recycled concrete aggregate

Steelmaking slag (Fig.2.) used in our study was obtained from steel production in U.S. Steel Kosice, Slovakia. Two different fractions, 4/8 and 8/16 mm were used as natural aggregate replacement in concrete mixtures.

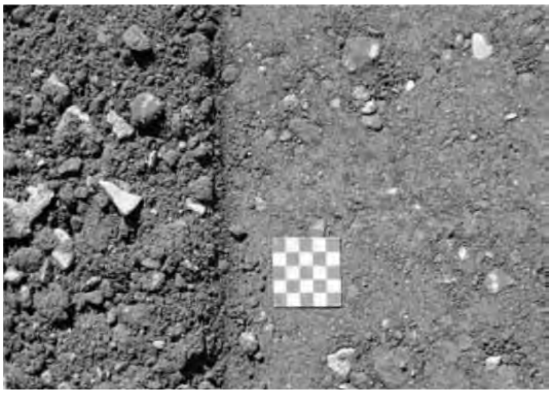

Fig. 2. Steelmaking slag

Three different fractions of natural aggregate (0/4 mm, 4/8 mm and 8/16 mm) from company VSH, a.s. (Turna nad Bodvou, Slovakia) was used for concrete samples preparing. Natural aggregate was evaluated according to the Slovakian standard [6].

The manufacture of concrete samples was used Portland slag cement CEM II/B-S 32.5 R from company Povazska cementaren, a.a., Ladce, Slovakia [7].

Table 1 shows proposal composition of 1 m3 concrete for strength class C 16/20. As an additive to concrete samples was used plasticizer Stacheplast. It is a plasticizer based on lignin, which specifically regulates the hardening of concrete samples with a strong plasticizing effect.

Table 1

Composition of 1m^3 concrete C 16/20

Composition	C 16/20 XC1, (SK) CL – 0,4 D_{max}16, S3
CEM II/ B-S 32,5 R [kg]	300
Water [l]	160
0/4 mm [kg]	955
4/8 mm [kg]	210
8/16 mm [kg]	710
Plasticizer [l]	2,15

Ten different mixtures based on recycled concrete aggregate (called R1-R10) at solid/liquid ratio of 0.55, including admixture Stacheplast was performed in our study. Sample R1 was reference sample prepared only with natural aggregate. In the other mixtures (R2-R10) natural aggregate fractions, 4/8 and 8/16 mm were replaced by washed recycled concrete aggregate. The replacement variation in the experimental mixtures was in range 0 to 100%, as it is shown in Table 2.

Table 2

Percentage replacement of natural aggregate by washed recycled concrete aggregate in the mixture

Sample	Recycled concrete aggregate	
	4/8 mm [%]	8/16 mm [%]
R1	0	0
R2	100	20
R3	100	40
R4	100	60
R5	100	80
R6	100	100
R7	20	100
R8	40	100
R9	60	100
R10	80	100

To detect steelmaking slag utilization as filler in concrete production, four concrete mixtures (called S1-S4) at solid/liquid ratio of 0.55, including plasticizer were proposed (sample S4 – reference sample). In other three samples fraction 0/4 mm of natural aggregate was always used and only amount of fractions 4/8 and 8/16 mm was varied. In sample S3 both fraction of natural aggregate were replaced by steelmaking slag fractions. In Table 3 composition of concrete samples with natural aggregate replacement by Slovakian steelmaking slag is given.

Table 3

Composition of concrete samples with natural aggregate replacement by steelmaking slag

Sample	Natural aggregate			Steelmaking slag	
	0/4 mm [%]	4/8 [%]	8/16 [%]	4/8 [%]	8/16 [%]
S1	●	●	-	-	●
S2	●	-	●	●	-
S3	●	-	-	●	●
S4	●	●	●	-	-

After a careful mixing of the all components concrete mixture were placed into cleaned plastic forms. Thus prepared forms were then over 15s compacted on a vibrating table. After filling, cubic forms were labelled and placed on a flat surface next 48 hours. After 48 hours, the cube bodies were removed from the forms and then placed in a water bath. Time hardening of samples contained recycled concrete aggregate was 2, 7, 14 and 28 days, and 28 and 90 days for samples based on steelmaking slag fractions.

Compressive strength testing was performed on samples shaped cubes with dimensions 150 x 150 x 150 mm according to the standard [8]. Compressive strength (only samples with recycled concrete aggregate) was tested at the time intervals specified in Table 4

Table 4

Compressive strength testing intervals for samples with recycled concrete aggregate

Sample	Days
R1	2, 7, 14, 28
R2	2, 7, 14, 28
R3	14, 28
R4	14, 28
R5	14, 28
R6	2, 7, 14, 28
R7	2, 7, 14, 28
R8	14, 28
R9	14, 28
R10	14, 28

The actual test compressive strength of the samples was carried out on the hydraulic bench press Dr MB 300.

Results and discussion

Figure 3 shows compressive strength samples prepared with recycled concrete aggregate after 2, 7, 14 and 28 days of hardening. The four concrete samples (R1, R2, R6 and R7) was monitored start-up compressive strength after 2, 7, 14 and 28 days of hardening. Figure shows, that samples R1 and R2 after 7 days meeting the minimum strength of 20 MPa according to [9], but samples R6 and R7 fulfills this requirement after 28 days. Of Figure 3 it is evident that all samples met the requirement of a standard (strength 20 Mpa), and already after 14 days setting. Highest compressive strength after 28 days of hardening reached sample R4 (34.68 MPa; 100% recycled fraction 4/8 mm, and 60% recycled fraction 8/16 mm), but these are only slightly different from the strength of the reference sample R1 (34.41 MPa). The lowest strength reached sample R8 (40% recycled fraction 4/8 mm, and 100% recycled fraction 8/16 mm).

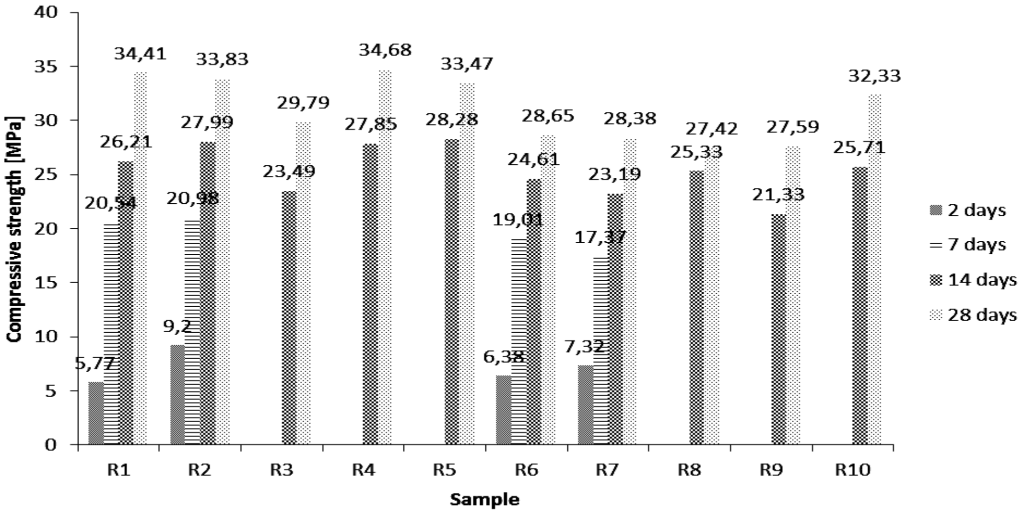

Fig. 3. Compressive strength samples prepared with recycled concrete aggregate after 2, 7, 14 and 28 days of hardening

The concrete samples called S1 and S2 with natural aggregate replacement by two different fractions of slag lead to higher compressive strength after 28 and 90 days of hardening compared to sample S4 prepared only with natural aggregate. The considerable increasing in compressive strength after 28 days was reached in sample S1 and after 90 days it was in sample S2. For sample S1, the compressive strength after 28 days was higher by 4.8% compared with a reference sample S4 (only natural aggregate), for sample S2 after 90 days higher by 3.9 Complete natural aggregate replacement by two fractions of slag together (sample S3) lead to decreasing of cube strength compared with reference sample S4. Increase the compressive strength of sample S3 was after 28 days 10.7% and after 90 days 0.85%. Figure 4 shows compressive strength samples after 28 and 90 days of hardening.

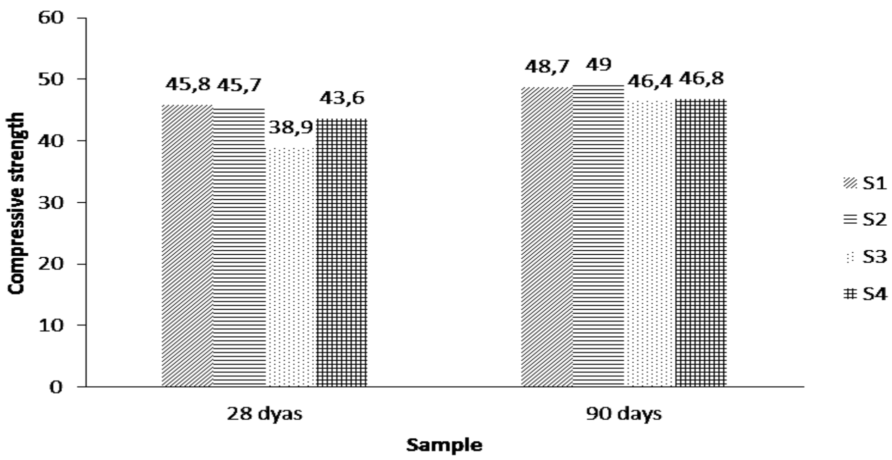

Fig. 4.Cubes compressive strength of concrete samples prepared with steelmaking slag after 28 and 90 days of hardening

Conclusion

Way of recovery of construction waste is most important to their recycling. Recycling will help to conserve natural resources and waste is used in further manufacture. Recycling technologies are from year to year, more modern and more powerful. Recycling of concrete waste generated and the subsequent use of recycled materials in the production of new concrete now has an increasing trend.

Results show that it is possible to replace the two fractions (4/8 mm and 8/16 mm) of natural aggregate by recycled concrete aggregate to making of recycled aggregate concrete lower strength classes. Thus concrete meet standardized requirements for final compressive strength.

The second part of this paper is aimed to natural aggregate replacement by selected fractions of steelmaking slag in concrete mixture. From the analysis of obtained results follows that steelmaking slag can be successfully used as a natural aggregate replacement in lower strength classes' concrete production and has not negative effects on the properties of hardened concrete. However, such use of steelmaking slag in concrete can be recommended, but first some important (durability and corrosion) properties of steelmaking slag concrete are necessary to investigate.

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