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Feasibility Analysis of Partial Replacement of Coarse and Fine Aggregates by Waste Steel Slag in Concrete Interlocking Paving Blocks

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ABSTRACT

Reinforcement steel manufacturing is an important industrial process relevant to the construction industry as reinforcements are essential products for civil engineering constructions in the present context. Steel slag is a byproduct generated in the manufacturing process of reinforcements steels. However, presently waste steel slag is not utilized for any meaningful usage even though there is a great potential to use it as a construction material especially in concrete mixes and products. Therefore, this study focused on analyzing the feasibility of partially replacing fine and coarse aggregates in concrete interlocking paving blocks. Accordingly, an extensive experimental study was carried out by partially replacing both fine and coarse aggregates in class 3 interlocking paving block production by waste steel slag. According to results of the study, the optimum partial replacement percentages of natural fine and coarse aggregates by separated steel slag particles were identified as 30% and 40% respectively considering mechanical, financial and sustainable perspectives. When the partial replacement percentages were increased further, it was noted that desired characteristics required for the concrete interlocking blocks were not achieved. Findings of this study would enable the effective utilization of waste steel slag as a raw material for concrete interlocking paving block production.

Keywords: Concrete interlocking, paving blocks Waste, steel slag, Coarse aggregates, Fine aggregates

1. INTRODUCTION

Steel slag is a byproduct generated during steel manufacturing processes. This byproduct is generated during either the conversion of iron to steel in a basic oxygen furnace, or the melting of scrap to make steel in an electric arc furnace. The slag occurs as a molten liquid melt as it is required to remove excess amount of undesired elements like carbon, silicon, manganese, phosphorus, etc. during the steel manufacturing process. Hence, it is a complex solution of silicates and oxides that solidifies upon cooling. There are quite a few steel reinforcement manufacturing companies functioning in Sri Lanka to cater the demand for the steel reinforcement requirement of the construction industry. Most of these companies used scrap metals as the raw material for their production. Therefore, considerable amount of metal slag is generated in these factories and presently, there is no effective usage of this material other than usage for land filling in local context. As per a study done by authors relevant to annual generation of steel slag at a factory, it was reported that annual generation is about 800-1000MT per year.

Concrete interlocking paving blocks are popular paving material for rural and internal roads, parking areas, walkways , gardens, etc. Competitive price, better infiltration ability, attractive appearance, easiness for maintenance and replacement are some major desired characteristics of concrete interlocking blocks for this popularity. However, scarcity of sand and metals, which are essential ingredients of concrete is becoming a serious concern in the construction industry in the country. As per a study done by Piyadasa 2011 [1], the annual sand requirement of the country of for construction activities is about 7–7.5 million cubic meters per year. According to a a study carried out by Dharmaratne 2016 [2], the production of course aggregates from natural rock quarries are ranging from 1500 m3 to 15,000 m3 per month. These have raised serious environmental concerns, and the government is regularly introducing strict rules and regulations for sand mining and rock quarry operations to mitigate environmental concerns. As a result of that, a scarcity and escalation of price of these raw materials are being experienced by the construction industry at the moment. Hence, the possibility of studying various alternative materials to use as fine and coarse aggregates is a timely need.

There are certain researches where steel slag has been used as coarse or fine aggregates for concrete and concrete products in global context. A study carried out by Olonade et al (2015) [3] on partially replacing fine aggregates of 1:2:4 concrete by crushed steel slag has indicted that compressive strength of concrete has increased until partial replacement percentage reached 50%. Also, a minimal effect on flexural strength has been reported with partial replacement of fine aggregates by crushed steel slag. Another study carried out by Sultan et al (2014) [4] on partial replacement of fine and coarse aggregates of concrete with steel slag waste have shown encouraging results of using steel slag as aggregates for concrete. In their study, they have separately replaced fine and coarse aggregates by various percentages upto 100% by steel slag and effects on mechanical properties of concrete have been studied. Increase of concrete strength has been reported even when percentage replacements of fine and coarse aggregates are high as 50-60% in this study. However, the natural coarse aggregates used in control mixes of this study are crushed limestone aggregates, which is rarely used in Sri Lankan context.

A study carried out by Shah et al [5] on partial replacement of coarse aggregates by steel slag has indicated that the optimum percentage replacement of coarse aggregates by steel slag as 40%, when it considered the compressive strength characteristics of concrete. Similar results have been indicated by a study carried out by Padmapriya et al [6] as well. According to the results of the study the optimum partial replacement percentage has been found as 40% based on strength results of concrete.

Olofinnade et al (2021) [7] has studied about the possibility of partially replacing course aggregates by steel slag particles in concrete interlocking paving block production. According to finding of their study, compressive strength of interlocking blocks have increased until percentage replacement reaches 40%. However, the highest split tensile strength have been reported with partial replacement percentage of 20%.

A Local research also have been carried out of using waste steel slag for production of interlocking blocks by Nirainenchan et al (2024) [8]. In their research too , coarse aggregates have been partially replaced by waste steel slag particles by different percentages up to 30%. Additionally, the fine aggregates have also been partially replaced by ceramic title waste by a fixed percentage of 25%. As per results of their, study the compressive strength and splitting tensile strength have been increased with the increase of partial replacement percentage of coarse aggregates by waste steel slag particles. Nevertheless, the reported compressive strength values of all partially replaced samples were less than strength values of control samples.

As per overall results of all of above studies, a great potential of using waste steel slag as aggregates in concrete production is clearly visible. However, when it considers collected slag waste at steel manufacturing yards, particle sizes of slag waste particles normally vary from 0.075mm to 14mm. Usually, when dispatching these stock of steel slags, managements of these yards are expecting to dispatch them as a whole lot and potential buyers also expect to utilize whole lot for any potential usage with minimum wastages. A photograph of stock of waste steel slag at a local reinforcement manufacturing yard is shown in Figure 1.

Figure 1. Stock of waste steel at a reinforcement manufacturing yard and obtained sample of waste steel slag

Therefore, if it is possible to use steel slag waste particles as both fine and coarse aggregates by partially replacing conventional aggregates in concrete production, it would be highly beneficial for effective utilization of waste steel slag. However, none of the above studies have been focused on this aspect. Therefore, this study was focused on studying the effects of partially replacing of both fine and coarse aggregates by waste steel slag simultaneously in concrete interlocking paving block production, and the identification of optimum partial replacement percentages in this regard through experimental testing.

2. MATERIALS AND METHODS

As per SLS 1425- Part I :2011[9], which is the local standard for interlocking concrete paving blocks, there are four (04) strength classes for concrete interlocking paving blocks. Strength class 1 to 3 has been recommended for vehicular traffic and strength class 4 has been recommended for pedestrian traffic. For most commercial applications, the most used strength class is Class 3 as the local standard allows us to use it up for vehicular traffic up to traffic class T4 (Equivalent Standard Axel (esa) =< 3x106). There are two main shapes discussed in the standard. Since, Rectangular shape is the most widely used type for commercial applications, it was decided to focus this study on blocks with rectangular shape (having standard size of 200 mm x100 mm x 80 mm) comply with Strength class 3. For Strength class 3, the expected minimum average compressive strength is 30N/mm2. DoE method was used for mix design for this study as most of previous studies [10-12] also adopted that method for development of mix designs for concrete interlocking paving blocks. Initially, mix design was developed considering usage of natural fine and coarse aggregates. The developed mix design is presented in Table 1. In the mix designed, the water/cement ratio was considered as 0.54 targeting a dry consistency for the mix as per the local practice adopted in the interlocking paving production industry.

Table 1. Quantities of ingredients used for the control mix

Materials	Quantity (kg per 1m3)
Cement	350
Fine aggregate	725
Coarse aggregate	1180
Water	190

According to objectives of this study, it was decided to partially replace both fine and coarse aggregates by waste steel slag. As the first step, the collected waste steel slag was sieved through 14 mm, 4.75 mm and 0.075 mm sieves to identify the particle size distribution of this material. The reported percentages of particles in different particle groups are presented in Table 2.

Table 2. Reported percentages of particles in different particle groups

Sieve size	Percentage of particles
14 mm >	0.0
14 mm - 4.75 mm	28.7
4.75mm - 0.075 mm	70.2
< 0.075mm	1.1

Accordingly, it is clear that whole range of particles of waste steel slag can be used as either coarse aggregates or fine aggregates. However, more than 70% of particles belong to the fine aggregate category. To check compliances of fine and coarse aggregates obtained from waste steel slag through above process to requirements of BS 882: 1992, sieve analyses were performed for coarse and fine aggregate segments separately . Sieve analysis results of fine and coarse aggregates obtained through waste steel slag are presented in graphical form in Figure 2 and Figure 3.

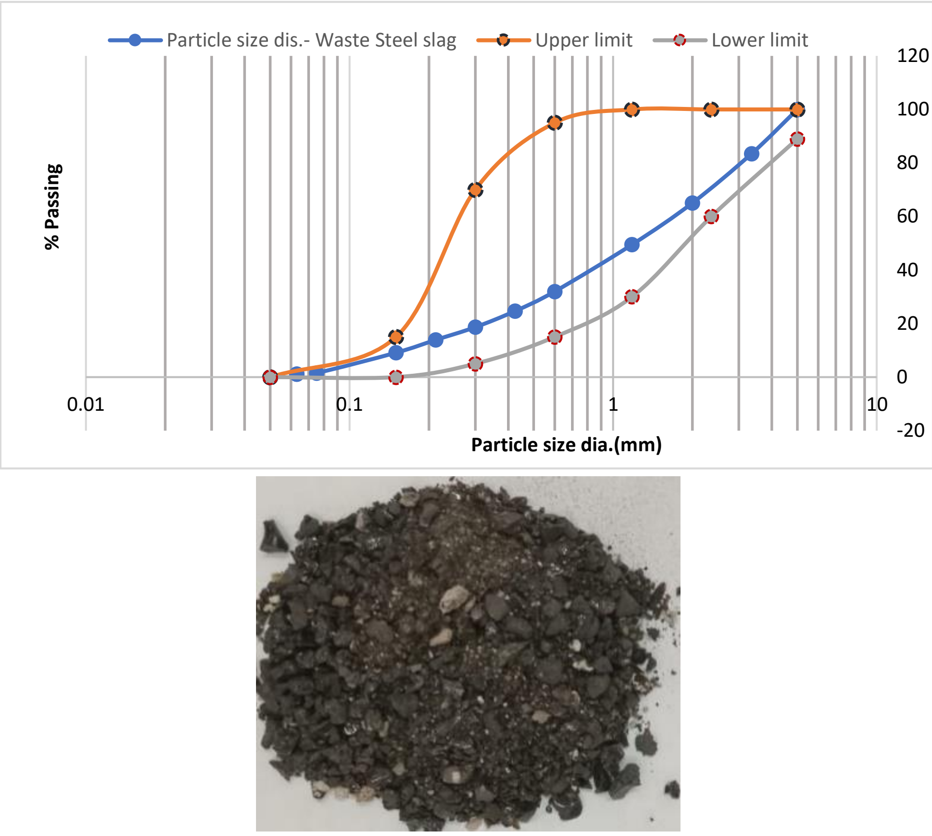

Figure 2. Sieve analysis results of separated fine aggregates from waste steel slag and a photograph of separated fine aggregates

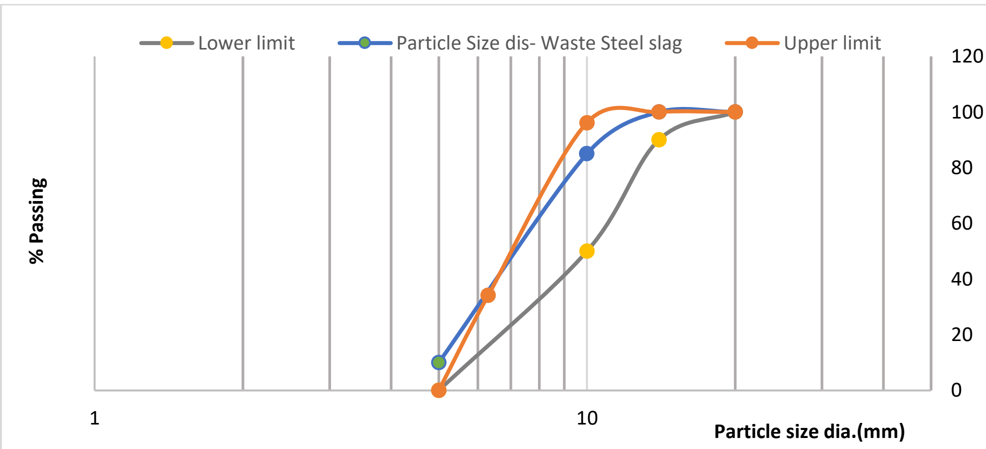

Figure 3. Sieve analysis results of separated coarse aggregates from waste steel slag and a photograph of separated coarse aggregates

According to the results, particle size distribution of waste steel slag as fine aggregates is well placed within the limits specified in BS 882: 1992. However, as per the pattern of the curve, fine waste steel slag particles have shown an Open graded variation. It means, amount of smaller particles is relatively less in the content. Hence, the increase of partial replacement percentage of natural fine aggregates by fine steel slag particles to a higher level would effect on desired strength characteristics of concrete.

In the case of considering waste steel slag as coarse aggregates, grading curve has placed close to the upper limits specified in BS882: 1992 as it can observe in Figure 3. Additionally, specific gravity of steel slag aggregates was checked as per the standard procedure, and it was found as 2.72. This is slightly higher than the specific gravity of natural aggregates. However, it is fairly close with the specific gravity of natural aggregates. Also, shape and texture of steel slag particles are more or less compatible with the same of natural aggregates.

Based on the results of previous studies [5,6] and findings of sieve analyses, it was decided to adopt a fixed partial replacement percentage of 40% for coarse aggregates for all samples. However, the percentage partial replacement of fine aggregates by separated waste steel slag particles was varied from 0% to 40%. The water/cement ratio was maintained at 0.54 for all mixes. Considered mixes with mix proportions are presented in Table 3. Ordinary Portland Cement (OPC) was used as the cement for production. During the batching process, each component was accurately measured and verified to maintain consistency. Once the materials were properly weighed, the concrete was hand-mixed to achieve uniformity in texture and consistency, ensuring the proper distribution of the ingredients. The freshly prepared concrete was then poured into rectangular moulds with dimensions of 200 mm × 100 mm × 80 mm. The concrete was thoroughly compacted within the moulds to eliminate air pockets and ensure a dense, uniform structure. After the initial setting time, samples were immersed in water tanks for curing as per the common industrial practices.

Table 3. Considered mixes with mix proportions for the study

Mixes	Cement (kg)	Fine aggregates		Coarse aggregates	
		Sand as fine aggrege. (kg)	Watse steel slag as fine aggrege. (kg)	Watse steel slag as coarse aggrege. (kg)	Watse steel slag as coarse aggrege. (kg)
Mix 1 (Control 1)	350	725	0	1180	**0**
Mix 2 (Control 2)	350	725	0 (0%)	472 (40%)	**708**
Mix 3	350	652.5	72.5 (10%)	472 (40%)	**708**

Mix 4	350	580	145 (20%)	472 (40%)	**708**
Mix 5	350	507.5	217.5 (30%)	472 (40%)	**708**
Mix 6	**350**	**435**	**290 (40%)**	**472 (40%)**	**708**

Note: percentage replacements were shown in bold letters relevant to each mix

At the time of preparation of concrete, workability of each mix was checked through standard slump tests to study the effect of partial replacement of aggregates by waste steel slag on fresh concrete. Then, the compressive strengths of blocks were checked at 7 days and 28 days. Further, flexural strength and splitting tensile strength of blocks were also checked at 28 days. The water absorption and dry weight of blocks were also checked for each considered mix. These tests were performed to study the effect of partially replacing aggregates by waste steel slag on mechanical properties of concrete interlocking paving blocks.

3. RESULTS AND DISCUSSION

3.1. Slump test

As workability of fresh concrete is an important characteristic when producing any type of concrete, the workability of considered alternatives was measured through standard slump cone test. Results of the test are presented in Table 4. As can be observed in Table 4, all mixes showed almost zero slumps. In the mix design, indicating dry consistency for the mix as it was targeted in the mix design. Further, as per results, partial replacement of fine and coarse aggregates by waste steel slag causes a minimum impact on workability irrespective of partial replacement percentages considered in this study.

Table 4. Slump test results

Mix ID	Steel slag as fine aggregate (%)	Steel slag as coarse aggregates (%)	Slump (mm)
Mix 1 (Control 1)	0	0	**0**
Mix 2 (Control 2)	0	40	**4**
Mix 3	10	40	**2**
Mix 4	20	40	**0**
Mix 5	30	40	**0**
Mix 6	**40**	**40**	**0**

3.2. Compressive strength

As per SLS 1425- Part I :2011 [1], the main mechanical property that should be checked is compressive strength of blocks. Accordingly, compressive strength blocks cast based on all considered mixes were tested at 7 days and 28 days as per the standard test procedure of the local standard. The results of tests are presented in Figure 4.

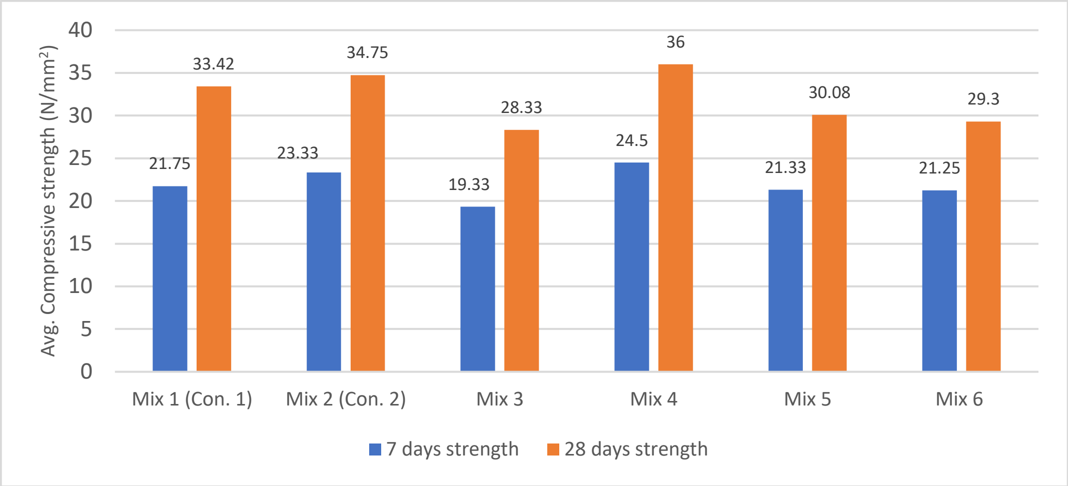

Figure 4. Compressive strength test results

According to the results, the highest compressive strengths on both 7 days and at 28 days were reported in Mix 4. However, samples of Mix 1 (Control 1), Mix 2 (Control 2) and Mix 5 also showed compressive strengths higher than the target average compressive strength of 30N/mm2. Further, in case of Mix 2 (Control 2), where only coarse aggregates were partially replaced by waste steel slag up to 40%, increase of average compressive strength from Mix 1 (Control 1- where no partial replacement was done for neither fine aggregate or coarse aggregates) was reported. Similar observations have been reported in previous studies [4,5,6,8] as well where coarse aggregates were partially replaced by waste steel slag.

As per various literature [7,14,15], the content of SiO2+Al2O3+ Fe2O3 is in the range of 30- 45% and the content of CaO is in the range of 35%-62% in steel slag. A study done by Jalil, 2018 [14] has highlighted the possibility of using steel slag in powder form as a Supplementary Cementitious Materials (SCM) by partially replacing cement in concrete. Hence, even when it is used waste steel slag as a fine and coarse aggregates by partially replacing natural aggregates as in this study, it could unintentionally act as a SCM as well. It may be the possible reason for reporting highest compressive strengths in Mix 4, where fine aggregates and coarse aggregates were replaced by steel slag by 20% and 40% respectively. However, when the partial replacement percentage of fine aggregates was increased further , reduction of compressive strengths was reported as it could observe in Figure 4. As already mentioned, reduction of amount of small particles in concrete mixes could occur when increasing partial replacement percentage of natural fine aggregates by fine steel slag particles. This would lead to the development of larger voids in between particles in the microstructure of the concrete. Hence, this could negatively affect on strength properties of blocks nullifying positive effects on strengths by steel slag as a SCM when partial replacement percentages were relatively high. This would be the most probable reason for the reduction of strengths when partial replacement percentage of fine aggregates are greater than 20%. Nevertheless, blocks of Mix 5 have also achieved 28 days average compressive strength higher than 30 N/mm2.

3.3. Tensile splitting test

SLS 1425- Part I :2011[1] does not specify any other strength test other than compressive strength test for concrete interlocking paving blocks. However, some other international such as Indian standard IS 15658 : 2006 [15] specifies tensile splitting test and flexural strength as optional requirements. Therefore, it was decided to carry out the tensile splitting strength test also under this study. Photographs of test setup used for tensile splitting strength tests as per IS 15658:2006 [15] are presented as Figure 5.

Figure 5. test setup used for tensile splitting strength tests

Once tests are performed under the above test setup, average flexural strengths for each mix were calculated as per equation 1. Tensile spitting strength (in N/mm^2) T = 0.637 x k x (P/S)

Equation 1

k = 1 (as per dimensions of the blocks)

P = Failure load (in N)

S = Area of the failure (in mm^2)

The results of average tensile splitting strength tests in graphical form are presented in Figure 6, However, IS 15658:2006 [15] does not specify any specific strength as the compliance criteria.

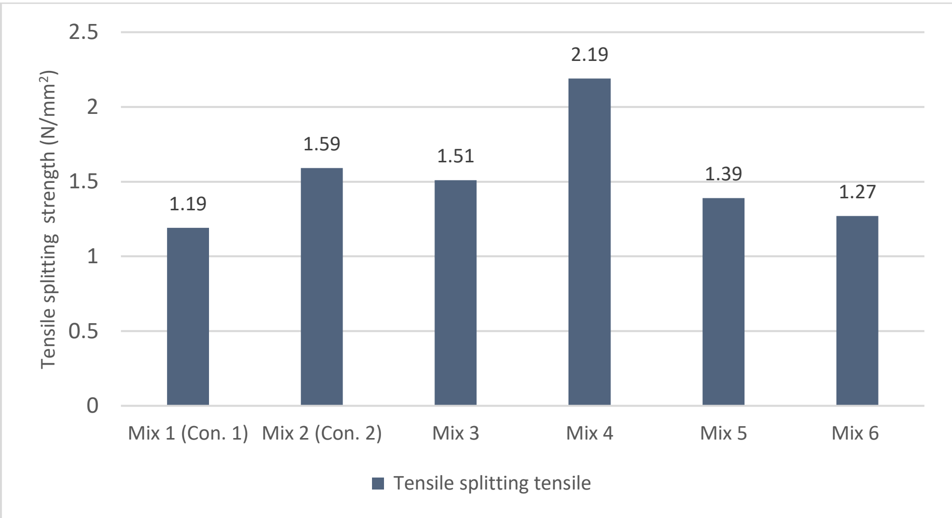

Figure 6. Results of average tensile splitting strength tests

As per results, the highest average tensile splitting strength was reported in Mix 4 samples. The lowest average splitting tensile strengths were reported in Mix 1 (Control 1) samples. According to results , partial replacements of fine and coarse aggregates by steel slag provided an improvement in tensile splitting strength up to a certain partial replacement percentage and a reduction of tensile splitting strength was reported after that. Somewhat similar results have been reported by Olofinnade et al (2021) [7] in their study where coarse aggregates were partially replaced by waste steel slag in concrete interlocking paving block production. According to the results of that study, the highest tensile splitting strength was reported when partial replacement percentage of coarse aggregates was 20%. However, in this study the highest tensile splitting strength was reported when partial replacement percentage of fine aggregates was 20% and partial replacement percentage of coarse aggregates was 40% (Mix 4). Already discussed, cementitious properties of steel slag and better interaction of steel slag particles with other ingredients of the concrete would be the probable reason for the increase of tensile splitting strength with the addition of steel slag as coarse and fine aggregates. However, when partial replacement percentages are very high, as already discussed, the effects of particle size distribution of waste steel slag would become the dominant factor causing the reduction of tensile splitting strength as it can be noticed here.

One noticeable feature observed when checking failure planes of tensile splitting test samples was splitting had been taken placed across certain coarse steel slag aggregates as well . However, failure across natural coarse aggregates was not observed in samples relevant to Mix 1 (control 1) . Figure 7 shows photographs taken on failure plane of a sample with steel slag aggregates where the spliiting has taken palce across coarse steel slag agrregares. Places where splitting has taken place across steel slag aggrgates are marked in red circles in Figure 7.

Figure 7. Photographs taken on failure plane of a sample with steel slag aggregates

3.4. Water Absorption

As per SLS 1425- Part I : 2011 [1], water absorption is another crucial factor that should be checked when selecting a concrete interlocking paving block. Accordingly, water absorption of all considered mixes were checked as per the standard procedure of the specification. Results of the water absorption of mixes considered are presented in Figure 8.

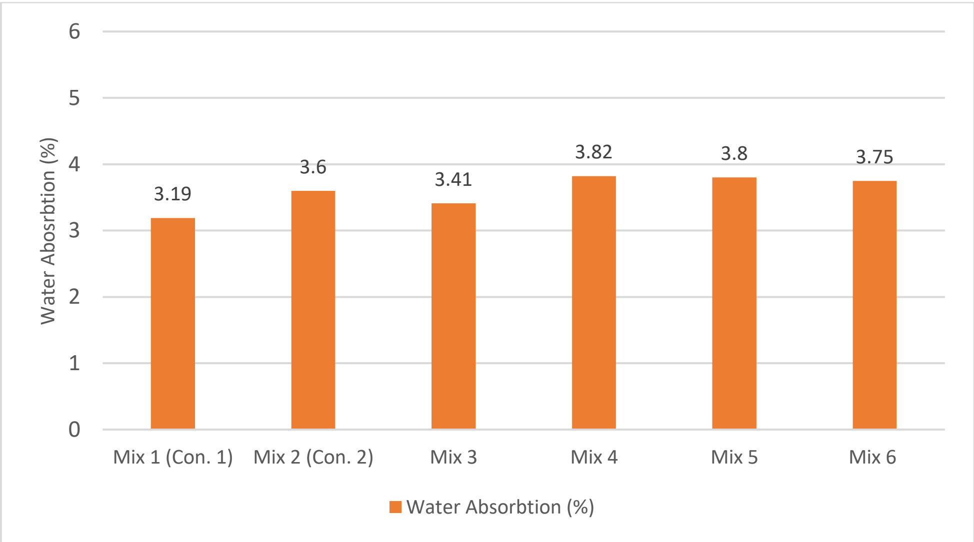

Figure 8. Results of water absorption tests

According to results, the maximum and minimum water absorption was reported in Mix 4 and Mix 1 (Control 1) respectively. However, all reported values are well within the specified value of 6% of the local specification. Any specific pattern of the variation would not be able to be found as per the recorded results. However, presence of excess voids in microstructures of samples when waste steel slag is used would be one probable reason for observing high water absorption percentages for samples with waste steel slag particles.

4. CONCLUSION

The aim of this study was studying the effects of partially replacing of both fine and coarse aggregates by waste steel slag simultaneously in concrete interlocking paving block production and the identification of optimum partial replacement percentages in this regard through experimental testing. According to the results of compressive and tensile splitting tests that were performed to identify effects on mechanical properties of concrete interlocking paving blocks, it was found that more desired strength characteristics could be achieved by partially replacing both coarse and fine aggregates. The highest average compressive strengths (for both 7 days and 28 days) and the highest average tensile splitting tensile strength were reported in the mix (Mix 4) , where coarse aggregates were replaced by 40% and fine aggregates were replaced by 20% waste steel slag with respective particle sizes. However, since increasing of partial replacement percentages are beneficial in financial and sustainable perspectives, Mix 5 (where fine and coarse aggregates were partially replaced by 30% and 40% respectively by waste steel slag) would be the optimal mix, since tested blocks cast by this mix still satisfy the required mechanical characteristics.

In terms of water absorption, blocks casted by mixes with waste steel slag aggregates showed slightly higher water absorption percentages compared with blocks of control mix (Mix 1). However, reported water absorption percentages for all mixes are far below the limit specified by the local standard.

Accordingly, it can recommend that replacement of natural fine aggregates up to 30% and natural coarse aggregates up to 40% by separated waste steel slag when producing class 3 concrete interlocking paving blocks as per the local standard. As this approach allows the effective utilization of entire rang particles removed as waste steel slag in steel reinforcement production, it would be a sustainable and cost-effective approach to utilize waste slag for the benefit of both paving block production industry and reinforcement manufacturing industry.

Nevertheless, influenced on durability aspects of interlocking blocks due to the usage of waste steel slag was not studied in the study and it is recommend investigating in future studies.

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AUTHORS CONTRIBUTION

This work was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The author (s) declared no potential conflicts of interests with respect to the authorship and/or publication of this paper.

5. REFERENCES

[1] Piyadasa R.U.K., River sand mining and associated environmental problems in Sri Lanka, Sediment Problems and Sediment Management in Asian River Basins(Proceedings of the Workshop held at Hyderabad, India, September 2009). IAHS Publ. 349, 2011. [View at Google Scholar]; [View at Publisher].

[2] Dharmaratne PG. Rock Quarrying and Sustainable Environment Management. In Proceedings of International Forestry and Environment Symposium 2016 (Vol. 21). [View at Google Scholar]; [View at Publisher].

[3] Olonade KA, Kadiri MB, Aderemi PO. Performance of steel slag as fine aggregate in structural concrete. Nigerian Journal of Technology. 2015 Jun 27;34(3):452-8. [View at Google Scholar]; [View at Publisher].

[4] Tarawneh SA, Gharaibeh ES, Saraireh FM. Effect of using steel slag aggregate on mechanical properties of concrete. American Journal of Applied Sciences. 2014 May 1;11(5):700. [View at Google Scholar]; [View at Publisher].

[5] Shah R., Kenil C., Nisarg P., Karankumar P., Malhar P., Thakkar J. , Evaluation of Compressive Strength by Utilization of Steel Slag in Concrete, IJIRT | Volume 7 Issue 11 | ISSN: 2349-6002. [View at Publisher].

[6] SLAG S. Study on Replacement of Coarse Aggregate by Steel Slag and Fine Aggregate by Manufacturing Sand in Concrete. INNOVAR. 2024 Aug 8. [View at Google Scholar]; [View at Publisher].

[7] Olofinnade O, Morawo A, Okedairo O, Kim B. Solid waste management in developing countries: Reusing of steel slag aggregate in eco-friendly interlocking concrete paving blocks production. Case Studies in Construction Materials. 2021 Jun 1;14:e00532. [View at Google Scholar]; [View at Publisher].

[8] Nirainenchan J., Gamage K., Chandrathilaka K. (2024) , Development of an optimum mix for paving blocks using waste steel slag and crushed tile waste as partial replacement of aggregates, Proceedings of Annual Sessions 2024, SSESL, AS2024-10, pp 88-93. [View at Publisher].

[9] SLS 1425-Prat I :2011 Sri Lanka Standard -Specifications for concrete paving blocks Prat 1: Requirements. [View at Publisher].

[10] Baskaran K, Gopinath K. Study on applicability of ACI and DOE mix design methods for paving blocks. Annual Transactions of Institution of Engineers, Sri Lanka. 2013:127-34. [View at Google Scholar]; [View at Publisher].

[11] Gunathilaka N, Mohamed S. Partial Replacement of Fine Aggregates by Lathe Waste in Concrete Interlocking Paving Blocks to Improve Desired Structural Characteristics. Journal of Civil Engineering and Materials Application. 2024 Sep 1;8(3). [View at Google Scholar]; [View at Publisher].

[12]Sampath J.A.K., Gunathilake A.M.L.N. , Identification of the optimum partial replacement percentage and w/c ratio for the partial replacement of cement by RHA in concrete interlocking paving block production, Modulus- June 2024 edition, Vol.34 No.2 , pp 13-17. [View at Publisher].

[13] No A. Specification for aggregates from natural sources for concrete. Bs. 1992;882:1-4. [View at Google Scholar]; [View at Publisher].

[14] Jalil A, Khitab A, Ishtiaq H, Bukhari SH, Arshad MT, Anwar W. Evaluation of steel industrial slag as partial replacement of cement in concrete. Civil Engineering Journal. 2019 Jan 27;5(1):181-90. [View at Google Scholar]; [View at Publisher].

[15] Li M, Lu Y, Liu Y, Chu J, Zhang T, Wang W. Influence of the Steel Slag Particle Size on the Mechanical Properties and Microstructure of Concrete. Sustainability. 2024 Mar 2;16(5):2083. [View at Google Scholar]; [View at Publisher].

[16] IS 15658:2006 Indian Standards – Pre cast concrete blocks for paving – Specification for concrete paving blocks Prat 1: Testing 2006.

[17] Krzywiński K, Chajec A, Sadowski Ł. The effect of the concentration of steel fibres on the properties of industrial floors. Technical Transactions. 2019;2019(Year 2019 (116)):115-32.. [View at Google Scholar]; [View at Publisher].