Lecture Notes in Mechanical Engineering

C. V. Chandrashekara
N. Rajesh Mathivanan
K. Hariharan *Editors*

Recent Advances in Materials and Manufacturing

Proceedings of ISME 2023

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Lecture Notes in Mechanical Engineering

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K. Hariharan
Editors

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Preface

The 21st in the series of Indian Society of Mechanical Engineers (ISME) Conference on Mechanical Engineering was jointly organized by Indian Society of Mechanical Engineers (ISME), New Delhi, PES University, Bengaluru, and Indian Institute of Technology Madras, Chennai, between 13th and 15th July 2023 at PES University, Bengaluru, Karnataka, India. ISME-2023 provided a platform for professionals from the industries, researchers, scientists, and academia to discuss latest trends, share knowledge, and exchange ideas in the various field of mechanical engineering.

The conference witnessed eleven keynote speakers drawn from both academia and industries. The keynote speakers are Prof. Subir Kumar Saha, Department of Mechanical Engineering, IITD, New Delhi; Mr. Vinod Kumar K., Senior Principal Scientist, Structural Technological Division, CSIR-NAL, Bengaluru; Dr. Raju, Centre Manager ARC Training Centre for AMAC, University of New South Wales, Sydney, Australia; Dr. Arshinder Kaur, Professor, Department of Management Studies, IITM, Chennai; Prof Sanjeev Sanghi, Head, Department of Applied Mechanics, IITD, New Delhi; Prof. A. Seshadri Sekhar, Director, IIT Palakkad; Dr. Prasad Patnaik B. S. V., Professor, Department of Applied Mechanics, IITM, Chennai; Prof. Navin Kumar, Professor, Department of Mechanical Engineering, IIT Ropar; Dr. Vivekanand Dabade, Assistant Professor, Department of Aerospace Engineering, IISc, Bengaluru; Prof. Pradeep Kundu, Professor, Smart Operations and Maintenance, Katholieke Universiteit Leuven, Belgium, and Mr. Dinesh M. Gupta, IOFS (Retd), Former DG and Chairman, Bengaluru.

The conference received 234 manuscripts as submission under three major tracks, viz. machine design; materials, manufacturing and industrial engineering; and thermal engineering, out of which 119 papers were accepted for the presentation at the conference, after subjecting them to peer reviewing. Out of 119 papers presented, 33 papers are recommended for publication in this present book.

The editors of the proceedings would like to sincerely express gratitude to all committee members, authors, peer reviewers, eminent keynote speakers, session chairs, participants, and all other members who have directly or indirectly supported in conducting the conference successfully. A special thanks to Prof. S. P. Singh,

Chairman, Prof. R. K. Pandey, Vice-Chairman, and Prof. Bhupinder Godara, Secretary, members of the ISME, New Delhi, for their continuous and tireless supports. Deeply express our gratitude for the generous support provided by Dr. M. R. Doreswamy, Chancellor, Prof. D. Jawahar, Pro-Chancellor, Prof. Ajoy Kumar, COO, Prof. J. Surya Prasad, Vice-Chancellor, and Prof. K. S. Sridhar, Registrar of PES University, Bengaluru.

We would also like to acknowledge all colleagues of the Springer Publication for their continuous support/guidance in the entire process of publishing this volume.

Bengaluru, India	Dr. C. V. Chandrashekara
Bengaluru, India	Dr. N. Rajesh Mathivanan
Chennai, India	Prof. K. Hariharan

Contents

Surrogate Model-Based Stochastic FPF Study of Tensile-Loaded Laminated Bamboo Composite 1
Deepak Kumar and Apurba Mandal

Nanotribological Properties of Graphene/h-BN Heterostructures 13
Srinivasa B. Ramisetti and M. Keerthivas

An Investigation on the Mechanical and Durability Properties of Concrete Structures Incorporated with Steel Slag Industrial Waste 21
L. Nirmala, M. L. Tejaswini, and M. L. Shilpa

Synthesis and Characterization of Al7075 Microcomposites with MgO/Mn 31
Avyakth S. Shekar, C. Balgopal, B. Akshay Vasista, Taniya Kaushik, and Sateesh Mudalagi

Effect of Stacking Sequence of Hybrid FML Subjected to Low-Velocity Impact 39
L. Sunith Babu, K. N. Mohandas, K. G. Jaya Christian, Parth Surelia, Manish Kumar Roy, Ninganagouda S. Paraddi, and Parth Priyadarshi

Optimization of Friction Stir Welding of Al–Cu Butt Joint Using Taguchi Method 53
J. Pratap Kumar and Anil Raj

Optimization of Friction Stir Welding Parameters for the Optimum Hardness of Al–Cu Butt Joints Using the Taguchi Method 63
J. Pratap Kumar, Anil Raj, Ivan Sunit Rout, G. Ravichandran, S. M. Darshan, S. J. Niranjana, and Stephan K. Vinod

Optimization of Process Parameters in Friction Stir Processing for the Development of Polymer-Derived Aluminum Matrix Composites 71
Sujith Kumar Kavanur Ramesh, Jagathram Subramanya, Govind Kumar, Satish V. Kailas, and Sateesh Mudalagi

Prediction of Hardness of Cast Iron Using Intelligent Tools 81
K. S. Sridhar, Abhilash Madabhushi, Ganapathi Viswanath, Nirmal Sudheer, and Sabrish Umesh

Feedstock Extrusion, Windability, and Printability Studies of Poly-lactic Acid (PLA) Material for Extrusion-Based Additive Manufacturing 87
Prashant Kumar, Naveen Kumar Bankapalli, Vishal Gupta, and Prateek Saxena

Experimental Evaluation of Failure Load of Composite Conical Thin Shell Without Bulkhead 97
R. Gopikrishna, T. Kirubakaran, M. Varadanam, and A. P. Das

Vibration Behavior of Syntactic Foam Core Sandwich Beam Using Natural Fiber Composite Face Sheets 109
Pratik M Karjagi, Guruprasad, Athiksh C Rao, R Mohan, and K S Srinivasa Prasad

Characterization of Ti-31 Alloy Coated with WC–Co/Cr by HVOF Technique 117
Sandeep Kumar K. Chavan, G. R. Gurunagendra, B. R. Raju, G. Madhusudan Reddy, and H. S. Siddesha

Investigations on the Effect of Applying Minimal Quantity Lubrication (MQL) Cooling for Surface Milling of Industrial Cast Iron Using Multi-Objective Optimization Technique 125
Harshit B. Kulkarni, Pradnya H. Kulkarni, and Ganesh R. Chate

Effect of Friction Stir Processing on Fatigue Properties of Al 6061-T6 Plates and Optimizing the FSP Parameters Using Machine Learning 135
M. Koushik, M. Madhu, and Sateesh Mudalagi

Study of Dry Sliding Wear Behaviour of Aluminium MMC 147
B. Venkata Sravana Kumar, Akshay S. Savakar, Adarsh Jaiswal, B. S. Jeeth, and B. Supriya

Flexible Piezoresistive Flow Sensor Based on PDMS and Graphite Particles 157
Abhinav Sharma, Suraj, Shivanku Chauhan, and Mohd. Zahid Ansari

Study of Friction Stir Processing on Al2219 Alloy, Surface Fabricated with B_4C and Graphite Particulates 169
M. Sharavann, R. Deepan, Mohanraj Jaishankar, Dhruv Kakde, and B. Supriya

Identification of Structural Damage Location and Severity Using Deep Learning 181
Sandip Kumar Roy Adhikari and Sivakumar M. Srinivasan

Experimental Study on Thrust Force and Torque on Post-drilling of Hybrid Glass/Kevlar FRP Laminates 187
N. S. Manjunatha Babu, K. Mohan Kumar, A. Sampath, A. Manjunath, N. R. Thyagaraj, and A. Srinivas

Ferrochrome and Graphite Transfer in Mild Steel Welds with E6013SS Electrode 203
Sunil Pandey, Manoj Kumar, and Madhav Mittal

Effect of Welding Current and Electrode Polarity on Weld Bead Geometry and Shape Relationships in Gravity-Assisted Mechanized Contact Shielded Metal Arc Welding 215
Manoj Kumar, Ritesh Shrimali, Ayush Kumar Singh, and Sunil Pandey

The Effect of Fe_2O_3 and Cr_2O_3 on Weld Bead Geometry Using Activated Metal Inert Gas Welding 227
Abhay Kumar Agrawal, Yashwant Koli, and S. Aravindan

Effect of Different Fluxes on the Weld Bead Formed on AZ91 Magnesium Alloy Using Activated Gas Tungsten Arc Welding 233
Lucky, Sasank Sekhar, and S. Aravindan

Experimental and Numerical Investigation of Tensile Strength of Hybrid Flax–Glass Epoxy Reinforced Composite 243
R. Rahul Reddy and Mantesh Basappa Khot

Optimization of Microwave Welding Parameters for Welding of PMMA Substrates Using Graphite Film as a Susceptor 259
K. Panneerselvam, S. John Vincent Jesuraj, Umang Dubey, and S. Mohan

Emissivity Study of Hierarchical GFRP-CNT Composites 271
A. R. Anilchandra, Jayaram R. Pothnis, Akshay K. Hajagolkar, Sathyapal Hegde, and Suhasini Gururaja

Analysis of Printing Parameters on the Performance of Robotic Gripper Jaws 281
Shivam Singh and S. B. Mishra

Design and Development of Hovercraft for Warehouse Application 293
V. Ananth Sai Gautham Konijeti, Syed Anas,
Vamsi Praneeth Gonugunta, Shaik Abdul Aahad, and D. Sethuram

Synthesis and Characterization of Composites of AA6063 with Graphene and Graphite Towards Corrosion for Marine Applications 309
H. Nagarjuna Raju, Nandeesh G. Handur, Piyush Singh, and S. V. Satish

Framework for Waste Collection Problem in a Low-Tech Urban Setting in India 323
Kaveri Kala and Nomesh B. Bolia

Defect Analysis and Improvement of Forged Component (Rocker Arm) to Improve Overall Productivity by Using Quality Tools 339
Sunil S. Karidkar and Nilesh Thombare

Models for the Indian Judicial System: A Study on Its Applicability and Challenges 353
Sri Harsha Dorapudi, S. G. Deshmukh, and Shaurya Shriyam

About the Editors

Dr. C. V. Chandrashekara is currently working as Professor and Associate Dean (Research) and Lead (Design Domain) in the Department of Mechanical Engineering, PES University, Bengaluru. He obtained his B.Tech. and M.Tech. from Sri Jaya Chamarajendra College of Engineering (SJCE), University of Mysore. He received his Ph.D. from Indian Institute of Technology Delhi (IITD), New Delhi. He served as Head of the Department of Mechanical Engineering for 16 years at JSS Academy of Technical Education, Noida, Uttar Pradesh. He also played a very important key role in Upper Krishna Project (UKP) in developing a unique and innovative software for Government of Karnataka, to take care of the effective disbursement of monitory benefits to the rehabilitees scientifically. He has published more than 50 papers in reputed peer-reviewed journals and international conferences. He is also serving as Executive Member of ISME. He served as Reviewer for many international journals and conferences. His area of interest is structural vibrations, modal analysis, dynamics of bio-medical engineering, and computational vibration analysis.

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An Investigation on the Mechanical and Durability Properties of Concrete Structures Incorporated with Steel Slag Industrial Waste

L. Nirmala, M. L. Tejaswini, and M. L. Shilpa

Abstract The construction sector constantly looks for novel approaches to promote sustainability, minimize environmental impact and improve structural properties of construction materials. This work explores the incorporation of steel slag, a by-product from steel manufacturing industry, into concrete blocks. This research investigates the effects of steel slag on the mechanical strength and durability of the prepared concrete blocks, through a series of laboratory tests, including compressive, tension, flexure strength, water absorption and acid attack. This study evaluates the viability and feasibility of incorporating steel slag into concrete block production. In this study, samples of concrete mixture were set with 0% to 20% insteps of 5% steel slag as coarse aggregate. The findings show that concrete blocks consisting 20% of steel slag exhibited better compressive, tensile, flexural strength, reduction in water absorption and improved resistance to chemicals.

Keywords Concrete · Steel slag · Mechanical strength · Durability

1 Introduction

Due to speedy growth in the industrialization, huge amount of waste materials are generated. On the other side, there is depletion of natural resources which affects severe challenges in various sectors due to rapid growth of urbanization. The effect of this is the huge demand in construction industries. These industries cater in developing a green environment by utilizing remains of industrial products. As many people shift from rural places to cities and towns, construction industries have to focus on alternate materials to avoid land fill, to control pollution and also to achieve

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sustainable economy. Therefore, there is an urge to utilize the industrial wastes to develop sustainable materials pertaining to construction field.

The concrete matrix is filled with 70% natural resources like fine aggregates and coarse aggregates. These aggregates which are considered as the prominent composition of concrete have significant impact on environment. The degree of risk involved makes it sensible to examine other sources of these raw ingredients, to eventually lessen their utilization and the energy consumption to achieve green concrete [1]. So there is a need to make use of industrial wastes. As Bangalore is considered as the fastest growing second metropolitan city in India, the steel usage has increased because of high-rise structures. Hence, the remains left over in the manufacturing of steel has to be treated which will in turn resolve the disposal problem, minimize the requirement of natural resources and overall lessen the energy and expenditure in making aggregates [2–4].

During the manufacturing of steel, impurities in pig iron undergo oxidation which results in the formation of residue called as steel slag [5]. For every 1 ton production of steel, around 20% of a ton of steel slag is generated. Presently, 19 MT of steel slag per year is generated [6, 7]. Hence, this work focuses on replacing coarser aggregate fractionally with steel slag in concrete. Storing steel slag for a very long period generates lot of filth due to process of weathering, which in turns spoils the quality of soil when the weathered steel enters into the ground during stacking process [8]. Cao, SiO_2, Al_2O_3, Fe_2O_3, FeO, MgO and MnO are the basic compositions present chemically in steel slag. This slag also contains dicalcium silicate, tricalcium silicate and calcium ferric aluminate as same as that of Portland cement [9–12]. By these compositions, steel slag has lot of cementitious properties and can be recommended for its use in concrete [13–16].

The durability behaviour like accelerated ageing, water absorption, porosity of concrete admixed with steel slag has been investigated and is lesser as compared to that of natural aggregates. The pop outs are formed on the concrete surface due to chemical reaction of acid, which forms a very expansive paste in turn exerting the pressure inside the concrete cubes [17] [18]. The aim of this research work is to incorporate steel slag in concrete of M40 grade and study its effect on strength and durability performance of concrete.

2 Material Collection and Characterization

In this study, the following are the materials collected. The cement used is Portland cement of 53 grade, IS 12269:1987. The characteristics of cement are determined and are shown in Table 1. High-quality aggregates meeting standard specifications locally accessible fine and coarse aggregates are used, and their characteristics are shown in Tables 2 and 3. An industrial waste steel slag procured locally is used in this study, and its characteristics are shown in Table 4. Necessary chemical admixture superplasticizer such as polycarboxylic ether-based superplasticizer MasterPolyheed 8760 confirm to IS 9103: 1999 with specific gravity of 1.08 is used.

Table 1 Characteristics of cement

S. no.	Characteristics	Experimental values
1	Specific gravity	2.98
2	Initial setting time	35 min
3	Fineness	2%

Table 2 Characteristics of fine aggregate

S. no.	Characteristics	Experimental values
1	Specific gravity	2.66
2	Fineness modulus	4.2

Table 3 Characteristics of coarse aggregate

S. no.	Characteristics	Experimental values
1	Crushing index	9.5%
2	Bulk density	1368 kg/m^3

Table 4 Characteristics of steel slag

S. no.	Characteristics	Experimental values
1	Specific gravity	3.58
2	Bulk density	2012 kg/m^3
3	Water absorption	2%

3 Experimental Investigations

Using a suitable mix design (IS-10262:2019), accurately weigh and blend the aggregates, cement, steel slag waste and water. To produce a mixture that is homogeneous, thoroughly mix the ingredients in a concrete mixer. Pour the concrete into moulds for preparing standard specimens for different tests (cubes, cylinders, prisms). The cubes of concrete having dimension of 0.15 m were prepared for compressive strength test, dimensions of 0.15 m length and 0.3 m diameter for tensile strength test and cubes of size 0.01 m for flexural test. The compressive test, split tensile test and flexure test are carried in accordance with IS 516:2021(Part-1s-1).

Prepared cubes are cured under standard curing conditions for the period of 7 to 28 days in steps of 7 days. The workability of steel slag concrete is tested by slump test as per IS code 1199–2018, and the targeted slump has been analysed. Further 12 cubes of size 0.15 m were prepared and immersed statically in 5% sulphuric acid solution, and same numbers of cubes were immersed in 5% magnesium sulphate solution for 60 days. Acid attack test on concrete is conducted based on IS 4860-1968, and sulphate attack test on concrete was performed in accordance with ASTM C1012.

4 Results and Discussions

The specified slump test is carried out in accordance with IS code IS 1199–2018. The experimental results of the slump test show that at 0% replacement level, the mixture of concrete gave a true slump value of 78 mm. The slump enhances as the percentage substitution level increases from 0 to 20% with w/c (water–cement ratio) of 0.4, 0.42 and 0.44. Adjusting the water–cement ratio ensures that there is adequate water to hydrate the cementitious materials, maintain workability and form a cohesive mix. The ratio which gave the best slump was selected.

In accordance with the results of the slump achieved, this falls under medium degree of workability. Figure 1 illustrates how the degree of workability of concrete increases in tandem with the percentage of steel slag. The uniform distribution of steel slag particles in the concrete mixture serves as an internal lubricant. By doing this, the mixture becomes more workable by minimizing the friction between the elements. Additionally, the lubricating effect keeps the concrete from segregating and guarantees a uniform consistency throughout. As an additional cementitious material, steel slag will undergo its own hydration reactions. The full workability of the concrete is facilitated by these hydration reactions. Hydration products increase the cohesion and slump of a mixture by coating and filling voids in the particles.

4.1 Mechanical Properties

The results obtained from the split tensile and compressive tests are shown in Figs. 2 and 3. Addition of steel slag to concrete, split tensile strength and compressive strength are enhanced. For standard curing time, the split tensile strength and compressive strength of concrete without steel slag are 4.5 N/mm^2 and 43 N/mm^2, respectively. For 5% steel slag incorporation, the split tensile strength is 4.7 N/mm2 and compressive strength is 45 N/mm^2, and for 10% steel slag incorporation, the split tensile strength is 4.9 N/mm^2 and compressive strength is 48 N/mm^2, for 15%

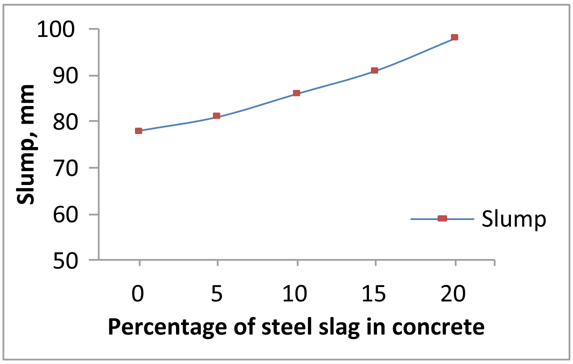


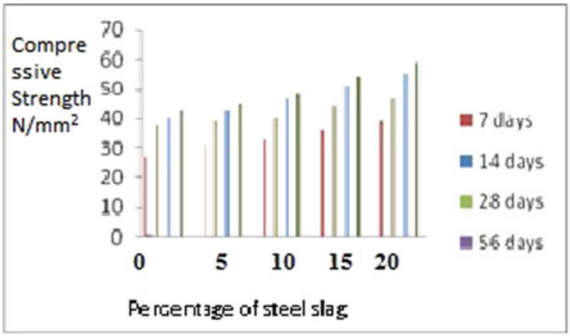
Fig. 1 Variation of slump with percentage of steel slag

steel slag incorporation, split tensile strength is 5.2 N/mm^2 and compressive strength is 54 N/mm^2, for 20% steel slag incorporation, split tensile strength is 5.5 N/mm^2 and compressive strength is 59 N/mm^2. The increase in strength is due to the uneven shape and surface texture of steel slag particles incorporated in concrete.

When uneven and textured surface steel slag particles are integrated into concrete, they will boost the packing density of particles, leading to substantial increase in strength, reduce the porosity and better bonding with the cement paste within the concrete [1, 2, 4]. The reactive compounds such as calcium oxide and silicate phases, present in steel slag help in forming additional hydration products during hydration reaction, which results stronger and denser concrete matrix. Steel slag reacts with calcium hydroxide in the presence of water during pozzolanic reactions to form additional cementitious compounds [14]. These reactions fund to the strength enhancement of concrete. Further steel slag itself has an extraordinary compressive strength. When it is used as a coarse aggregate in concrete, it provides a strong framework within the concrete mix, enhancing the overall structural strength.

Flexural test results are shown in Fig. 4. Flexural strength of concrete increases with addition of steel slag. For standard curing time, the flexural strength of concrete

Fig. 2 Variation of compressive strength with steel slag in concrete



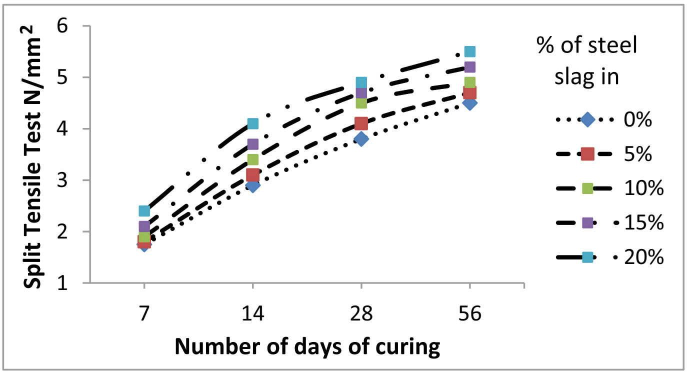


Fig. 3 Variation of split tensile strength with percentage of steel slag in concrete

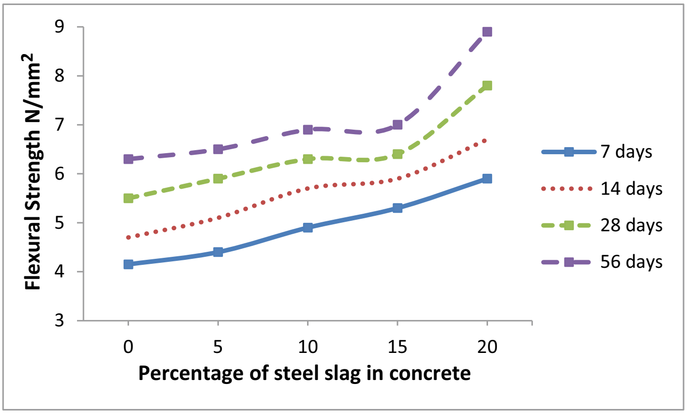


Fig. 4 Variation of flexural strength with percentage of steel slag

without steel slag is 6.3 N/mm^2. For 5%, 10%, 15% and 20% incorporation of steel slag in concrete, the flexural strength is 6.5 N/mm^2, 6.9 N/mm^2, 7 N/mm^2 and 8.9 N/mm^2, respectively. Rupture modulus of concrete increased with increase in steel slag, due to better bonding of steel slag with the cement paste. As the steel slag has rough surface, improved bonding between the aggregate and the paste takes place, which gives in a more cohesiveness and stronger concrete mix.

4.2 Durability Properties

Sulphate attack and Acid attack tests

The loss of concrete for the cubes immersed in sulphate solution is shown in Fig. 5. The loss of material from concrete incorporated with steel slag is less than that of the cubes without steel slag in concrete. Hence, the compressive strength of the concrete cubes incorporated with steel slag immersed in sulphate solution increases in comparison with the concrete cubes without steel slag. The loss of material from concrete without steel slag is 11.62% and from concrete with steel slag of 5, 10, 15 and 20% is 0.82%, 1.98%. 1.99% and 1.86%, respectively. This is due to the evidence of ettringite and gypsum which makes the concrete to condense, thereby increasing the stiffness of the concrete. The sulphate attack is concentrated mainly on the surface area of the concrete. Hence, the modulus of elasticity increases rapidly at the initial stages [19].

Sulphate attack on concrete without steel slag leads to expansion and cracking due to silica–alkali reaction. Concrete with steel slag is less responsive with alkalis compared to natural aggregates. This decreases the risk of silica–alkali reaction, leading to long-lasting strength and durability. So minerals present in steel slag will impart sulphate resistance to the concrete than the ordinary compounds formed

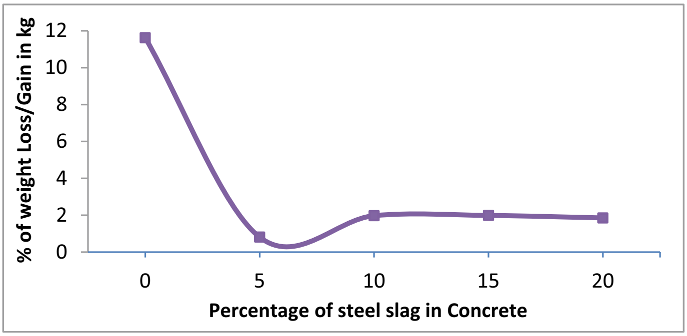


Fig. 5 Percentage weight loss/gain of concrete block due to sulphate attack

in regular concrete. Steel slag also consists of compounds like calcium and silica, and these compounds react with water and cementitious materials during hydration process forming additional hydration products such as silicate hydrate gel; this gel will occupy the voids and decreases the permeability of concrete; hence, sulphate ions cannot penetrate easily and cause deterioration. Lesser permeability concrete can also resist to aggressive environments [8]. Hence, partial replacement of natural aggregates with steel slag is advantageous.

For the cubes with steel slag when immersed in hydrochloric acid solution, the concrete loss is 11.02%, 10.95%, 10.88% and 10.82% as shown in Fig. 7. And for normal concrete cubes, the loss of concrete was 2.96%. Figure 7 depicts compressive strength of concrete cubes after exposing to acid solution. The drop in the compressive strength for the cubes immersed in acid solution is due to the consequence of leaching and dissolution of constituents which are more prone to acid, i.e. calcium hydroxide from the concrete mixture. This performance of the concrete is due to increase in capillary porosity, low cohesiveness and finally loss of strength [20] (Fig. 6).

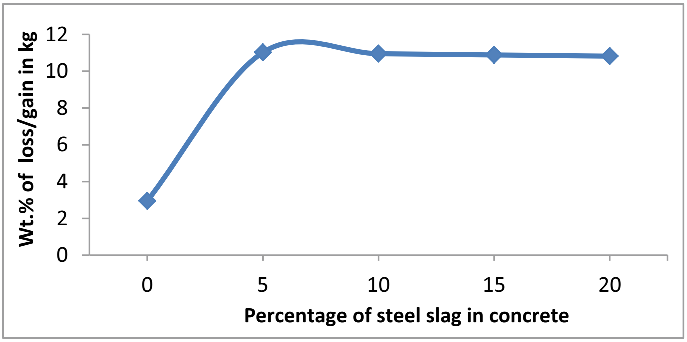


Fig. 6 Weight loss/gain of concrete block due to acid attack

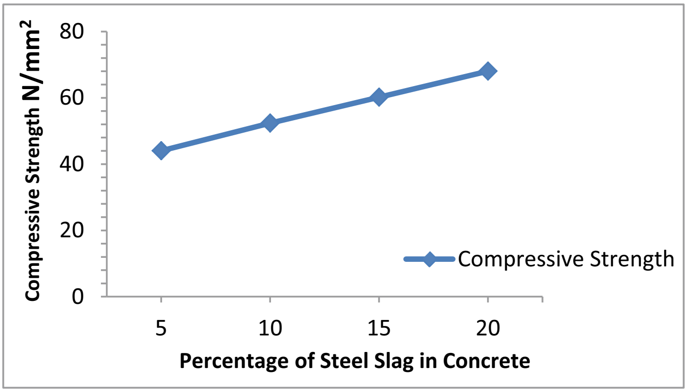


Fig. 7 Compressive strength of admixed concrete due to sulphate attack

4.3 Water Absorption Test

In this study, the concrete cubes with and without steel slag were initially dried out in an oven at 100–115 °C for a period of 24 h, and then, their weights were noted. Later, these specimens were completely immersed in water for a time period of 24 h. Afterwards, these specimens were removed and the surfaces were air dried. Finally, their weights were noted and are shown in Fig. 8. Water absorptivity for normal concrete is 1.28%, and for 5% incorporation of steel slag as a coarse aggregate, the water absorptivity was found to be 0.14%. Similarly, for 10, 15 and 20% inclusion of steel slag, the water penetration values were found to be 0.75%, 1.62% and 2.49%.

Water absorptivity of concrete cubes incorporated with steel slag is lesser when compared to concrete blocks without steel slag and is due to water-resistant nature of steel slag than that of normal aggregates. Compared to natural aggregates, steel slag particles are denser and less permeable. They result in a denser concrete matrix

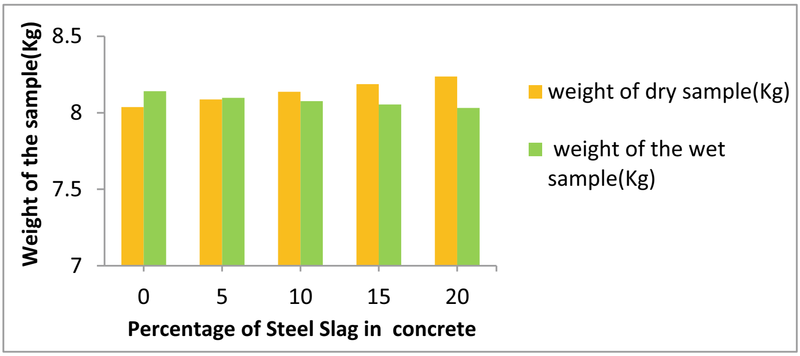


Fig. 8 Difference in weights of cubes before and after immersion in water

with fewer voids when they are added to concrete. This tighter structure limits water travel around and inside the concrete, lowering its overall capacity to absorb moisture. Further steel slag helps to form additional compounds during hydration process, and these compounds fill the voids. The properties like lesser permeability and strength of concrete cubes incorporated with steel slag are leading to lesser water absorption [21].

5 Conclusions

- The compressive strength, split tensile strength and flexural strength of concrete incorporated with 20% steel slag are found to be increased by 37.2%, 65.71% and 41.26%, respectively.
- Steel slag particles are irregular shape and varied surface texture compared to natural aggregates. When incorporated into concrete, they enhance the packing density of the particles, significantly increasing strength, reducing porosity, and improving bonding with the cement paste within the concrete. Hence, partial replacement of slag does not lead to expansion and cracking of concrete when exposed to sulphate solution, so steel slag minimizes loss of concrete when exposed to sulphate solution.
- The deposition of primary component (ettringite) and gypsum present in the cement makes the concrete more condense, thereby increasing the stiffness of the concrete when the cubes are immersed in sulphate solution.
- The reduction in the compressive strength for the cubes immersed in acid solution is due to the effect of leaching and dissolution of constituents which are more prone to acid, i.e. calcium hydroxide from the concrete mixture.
- The water absorptivity of the concrete cubes incorporated with steel slag is less when compared to concrete without steel slag. The reason behind this is the impermeable nature of the low carbon steel slag as coarse aggregate compared to that of normal aggregates.

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