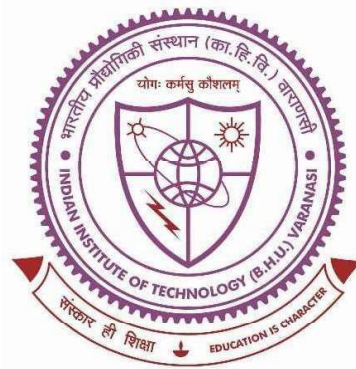


*Effect of Mold Material on the Evolution of
Morphology in Al-Si alloys*



Thesis submitted in the partial fulfilment
for the award of degree

Doctor of Philosophy

By

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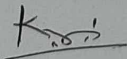
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Thesis

To My

Beloved Parents

ACKNOWLEDGEMENTS

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The world is going through some unprecedented times as the normal has been upended by the arrival of the deadly coronavirus pandemic. People across the globe are battling with Covid-19. Many who are locked at home like us are doing their part also by helping the people in many ways. But, others like doctors, soldiers, teachers, bank employee, office staff, railway employee, social volunteers etc. who are working outside to fulfil our requirements and taking care of the affected ones by risking their lives. I would like to thank them for their service towards humanity. Also, I would like to express my deepest condolences to those who lost their lives during this pandemic. Hope can always help pull people out of the most difficult of times. It is a powerful force and can prove to be a source of reassurance. Hence, I am immensely optimistic that very soon we will win this battle.

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Nitesh Kumar Sinha

CONTENTS

ACKNOWLEDGEMENTS	XI
LIST OF FIGURES	XVII
LIST OF TABLES	XXI
CHAPTER 1 INTRODUCTION	1
1.1 Introduction.....	2
1.2 The Major Industrial Solid Waste	2
1.3 Utilization of solid waste beneficial	3
1.4 Statement of the problem	4
1.5 Significance of Scope	5
1.6 Aim and Objective of the present work	6
CHAPTER 2 LITERATURE REVIEW	9
2.1 Introduction.....	10
2.2 Blast furnace slag	10
2.2.1 Characteristics of blast furnace slag	10
2.2.2 Research status of comprehensive utilization of blast furnace slag.....	12
2.3 Ferrochrome slag	13
2.3.1 Characterization of ferrochrome slag.....	14
2.3.2 Research status of comprehensive utilization of ferrochrome slag	14
2.4 Red Mud	15
2.4.1 Characterization of red mud.....	17
2.4.2 Research status of comprehensive utilization of red mud	17

2.5 Olivine sand	18
2.5.1 Characterization of Olivine sand	19
2.5.2 Research status of comprehensive utilization of olivine sand	20
2.6 Silica sand	20
2.6.1 Silica sand phase	21
2.6.2 Characterization of silica sand	22
2.6.3 Research status of comprehensive utilization of silica sand	22
2.6.4 Properties of sand mold	24
2.6.5 Advantages of sand-casting process	25
2.7 Summary and Outlook	30
CHAPTER 3 CHARACTERIZATION OF INDUSTRIAL SOLID WASTE AS A MOLD MATERIAL	31
3.1 INTRODUCTION.....	32
3.2 CHARACTERIZATION	32
3.2.1 Chemical analysis	32
3.2.2 Xray- diffraction (XRD)	33
3.2.3 Thermogravimetric analysis (TGA).....	33
3.2.4 Clay and moisture content	33
3.2.5 Sieve analysis.....	34
3.2.6 Flowability behaviour	36
3.3 RESULT AND DISCUSSION	38
3.3.1 Chemical analysis	38
3.3.2 Physical appearance	39
3.3.3 X-Ray Diffraction (XRD)	39
3.3.4 Thermogravimetric analysis (TGA).....	40
3.3.5 Particle Shape and particle size distribution	42
3.3.6 Clay and moisture content	45
3.3.7 pH value	46
3.3.8 Flowability behaviour	46
3.3.9 Relationship between particle shape, particle size distribution, and flow rate	49

3.4 Conclusions.....50

CHAPTER 4 FABRICATION OF SAND- SOLID WASTE MOLD USING CO₂ MOLDING PROCESS AND CHARACTERIZATION AS WELL AS COMPARISON OF MOLD PROPERTIES51

4.1 INTRODUCTION52

4.2 MOLD PREPARATION.....52

4.2.1 CO₂ molding process52

4.2.2 Silica sand- solid waste mold.....53

4.3 CHARACTERIZATION55

4.3.1 Mold properties55

4.3.2 Compressive strength.....55

4.3.3 Shear strength55

4.3.4 Hardness.....56

4.3.5 Permeability56

4.3.6 Compactness56

4.3.7 Thermal analysis57

4.4 RESULTS58

4.4.1 Compressive strength.....58

4.4.2 Shear strength61

4.4.3 Hardness.....64

4.4.4 Permeability65

4.4.5 Compactness69

4.4.6 Melting and casting.....70

4.4.7 Thermal analysis74

4.5 CONCLUSIONS77

CHAPTER 5 MICROSTRUCTURAL, MECHANICAL, AND WEAR BEHAVIOUR OF A 319 ALLOY CAST IN A DIFFERENT MOLD79

5.1 INTRODUCTION80

5.2 CHARACTERIZATION	80
5.2.1 Microstructural Analysis.....	80
5.2.2 Secondary dendritic arm spacing (SDAS)	81
5.2.3 Density/ Porosity.....	82
5.2.4 Tensile strength.....	82
5.2.5 Hardness.....	83
5.2.6 Wear.....	83
5.3 RESULTS	85
5.3.1 Microstructure.....	85
5.3.2 Tensile properties.....	93
5.3.3 Hardness.....	97
5.3.4 Density and Porosity	98
5.3.5 Wear rate	100
5.3.6 Coefficient of friction (COF)	103
5.4 CONCLUSIONS	109
CHAPTER 6 CONCLUSIONS AND FUTURE SCOPE	111
6.1 SOME MAJOR CONCLUSIONS OF THE PRESENT STUDY ARE AS FOLLOWS:.....	112
6.2 FUTURE SCOPE:	113

Referances

Publications

LIST OF FIGURES

Figure 1.1: Industrial solid waste system.....	2
Figure 1.2: Steel slag generation in India	4
Figure 1.3: Volume of the global casting production	6
Figure 1.4: Phase diagram of Al-Si alloy	6
Figure 1.5: Asymmetrical phase diagram of Al-Si and coupled region	7
Figure 2.1: Process flow of blast furnace slag	11
Figure 2.2: Process diagram of Bayer's process.....	16
Figure 2.3: Major country bauxite production(2019-2020)(in 1000 metric tons)	16
Figure 2.4: Silica sand resources as per grade	21
Figure 2.5: Phases of silica sand	22
Figure 2.6: Sand casting process.....	23
Figure 3.1: Particle size distribution	35
Figure 3.2: Setup of the angle of repose	37
Figure 3.3: Material used for mold preparation (a) blast furnace slag (b) ferrochrome slag (c) red mud (d) olivine sand (e) silica sand.....	39
Figure 3.4: XRD pattern of (a) blast furnace slag (b) ferrochrome slag (c) olivine sand (d) red mud (e) silica sand	40
Figure 3.5:TGA plot of (a) blast furnace slag (b) ferrochrome slag (c) silica sand (d) olivine sand (e) red mud	41
Figure 3.6: SEM images showing particle shape (a) blast furnace slag (b) ferrochrome slag (c) olivine sand (d) red mud (e) silica sand.....	42
Figure 3.7: Particle size distribution	45
Figure 3.8: Clay content of various mold materials	46

Figure 3.9: Formation of bond between grains.....	46
Figure 3.10: Occurrence of cone and static angle of repose of five materials.....	47
Figure 3.11: Angle of repose and flow behaviour	48
Figure 3.12: (a) Discharge time (b) Hausner ratio with respect to mold materials	49
Figure 4.1: CO ₂ molding processes	53
Figure 4.2: Standard size sample of (a) blast furnace slag (b) ferrochrome slag (c) silica sand (d) red mud (e) olivine sand used for the investigation of mold properties	54
Figure 4.3: Cross sectional view of mold and recording of temperature with thermocouple	57
Figure 4.4: Cooling curve	58
Figure 4.5: Gasified compressive strength of the mold	60
Figure 4.6: Failure of mold during a compression test.....	61
Figure 4.7: Gasified shear strength of the mold.....	62
Figure 4.8: Failure of mold during shear test.....	63
Figure 4.9: Gasified mold hardness of various mold.....	64
Figure 4.10: Gasified permeability of mold.....	66
Figure 4.11: Bonding between the grains of mold materials	68
Figure 4.12: Compactability of different mold	69
Figure 4.13: Mold fabrication process (a) Mold ingredient mixed in proportion (b) Cavity and venting hole in mold (c) Placing of cope and drag in position	72
Figure 4.14: Casting of A319 alloy in various mold	72
Figure 4.15: Cast product of various mold	73
Figure 4.16: Surface micrograph of cast sample	74
Figure 4.17: The cooling curve of A319 alloy cast in a different mold.....	75
Figure 5.1: Schematic view of the Test Sample	80

Figure 5.2: Secondary dendritic arm spacing	81
Figure 5.3: Tensile sample.....	83
Figure 5.4: Sample of wear test	84
Figure 5.5: Wear test machine universal tribometer and Schematic view of reciprocating wear.....	85
Figure 5.6: Position of sample and steel ball	85
Figure 5.7: Microstructure of A319 alloy cast in a sand mold	86
Figure 5.8: XRD of A319 alloy cast in a different mold	87
Figure 5.9: Porosity micrograph of A319 alloy cast in(a) silica sand mold (b) blast furnace slag mold (c) ferrochrome slag mold (d) red mud mold.....	88
Figure 5.10: Dendritic microstructure of A319 cast in ferrochrome slag mold	89
Figure 5.11: Dendritic microstructure of A319 cast in blast furnace slag mold.....	89
Figure 5.12: Dendritic microstructure of A319 cast in red mud mold	90
Figure 5.13: Secondary dendritic arm spacing (SDAS) of A319 alloy cast in a different mold	90
Figure 5.14: The cooling curve of A319 alloy cast in a different mold.....	92
Figure 5.15: Fracture pattern of the tensile test sample of A319 alloy.....	93
Figure 5.16: Tensile strength and elongation of A319 alloy cast in a different mold	93
Figure 5.17: Stress - strain curve of A319 alloy cast in a different mold.....	94
Figure 5.18: Fractograph of A319 alloy cast in a 70% slag-sand mold.....	96
Figure 5.19: Hardness of A319 alloy cast in a different mold.....	97
Figure 5.20(a): Density and porosity of A319 alloy at location 1 cast in a different mold	98
Figure 5.20(b): Density and porosity of A319 alloy at location 2 cast in a different mold	99

Figure 5.21(a): Wear rate of A319 alloy against mold materials at different loads and frequency..... 101

Figure 5.21(b): Wear rate of A319 alloy against mold materials at different loads and frequencies 102

Figure 5.22(a): Coefficient of friction (COF) of A319 alloy against mold materials at different loads and frequencies 105

Figure 5.22(b): Coefficient of friction (COF) of A319 alloy against mold materials at different loads and frequencies 106

Figure 5.23(a): Worn surface morphology of A319 alloy cast in a different mold at 05N load with variation in the frequency 5Hz-15Hz..... 107

Figure 5.23(b): Worn surface morphology of A319 alloy cast in a different mold at 15N load with variation in the frequency 5Hz-15Hz..... 108

Figure 5.24: XRD of wear debris 109

LIST OF TABLES

Table 2.1: Composition of Blast furnace slag.....	11
Table 2.2: Composition of ferrochrome slag[59]	14
Table 2.3: Chemical composition	17
Table 2.4: Chemical composition of several olivine sand	20
Table 2.5: Chemical composition	23
Table 3.1: Flow behaviour	36
Table 3.2:Chemical composition of mold materials	38
Table 3.3: High sensitivity circularity (HSC) and GFN of materials	43
Table 3.4: pH value and moisture content of materials	46
Table 3.5: Hausner ratio with flow behaviour	49
Table 4.1: Chemical composition of A319 alloy	71
Table 4.2: Mold composition.....	71
Table 4.3: Thermal conductivity of materials.....	76
Table 4.4: Experimental solidification parameter.....	77
Table 5.1: Formation of phases at the interval of temperature	87

LIST OF SYMBOLS

1. Abbreviation

SS	Silica sand
BS	Blast furnace slag
FS	Ferrochrome slag
RM	Red mud
OL	Olivine sand
MT	Million tonne
Al	Aluminium
Si	Silicon
w ₁	Weight of the dried sample taken for the test
w ₂	Weight of the dried sample free from clay
A	Loss of weight of the sample after drying
B	Weight of the initial sample
M _n	Multiplying factor of the nth sieve
f _n	Percentage of sand remains on the nth sieve
h	Height of granules pile
D	Diameter of granules pile and
d	Internal diameter of the funnel
ΔT_{l-e}	Temperature difference liquid-eutectic range
ΔT_{l-s}	Temperature difference between liquid-solid range
Δt_{l-e}	Time difference between liquid-eutectic range
Δt_{l-s}	Time difference between liquid-solid range

T	Temperature
T_e	Eutectic temperature
T_l	Liquidus temperature
T_s	Solidus temperature
μm	Micrometre
L_p	Distance between first to last secondary dendrite arm
ns	Number of secondary dendritic arms
ρ	Density
m_a	Mass of the sample in air
m_w	Mass of sample in water
ρ_{th}	Theoretical density
ρ_{ac}	Actual density
a	Area of contact
P	Maximum contact pressure
ν_1, ν_2	Poisson ratio of sample and ball
E_1, E_2	Elastic modulus of sample and ball
d_1, d_2	Diameter of a sample ($d_1 \rightarrow \infty$)
cc	Cubic centimetre

2. Acronyms

3BS/30BS	30%BS + 70%SS + 5% sodium silicate
5BS /50BS	50%BS + 50%SS + 5% sodium silicate
7BS/70BS	70%BS + 30%SS + 5% sodium silicate
3FS /30FS	30%FS + 70%SS + 5% sodium silicate
5FS/50FS	50%FS + 50%SS + 5% sodium silicate
7FS/70FS	70%FS + 30%SS + 5% sodium silicate

3RM/30RM	30%RM + 70%SS + 10% sodium silicate + 2% water
5RM/50RM	50%RM + 50%SS + 10% sodium silicate + 2% water
7RM/70RM	70%RM + 30%SS + 10% sodium silicate + 2% water
3OL/30OL	30%OL + 70%SS + 5% sodium silicate
5OL/50OL	50%OL + 50%SS + 5% sodium silicate
7OL/70OL	70%OL + 30%SS + 5% sodium silicate
ASTM	American Society for Testing and Materials
EPMA	Electron Probe Micro Analyzer
WDS	Wavelength Dispersive Spectroscopy
SEM	Scanning electron microscopy
GFN	Grain fineness number
HR	Hausner ratio
CI	Carr index
HSC	High sensitivity circularity
PSR	Primary solidification rate
TSR	Total solidification rate
U.T.S	Ultimate tensile strength
Y. S	Yield strength
% EL	Percentage elongation
AOR	Angle of repose
XRD	Xray- diffraction
TGA	Thermogravimetric analysis
SDAS	Secondary dendritic arm spacing

PREFACE

Utilizing industrial solid waste is well known to reduce the need for energy, natural resources, environmental harm, and other costs. Industrialization, which is the answer to national development, has a direct relationship to waste. As the country develops, a massive amount of waste is created, leading to environmental issues with disposal, health concerns, and pollution. Recent decades have focused on recycling garbage and using waste as a value-added product in several businesses. The resulting waste has been dumped in landfills and piled on the ground, causing environmental problems and land deterioration. The use of industrial waste is restricted to some businesses, such as cement production and road building, which do not balance out the production of industrial waste. Consuming industrial waste is still a major concern today. The foundry industry is one of those sectors where sand demand rises globally on a daily basis, making it a good candidate for testing the viability of using industrial waste materials like red mud, ferrochrome slag, and blast furnace slag.

The present work has been divided into six chapters.

Chapter 1 presents a brief introduction to solid waste generation, various industrial solid waste, a statement of problem related to the handling and disposal of this waste, and beneficial of the utilization of solid waste. The sand consumption globally in the sand-casting process. The Al-Si phase diagram elaborates the phase present in the A319 alloy such as α -Al, eutectic Al-Si, and primary silicon whereas the presence of Cu contributes to the formation Al_2Cu .

Chapter 2 critical literature review on the extraction process of industrial solid waste such as blast furnace slag, ferrochrome slag, and red mud and various utilization sector of these wastes are discussed with variations in the content of solid waste in parent substrate. The

utilization of sand in the foundry practice with the different aspects of binder, moisture, and additives. As well as with alternative sand to replace sand in foundry practice such as ant hill power, groundnut shell ash, and fly ash. The effect of various ingredients of the foundry on the microstructure and the mechanical properties of cast alloy.

The mold material is one of the important aspects of the foundry industry. The properties of cast alloy also depend upon the mold material used. The quality of the mold depends on the appropriate composition of molding materials and the molding process. The molding materials include such as foundry sand, binder, additives, etc. In the casting of ferrous and non-ferrous, the mold must have high strength, low friability, high permeability, and low thermal expansion.

Chapter 3 deals with the materials used for the present investigation and the experimental procedure for the physical, chemical, and flowability behaviour was discussed with the comparison of conventional sand used in foundry industries. The experimental details and selected parameters based on various standards as well as literature were also included. Different characterization techniques such as EPMA, XRD, TGA, and SEM for the present study of chemical composition, phase analysis and also clay content, thermal analysis, sieve analysis, and flowability behaviours have been discussed in detail.

Chapter 4 presents a detailed discussion of the CO₂ molding process, Slag-sand mold preparation, and mold properties such as compressive strength, shear strength, permeability, compactness, and hardness of the fabricated slag-sand mold and compared with the conventional mold properties. Casting A319 alloy in different molds and estimating the solidification rate of alloy cast in different molds with the help of a cooling curve.

Partially replacement of sand in the mold practice with blast furnace slag (30%-70%), ferrochrome slag (30%-70%), red mud (30%-70%), and olivine sand (30%-70%) using a CO₂ molding process enhanced the mold properties such as compressive strength of mold increased to 6% -15% with the addition of solid waste in a sand mold.

Chapter 5 presents a detailed discussion of, microstructural evaluation, secondary dendritic arm spacing (SDAS), porosity and density, microhardness, tensile strength, fracture morphology, wear rate, and worn surface morphology of A319 alloy cast in slag-sand and compared with conventional mold. Different characterization techniques such as optical microscopy, density measurement, Vickers hardness, tensile test, and reciprocating wear have been discussed in detail.

The micrograph was obtained by optical induced dendritic structure along with primary α -aluminum dendritic arms with secondary dendritic arm spacing. The size of SDAS measured with the Image software and the content of slag in the mold reflect on the size SDAS leading to an increase in the mechanical and tribological behaviour of a cast alloy. An in-depth understanding of the wear mechanisms, such as adhesion, abrasion, delamination, and oxidative wear, was obtained by using a scanning electron microscope to examine the worn surface. An alloy's wear resistance is reduced by the porosity in the cast.

