

Investigations on the Interaction Behaviour among Direct Reduced Iron and Various Melts

Abstract

Since the European Union described bold CO₂ emission targets, low-carbon-emission options to the huge incorporated blast furnace (BF)—fundamental oxygen furnace (BOF) steelmaking strategy—are demanded. Direct discount (DR) with herbal fueloline because the decreasing agent, already an industrially implemented era, is such an alternative. Consequently, the melting conduct of its intermediate product, i.e., direct decreased iron (DRI), in both an electric powered arc furnace (EAF) and a submerged arc furnace (SAF), is of incredible hobby. Based at the situations in those aggregates, a take a look at collection to experimentally simulate the primary few seconds after charging DRI became described. DRI samples with distinctive carbon contents and warm briquetted iron (HBI) had been immersed in excessive- and low-carbon melts in addition to excessive- and low-iron oxide slags. The reacted samples had been quenched in liquid nitrogen. The specimens had been qualitatively evaluated with the aid of using investigating their surfaces and pass sections. The dissolution of carbon-unfastened DRI stepped forward incredibly slowly and became pushed with the aid of using warmth transfer. However, carbon, gift both with inside the DRI pattern or with inside the melt, now no longer simplest improved the dissolution procedure, however additionally reacted with residual iron oxide with inside the pellet or the slag.

Keywords: Direct decreased iron • Electric powered arc furnace • Low-CO₂ steelmaking • Submerged arc furnace • Hydrogen-primarily based totally steelmaking • DRI dissolution

Introduction

In 2021, greater than 1.eight billion heaps of crude metallic had been produced worldwide. The incorporated course Blast Furnace (BF)—Basic Oxygen Furnace (BOF)—continues to be the important steelmaking strategy, with a percentage of greater than 70% of the worldwide metallic production [1]. The 2d maximum crucial steelmaking course is the scrap-primarily based totally electric powered arc furnace (EAF) procedure. However, because the availability of outstanding scrap indicates it'll now no longer be viable to satisfy the call for for metallic without ore-primarily based totally uncooked materials [2]. Due to the restricted capacity for decreasing CO₂ emissions of the blast furnace, new iron ore discount technology are required. A suitable era is the hydrogen-primarily based totally direct discount procedure. Direct discount (DR) refers to a solid-fueloline discount reaction for example, in a shaft furnace or a fluidized bed reactor the ore, in shafts; both pellet and lump ore is transformed into the so-known as sponge iron or direct decreased iron (DRI) as an intermediate product that is generally melted in an EAF for further steelmaking. In 2020, approximately 104 million heaps of DRI had been produced, primarily based totally on herbal fueloline (NG) [3]. Although this bills simplest for a small percentage of the worldwide crude metallic production, it's miles a extensively used steelmaking strategy, especially however now no longer exclusively, in NG-wealthy countries. Besides the EAF, processing sponge iron into pig iron the use of a submerged arc furnace (SAF) might be a 2d option These aggregates

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Received: 01-Aug-2022, Manuscript

No. AAAMSR-22-72821; Editor

assigned: 05-Aug-2022, **Pre-QC**

No. AAAMSR-22-72821 (PQ);

Reviewed: 19-Aug-2022, QC No.

AAAMSR-22-72821; **Revised:**

24-Aug-2022, Manuscript No.

AAAMSR-22-72821 (R); **Published:**

30-Aug-2022 DOI: 10.37532/

aaasmr.2022.5(4).79-83

are generally used to provide ferroalloys and procedure DRI crafted from ilmenite- or titanomagnetite-primarily based totally ores into warm metal. Since it's miles predicted that the defined processing techniques turns into greater crucial, the conduct of sponge iron while immersed in drinks is of incredible hobby for the optimization of the melting procedure. The DRI properties and their affect at the EAF operation were investigated notably some key.

Implemented mass and strength balances to research numerous DRI scrap ratios and their effect on distinctive procedure parameters. As sponge iron contained a better share of oxides, the strength call for, slag quantity, and lime consumption increased. Further, a better carbon content material and a excessive metallization degree decreased the electric strength consumption [4].

Defined a calculation version to investigate the effect of diverse DRI quantities at the EAF manner. One of the important thing findings became the growing electricity intake with a growing DRI fraction, attributable to the bigger amount of slag and endothermic discount reactions with unreduced iron oxide. If the carbon content material with inside the DRI became cautiously balanced, the oxygen addition remained surprisingly constant, however the yield reduced with extra sponge iron with inside the charge. Furthermore, Kirschen et al. as compared manner facts from sixteen business EAF with various scrap and DRI combos in an extra latest study. Based at the effects, decrease basicity is recommended to lessen the slag amount. Further, the MgO saturation has to be taken into consideration whilst reducing the basicity to keep away from a multiplied put on of the refractory material [5]. Compared to scrap charges, higher fluctuations in FeO content material had been measured for the slags. Possible explanations may be low metalized DRI fines and a reduced performance of the carbon injectors. As a part of this study, the authors additionally optimized a previously posted EAF version with appreciate to the software of DRI. presented effects from the ArcelorMittal Lázaro Cardenas soften shop, focusing at the conduct of nitrogen. High-carbon DRI became useful for making nitrogen-important metal grades because of the giant formation of CO bubbles [6].

Further, there are guides approximately business practices with excessive-DRI EAF charges. The following widespread conclusions may be drawn

from those guides: a higher DRI fraction led to a growing electricity intake, specifically whilst the acidic gangue content material multiplied; because of the improved slag volume, the iron yield reduced as extra Fe became misplaced with inside the slag; concerning tramp factors such as P or Cu, an multiplied DRI ratio became useful; furthermore, the metallization of the sponge iron need to be as excessive as viable [7].

Lowering FeO with inside the DRI and progressing with FeO with inside the slag. Sadrnezhad and Elliot performed comparable experiments. Beside the fueloline volume, additionally the temperature evolution withinside the pellet became measured. Based at the effects, the authors defined the formation of a stable slag shell on a cold pattern. In a in addition study, this concept became utilized by Martinez et al. for the improvement of a melting kinetic version [8]. The effect of carbon withinside the liquid at the melting conduct of stable metals became significantly investigated, e.g., through Szekely et al. Penz and Schenk summarized the modern-day know-how on this subject matter in an assessment paper. In addition to figuring out parameters together with the warmth switch coefficient, a vital phenomenological locating is the diffusion-primarily based totally melting manner, i.e., the diffusion of carbon from the liquid warm metallic into the stable metallic [9]. This decreases the latter's liquidus temperature, an important step withinside the interplay among scrap and warm metallic in the fundamental oxygen furnace (BOF) [10].

These paintings aimed to examine the interplay among a DRI pellet and molten metallic immediately after charging. DRI samples had been dipped into liquid metal, warm metallic, and regular EAF and SAF slags for a particular time period. While the preceding research defined above targeted on business, carbon-containing samples, in our case, DRI with 0%C became additionally taken into consideration [11]. Subsequently, the immersed specimens had been visually and metallographically tested and qualitatively as compared regarding the interplay conduct among the sponge iron pattern and the soften. The detailed evaluation of the specific version instances is a novelty for analyzing influencing parameters together with the carbon content material of the soften in addition to of the DRI or the distinction among slag and metal because the liquid medium [12].

Materials and Methods

The substances utilized in our research have been composite resins (RBC) with the identical polymer matrix (BIS-GMA, TEGDMA, BIS-EMA), however exclusive filler (micro/nano filler) commercially to be had available in the marketplace in Romania. Sample 1 is ValuxTMPlus Restorative 3M ESPE, a primary-era composite resin fabric which includes Bis-GMA and TEGDMA resins and 66% vol. zirconia/silica inorganic filler with a particle length variety of 3.5 to 0.01 micron. Is BrilliantTMNG Coltene, a second-era composite resin fabric that is a Nano composite with pre-polymerized particle filling with excessive Nano metric particle content is available in five sun sunglasses to be had in four g a duo colouration device withinside the identical syringe simplifying the choice of colour and stock of syringes has syringes Both samples have warning signs for anterior and posterior restorations such as inlays, onlays, and veneers [13]. The traits of the samples are presented.

Small discs with a diameter of five mm and a thickness of one mm have been organized so as to research the density of the fabric. Curing turned into finished with an LED lamp (mild emitting diodes, $\lambda = 420 \div 480$ nm, Kerr Corp., Orange, CA, USA), with exclusive curing programs (variable mild depth, exclusive time costs and mixed). As a primary step of the research, the variant withinside the density of the samples turned into tested earlier than and after curing (curing time forty five s) the usage of the Archimedes' principle (pycnometer from Paul Marienfeld GmbH, Lauda-Königshofen, Germany). Density correction for water turned into implemented to the consequences [14].

For the composite healing, the standardized mesio-occluso-distal (MOD) hollow space education turned into finished in an extracted top human premolar, the usage of a medium-grained diamond bur. The molar extraction turned into finished at some point of the complicated remedy of the top jaw, for a sinus raise augmentation of a affected person as reported. The identical bioethical approval turned into implemented. (ValuxTMPlus Restorative 3M ESPE) turned into incrementally implemented and mild-cured for 20 s from the LED mild-curing device, transferring output depth from 1.a hundred mW/cm² to a top of one.330 mW/cm² a couple of instances in the course of the curing cycle [15].

Raman spectroscopy assessment turned into finished with a BTR111—785 RAMAN

spectrometer device ($\lambda = 785$ nm, output energy $p =$ three hundred mW, and spectral decision four cm⁻¹) withinside the Raman shift variety a hundred–2200 cm⁻¹. The spectrometer is prepared with BAC101 immersion Raman probe, with the minimal spot length for excitation of a hundred μ m at 0.5 mm. The 785 nm laser energy used for all measurements turned into 30 mW (10% from three hundred mW to be had) which offers an irradiance of approximately 382 W/cm². The laser spot and irradiance tiers have been saved regular at some point of Raman spectra acquisition. Energy Dispersive X-Ray Spectroscopy (EDX) and Scanning Electron Microscopy (SEM) have been finished in a Zeiss Evo 50 XVP microscope, at room temperature (RT), prepared with a secondary electron detector in low vacuum and a stable nation BSE detector, plus an auxiliary micro analytic SDD radiation detector .

Raman Spectroscopy

A manually operated pneumatic cylinder managed the dipping manner all through the check. Every trial became filmed to assess the precise immersion time. After discharging, the pattern became quenched thru liquid nitrogen to keep away from giant reoxidation. Per every soften, 3 samples had been immersed; after the 0.33 check, the soften temperature became measured with Heraeus Type S thermocouples (Heraeus, Hanau, Germany). Before the metallographic preparation, we took photos of every pattern the usage of a Sony Alpha 6000 DSLM camera (Sony Group Corporation, Tokyo, Japan). Afterward, the specimens had been cold-embedded, halved, ground, and polished. The microsections had been investigated the usage of a Keyence VHX 7000 virtual microscope (Keyence Corporation, Osaka, Japan).

Immersion Test Program

As stated above, DRI manner routes are viable withinside the future, because of this that the DRI manufacturing may be blended with both EAF and SAF. With this in mind, check software became set up for the subsequent components of DRI melting. Influence of C content material in DRI (carbon-free, hydrogen-primarily based totally DRI became as compared to carburized DRI, which approximates herbal fueloline-primarily based totally DRI) Composition of the liquid metallic (low and excessive C content material) Composition of the slag (EAF and SAF slag) Density of the DRI samples (DRI vs. HBI).

Results and Discussion

During the experiments, some elements had been sizeable. In a few exams with the carburized samples, sparks and splashes will be observed. This will be because of the chemical response among C and FeO, which generates CO Fueloline. This phenomenon turned into maximum stated whilst DRI or HBI turned into immersed in warm metallic.

In all exams with warm metallic (zero%C-HM-1, zero%C-HM-2, and HBI-HM-1), the sample had been melted entirely after a three–four s dipping time. As a consequence, no extra investigations had been possible. A similarly discount of the immersion time turned into now no longer manageable, since the actuator for controlling the pneumatic cylinder motion turned into at its limit. Another noteworthy factor is the notable temperature distinction among the furnace and the soften throughout the recent metallic exams. The endothermic discount reactions of FeO with C throughout the immersion of the samples are the maximum likely reason behind this phenomenon.

After the exams, the samples had been evaluated visually. The following turned into sizeable approximately the images. The zero%C samples in confirmed easy surfaces for metallic and slags. This suggests that no chemical reactions came about among DRI and the liquids. After an accelerated immersion time, see pattern zero%C-ULC-10s-three in the optical influence of the floor turned into much less vibrant and regarded matte. As the DRI carbon content material accelerated, a discount of the last iron oxide regarded to happen. Consequently, the floors have become extra fissured with growing carbon levels. Frozen fueloline bubbles at the adhering soften residues indicated fueloline formation. When a fairly carburized DRI-pellet turned into immersed in a slag containing iron oxide, a response of C from the pattern with FeO withinside the slag might have occurred.

When immersed withinside the SAF slag, no reactions had been expected, because the temperature turned into lots decrease. The poorer slag adhesion at C800-SAF, shown in, suggests much less wetting than for the carbon-loose pattern zero%C-SAF, seen in. This statement is steady with slag wetting on carbon-containing refractory material. ULC experiments the outcomes of dipping zero%C samples and HBI right into a low carbon soften indicated that

warmth switch turned into the using pressure on this case. The zero%C-ULC-three specimen showed this, because it confirmed the increase of a liquefied shell. The better the carbon content material, the thicker the shell at comparable dipping times. The decrease liquidus temperature defined the quicker melting in iron–carbon mixtures. In principle, the observations accept as true with the calculated outcomes of González et al. i.e., an growing pattern diameter straight away after immersion, accompanied with the aid of using the melting of this floor layer. However, the melting time strongly rely upon parameters inclusive of DRI porosity, preliminary diameter, or gangue content material.

Therefore, it turned into hard to make quantitative comparisons. Additionally, the high-carbon samples in Figure four and had a difficult floor with many bubbles because of the discount of a few residual iron oxides with carbon. These reactions, at the side of the ensuing blisters, can also additionally benefit the EAF process. Various authors said blessings in phrases of decrease electric energy consumption, much less nitrogen content material, or higher slag foaming.

Hot Metal experiments: The DRI and HBI samples had been absolutely melted after three–four s of immersion withinside the warm metallic. At first sight, this turned into now no longer expected, because the liquidus temperature of natural iron (approx. 1538 °C, in keeping with FactSage™ 8.zero and the FactPS database) turned into better than the recent metallic temperature. Further, this differs from the outcomes for ULC metallic. Penz et al. investigated the dissolution of scrap in warm metallic, which is a comparable process.

Conclusion

A vertical furnace turned into used to analyse the conduct of sponge iron in touch with liquids. High, medium, and carbon-loose-DRI, in addition to HBI, had been immersed into melts of ULC, warm metallic, and slags. Based on metallographic examinations, processes going on in exclusive instances had been characterized. Carbon, both withinside the sponge iron or withinside the soften, accelerated the melting price because of its impact at the liquidus temperature of iron. Further, discount reactions of iron oxides, both withinside the DRI pellet or withinside the high-FeO slag, will be observed, as indicated with the aid of using the incidence

of fueloline bubbles at the surfaces of those samples. Even the high-carbon DRI pattern remained unmelted whilst in touch with iron oxide-loose slag. This indicated exclusive warmth switch situations among liquid slag and metallic, which turned into showed with the aid of using calculating the Prandtl numbers. While HBI additionally confirmed a speedy dissolution in warm metallic, the conduct in a low-carbon soften turned into similar to for zero%C-DRI that of sponge iron without carbon. Therefore, particle density turned into additionally an essential parameter withinside the melting conduct.

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