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Effect of the Content of Graphite in the Slag Powder of the Steel LRF on the Microstructure and Properties of SAW of Ductile Iron

Bahram Ghazanfarian[1] Kamran Dadashnia[2]
Seyed Ebrahim Vahdat*[3]

1. Introduction

Steel slag is one of the main wastes of steel industry. For each ton of steel produced, 2 kg of ladle refining furnace (LRF) slag is obtained as a waste, which is sold with a cheap price of 2.4 US$ per ton. On the other hand, reprocessed steel LRF slag powder may be a good alternative to the flux in submerged arc welding (SAW). Therefore, the use of waste in strategic industries is an important step towards self-sufficiency and sustainable development. In this research, authors used reprocessed steel LRF slag with 0, 10 and 25 wt.% of graphite powder with conventional flux to make SAW welds.

2. Material and Methods

Graphite powder and reprocessed steel LRF slag powder were prepared from Hormozgan Steel Company (Table 1). Ductile iron was made at the Foladin Zob Amol Company (Table 2). A CNC wire-cut machine applied in Yekta Sanat Company for preparation of hardness and tensile test specimens.

SAW was carried out using a SAW device, model G2310, Gaam Electric with a current of 450 A and a speed of 560 mm/min at a distance of 5 mm from welding wire with a diameter of 3 mm with the chemical composition as Table 3. One SAW pass was applied without backing. Tensile strength was measured before and after welding. Vickers hardness test was performed for three times from three weld zones. The microstructure of the three regions was studied by the Field Emission Scanning Electron Microscope, brand of TESCAN MIRA3.

3. Results and Discussion

The average Vickers hardness results of heat affected zone (HAZ), welded site, and base metal, as well as the average ultimate tensile strength (UTS) are given in Table 4. By increasing the content of graphite powder in the reprocessed LRF slag powders from 0 to 25 wt.%, the hardness of the SAW specimen in the HAZ, bonding site, and the base metal was increased from 265, 212, and 218 to 471, 715, and 848 Vickers, respectively. The observed changes in the hardness values could be due to the increase in the content of graphite powder, which provides the conditions for the formation of carbide and martensite. According to Tables 2 and 3, the matrix of control specimen lacks carbide or martensite phases, so its hardness (160 Vickers) is much lower compared to the hardness of the weld metal and the bonding site of the samples welded with SAW (with a hardness between 212 and 848 Vickers). Furthermore, due to the SAW and rapid cooling process, martensite is formed in the microstructure of the metal in the HAZ, which increased the hardness (with hardness between 265 and 471 Vickers) relative to the base metal or control specimen (160 Vickers).

Table 4 shows that with increasing the content of graphite powder in the reprocessed LRF slag powders from 0 to 25 wt%, the UTS of the welded part is increased from 58 to 79 MPa, respectively, but is still less than the UTS of the ductile iron as the base metal (85 MPa).

When performing the SAW, it was observed that with increasing the content of graphite powder from 0 to 25 wt%, the arc may become more uniform and stable, hence improving the quality of the welding zone. Also, the mechanical properties were improved by increasing of the content of graphite powder.

[1] MSc, Department of Engineering, Bandar Abbas Branch, Islamic Azad University, Bandar Abbas, Iran.

[2] BSc, Department of Engineering, Ayatollah Amoli Branch, Islamic Azad University, Amol, Iran.

[3]* Corresponding Author, Assistant professor, Department of Engineering, Ayatollah Amoli Branch, Islamic Azad University, Amol, Iran. Email: e.vahdat@iauamol.ac.ir

Table 1: Comparison of composition, particle size, and alkali of commercial, reprocessed LRF slag powder and graphite powders

Commercial powder	Composition	CaF_2		Al_2O_3 +MnO	CaO +MgO	SiO_2 +TiO_2	*Alkali	Particle size mm	Density g/cm^3
	Content	5-30%		20-55%	30-55%	10-25%	0.5-3	0.2-1.6	1.1-1.6
reprocessed LRF slag powder	Composition	Others	FeO +P_2O_5	Al_2O_3 +MnO	CaO +MgO	SiO_2 +TiO_2	*Alkali	Particle size mm	Density g/cm^3
	Content	3.5%	0.75%	33.6	50.6%	11.5%	≈1.2	1-3	≈1.4
Graphite powder	Composition	Others	Carbon				---	Particle size mm	Density g/cm^3
	Content	Balance	99.9%				---	1-3	2.1

* Bonijowsky alkali factor

Table 2: Chemical composition and Nodule Count of ductile iron (control specimen or base metal)

Graphite Nodule Count	Chemical composition wt%										
	Fe	C	Mn	Si	S	P	Al	Ti	Cu	Mo	Cr
≈160 mm^{-2}	Balance	3.7	0.6	2.5	0.02	0.05	0.03	0.01	0.02	0.3	0.2

Table 3: Chemical composition of the SAW wire, DIN EN S2CrMo1 (AMA 5022)

Iron	Carbon	Molybdenum	Manganese	Silicon	Chromium
Others	0.05 to 0.10%	0.5%	1.4 to 1.8%	0.5 to 0.8%	1%

Table 4: Results of microstructure and UTS

No.	Specimen category	Average Vickers hardness (HV)			Average of UTS	Description
		HAZ	Bonding	Weld metal		
1	Control (non-welded)	160			85 MPa	Failure within acceptable range
2	LRF Powder without graphite	265	212	218	58 MPa	Failure at the weld edge
3	LRF Powder with 10 wt% graphite	375	515	545	65 MPa	
4	LRF Powder with 25 wt% graphite	471	715	848	79 MPa	

4. Conclusions

In the present study, the Vickers hardness and UTS of the ductile iron before and after the SAW with the reprocessed LRF slag powders containing 0 to 25 wt% of graphite were compared. The results indicated that:

1-With increasing the content of graphite powder in the reprocessed LRF slag powders, the UTS of the SAW welded metal is closer to the UTS of the control specimen, and also, the content of hard phases rich in carbon, silicon, and iron increased.

2-The hard phases and soft graphite particles have created similar trend to those of the composite material. Because, the Vickers hardness of the SAW specimens increased from 212 to 585 HV, and accordingly, the UTS reached from 58 MPa to 79 MPa, i.e. the hardness had a direct relationship with strength; while the Vickers hardness of control specimen was 160 HV (lower than the SAW specimens) and the UTS of control specimen was 85 MPa (higher than the SAW specimens). Because of cast irons have the composite behaviors. This means that graphite plays like as a component in the iron matrix.