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Effect of Submerged Arc Welding Parameters on Hard facing with Different Proportions of Alloy Mix upon Mild Steel

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Abstract
The optimum values of various parameters and their levels were determined for minimum dilution level in SAW process. The element infusion in hard facing was determined by optical emission spectra analysis.
This study will help the engineers to select the proper parameters for required weld bead geometry. Also to use various elements and ferro-alloys in proper composition to develop localized alloying on mild steel to reduce wear losses.

1. Introduction

Welding is a fabrication process used by almost every industry. It is a principal means of fabricating and repairing metal products. The process is efficient, economical, and dependable as a means of joining metals. The survival of the mankind has become so much dependent on welding that it would be almost impossible to think of computers, aircrafts, rockets, ships, submarines, nuclear reactors, home appliances, automobiles, pressure vessels, utility stations etc. This is the only process which has been tried in the space. The process finds its applications in air, underwater and in space.

So many other welding processes were developed with time and welding is not just remaining a joining process but it is utilized for special purposes like cladding, hard facing, cutting etc. Hard facing by welding is the process where harder or tougher material is applied to a base metal. It is basically a surfacing operation to extend the service life of industrial components, pre-emptively on new components, or as part of a maintenance program. The result of significant savings in machine down time and production costs has meant that this process has been adopted across many industries such as steel, cement, mining, petrochemical, power, sugar cane, and food.

Steel is the widely used material by industries. One major problem which is faced by the industries are wear and tear of the components The present trend in the fabrication industries is to use hard facing to improve wear and abrasion of worn out parts. Automated welding processes are necessary to obtain high production rates, high precision and greater reliability of the hard faced components. To automate a welding process it is essential to establish the relationship between process parameters and weld bead geometry to predict and control weld bead quality and also for the overlay elements used for hard facing.

2. Literature Review

Tarng et al. in 2002, used grey-based Taguchi methods for the optimization of the submerged arc welding process parameters in Hard facing with considerations of multiple weld qualities was reported. In this approach, the grey relational analysis was adopted to solve the SAW process with multiple weld qualities. Optimal process parameters were determined by using the parameter design proposed by the Taguchi method.

Chatterjee in 2003, studied the abrasive wear behavior of different hard facing electrodes deposited on grey cast iron used for the top bearing plate of a coal crushing unit. The results showed that different hard facing electrodes as well as the weld procedure variation using similar electrodes have large effects on low stress abrasion resistance of the deposit. Carbon content is an important factor determining microstructure of such hard facing electrodes and therefore wear resistance. Behcet 2003, in this study, worn parts were welded using the submerged arc welding process. Various wires and fluxes were used for this purpose. These welded parts were subjected to wear tests under different loads, and changes in the hardness and microstructures were examined. A pin-on-disk wear test apparatus was used. The results showed that the hardest weld metal showed the highest wear resistance, while the least hard weld metal showed the least wear resistance. The weld hardness and wear resistance obtained were found to be dependent on the chemical composition of the weld wire and flux.

Kanjilal et al. 2006, developed rotatable designs based on statistical experiments for mixtures to predict the combined effect of flux mixture and welding parameters on submerged arc weld metal chemical composition and mechanical properties. Agglomerated fluxes used in the study were prepared by varying the ingredients CaO, MgO, CaF_2 and Al_2O_3. The ranges of each flux ingredients as well as welding parameters used in the study were determined by trial run in submerged arc welding. Chatterjee in 2006, studied effect of welding procedural variation upon the cracking sensitivity and performance of interface between substrate cast iron and deposited layers using various welding procedures. The results show that crack lengths per unit area of the deposits were affected by the welding procedure and Cr/C ratio of the hard facing electrodes used.

Palani et al. in 2007, investigated the effect of cladding parameters such as welding current, welding speed, and nozzle-to-plate distance on the weld bead geometry. Mathematical equations were developed by using the data obtained by conducting three-factor five-level factorial experiments

Shahi et al. in 2008, carried out an experimental study to analyse the effects of gas metal arc welding (GMAW) and universal gas metal arc welding (UGMAW) process parameters on dilution in single layer stainless steel cladding of low carbon structural steel plates. Four factors five levels central composite rotatable design was used to develop relationship for predicting dilution, which enables to quantify the direct and interactive effects of four numeric factors i.e. wire feed rate, open circuit voltage, welding speed and nozzle-to-plate distance and one categorical factor preheat current. Beidokhti in 2009, investigated the effect of titanium addition on the SAW weld metal microstructure of API 5L-X70 pipeline steel. The relationship between microstructure and toughness of the weld deposit was studied by means of full metallographic, longitudinal tensile, Charpy-V notch and HIC tests on the specimens cut transversely to the weld beads. The best combination of microstructure and impact properties was obtained in the range of 0.02–0.05% titanium.

3. Experimental Design

The Substrate material (base metal) used in the study is mild steel. The chemical composition of base metal is given in Table 1, which was determined by optical emission spectra (OES) method.

The elements used for overlay implication in the steel for hard facing are:

- Graphite (C)

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- Ferro Chrome (Fe-Cr)
- Ferro Manganese (Fe-Mn)
- Felspar(CaF_2)

Table 1: Chemical composition of base metal.

Chemical composition						
C	Si	Mn	S	P	Cr	Cu
0.3	0.256	0.68	0.048	0.047	0.013	0.02

In present study, L_9 orthogonal array with four columns and nine rows is used. Each parameter is assigned to each column of the orthogonal array. Therefore, only nine experiments are required to study the entire parameter space using L_9 orthogonal array. 4 parameters and 3 levels are available for the experimentation. The four parameters taken are Graphite, Ferro chrome, Ferro manganese, and Felspar. Their three levels low medium and high are selected by conducting trail runs. Table 2 is showing the planning of the experimental design of hard facing elements for the investigation. Parameter values taken are in weight percent.

Table 2: Balanced design of orthogonal array

Run no.	%C	%Fe-Cr	%Fe-Mn	%CaF_2
1	12.5	62.5	12.5	12.5
2	8.7	60.9	17.4	13
3	6.7	60.0	20.0	13.3
4	18.2	45.5	18.2	18.2
5	15.4	53.8	23.1	7.7
6	14.8	66.7	7.4	11.1
7	24.0	40.0	24.0	12.0
8	23.1	53.8	7.7	15.4
9	20.0	60.0	13.3	6.7

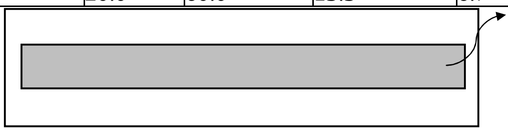

Fig. 1: Schematic of base metal plate after applying overlay.

Using the same parameters, beads were deposited on plates, cut, polished for metallographic analysis and the results were analyzed.

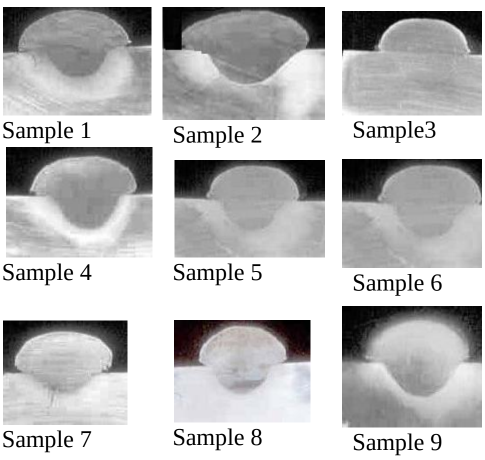

Fig. 2 Samples prepared for analysis

4. Results and Discussions

Experimental data is analyzed and S/N ratio is calculated for each response variable under the investigation. For depth of penetration and percent dilution "the smaller is better" S/N ratio has been chosen because these are to be minimized. Similarly for Bead width "larger is better" S/N ratio has been chosen as the goal is to maximize these response variables

Table 3: Ranking of significant factors for %Dilution.

Level	S/N Ratio			
	Graphite	Ferro Chrome	Ferro Manganese	Felspar
1	-30.324	-12.739	-14.1436	-13.906
2	-30.070	-14.870	-14.3529	-12.991
3	-28.433	-14.450	-13.5639	-15.161
Δ	1.89	2.22	0.86	1.73
Rank	2	1	4	3

Table 4: Optimum Levels of Overlay factors for %Dilution.

Symbol	Overlay elements	Level	Level Description (wt %)
C	Graphite	3	30%
Fe-Cr	Ferrochrome	1	50%
Fe-Mn	Ferromanganese	3	30%
CaF_2	Felspar	2	15%

Table 5: Ranking of Significant factors for Depth of Penetration

Level	S/N Ratio			
	Graphite	Ferro Chrome	Ferro Manganese	Felspar
1	-15.20	-12.739	-14.14	-13.90
2	-14.08	-14.870	-14.35	-12.99
3	-12.77	-14.450	-13.56	-15.16
Δ	2.43	2.13	0.79	2.17
Rank	1	3	4	2

Table 6: Ranking of significant factors for Bead Width.

Level	S/N Ratio			
	Graphite	Ferro Chrome	Ferro Manganese	Felspar
1	26.20	25.05	25.00	24.86
2	24.86	24.94	25.15	25.09
3	24.13	25.20	25.05	25.24
Δ	2.06	0.26	0.15	0.37
Rank	1	3	4	2

Table 7: Optimum levels the factors for Bead Width.

Symbol	Overlay elements	Level	Level Description (wt %)
C	Graphite	1	10%
Fe-Cr	Ferrochrome	3	90%
Fe-Mn	Ferromanganese	2	20%
CaF_2	Felspar	3	20%

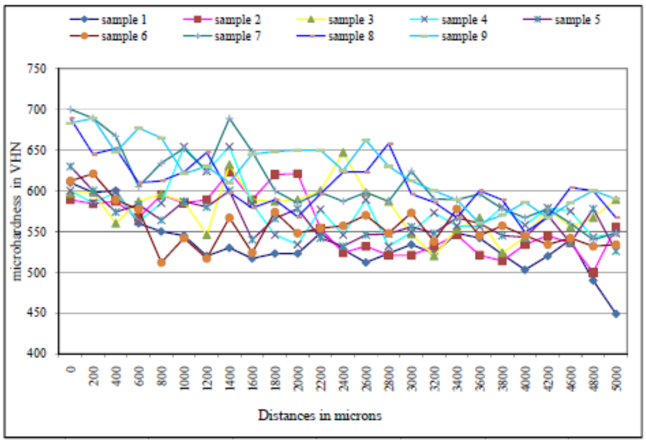

Fig. 3 Microhardness profile

4.1 Micro hardness

Micro hardness profile shows that there is decrease in the hardness as we move downward from the top surface. But this trend is not uniform as there are some variations observed in the hardness as we move downward. There is an appreciable change in hardness as we enter in the heat affected zone and further to the base metal.

As per the hard facing elements infusion is concerned the maximum carbon infused is 0.93% in sample no.7 and minimum is 0.434% in sample no 2. The maximum chromium infused is 2.32% in sample no.3 and the minimum of 1.48% in sample no.4. The maximum manganese infused is more than 2 5% in sample no.5 and the lowest in sample no.1.

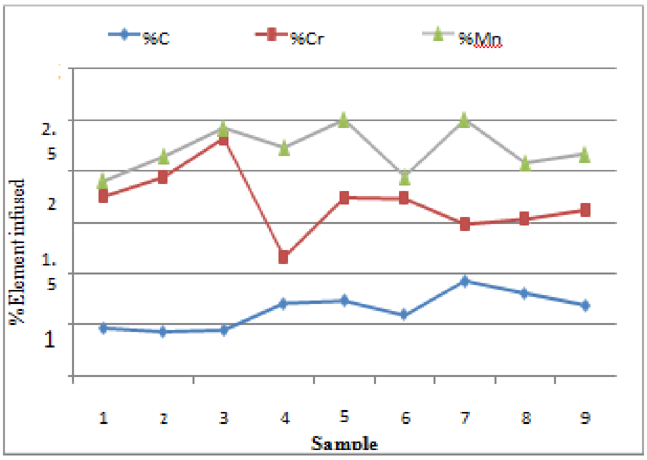

Fig. 4 Plot of % element infusion.

Table 8: Micro hardness of samples at various depths

Depth (Micron)	sample 1	sample 2	sample 3	sample 4	sample 5	sample 6	sample 7	sample 8	sample 9
0	610	589	597	600	630	612	700	689	683
200	598	584	598	585	600	621	689	645	689
400	600	587	560	598	574	589	667	652	647
600	560	567	587	562	583	577	605	610	677
800	550	595	596	585	564	512	634	612	665
1000	545	585	587	654	587	542	652	623	621
1200	520	589	546	624	580	517	624	647	630
1400	530	623	632	654	600	567	689	598	610
1600	517	589	589	584	540	524	648	579	645
1800	523	620	587	546	566	574	600	589	648
2000	523	621	589	534	578	548	585	568	650
2200	548	554	600	577	542	554	598	596	650
2400	528	524	647	546	532	557	587	623	625
2600	512	532	598	589	546	570	598	623	662
2800	523	521	587	532	547	548	587	658	630
3000	534	521	547	549	556	573	624	596	612
3200	523	532	520	573	548	538	590	586	600
3400	548	546	553	557	567	578	589	567	589
3600	542	521	567	556	560	545	596	600	560
3800	522	514	524	580	545	557	578	589	570
4000	503	534	543	558	543	545	567	549	586
4200	520	545	578	579	570	534	578	567	567
4600	540	536	556	575	536	542	560	604	585
4800	490	500	567	543	578	532	540	600	600
5000	449	556	589	548	526	534	548	567	590

The spectrometry analysis reviled that the other elements in the steel were well within their ranges. Phosphorus aids fusibility and fluidity but induces brittleness if it exceeds 1% in steel was found 0.4-0.7%. Sulpher lowers the viscosity of the melt gives harmful effects if exceeds 0.1% was found 0.02-.06%. It was clear from the experimental data for Microhardness profile of the samples that the average hardness values were recorded around 550 HV. Higher values of hardness above 700 VHN were reported in some cases. Hence, the increase in hardness from the base metal (approx.180 VHN) was recorded as three times (300%)

5. Conclusions

The optimum values of various parameters and their levels were determined for minimum dilution level in SAW process. The element infusion in hard facing was determined by optical emission spectra analysis. Following results were concluded from the experimental work.

- Graphite, Ferrochrome, and Felspar were the dominant factors influencing penetration apart from the welding process parameters for depth of penetration.
- Graphite was the lone parameter that influences the weld bead width.
- Graphite, Ferrochrome, and Felspar were the significant factors for percentage dilution.
- It was clear from the experimental data for Micro hardness profile of the samples that the average hardness values were recorded around 550 HV. Higher values of hardness above 700 VHN were reported in some cases. Hence, the increase in hardness from the base metal (approx.180 VHN) was recorded as three times (300%)
- From the spectrometry analysis of samples, it was clear that the sample which was having highest carbon percentage along with manganese has shown maximum hardness as carbon is directly responsible for hardness and it is the dominant factor. The chromium which is responsible for hardness and toughness is second most significant factor.

This study will help the engineers to select the proper parameters for required weld bead geometry. Also to use various elements and ferro-alloys in proper composition to develop localized alloying on mild steel to reduce wear losses.

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