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Arc Stability Study of Submerged Arc Welding for SiO_2 and TiO_2 Based Flux Systems

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Abstract—*In the present study submerged arc welding fluxes were designed by the use of ternary phase diagram of CaO-SiO_2-Al_2O_3 and CaO-TiO_2-Al_2O_3 flux systems. Submerged arc welding was performed with various combination of machining parameters and flux constituents. Taguchi L9 orthogonal array was used to design the flux. Three variable of flux constituents were varied at three levels. Total 18 fluxes were designed. 9 each for SiO_2 and TiO_2 based flux system. Bead on plate weld was performed at open circuit voltage i.e. 34Volt. By this study, an attempt has been made to study the arc stability of SiO_2 and TiO_2 based flux system. Voltage and current transient were recorded by the use of high speed data acquisition system. Standard deviation of voltage and current was calculated from the recorded data. MATLAB 9 and Sigma plot 11 were used to plot the graph of time v/s voltage and current, to visualize the behavior of arc at different duration of weld for both types of flux systems. In SiO_2 flux system, flux no 4 gave optimized results whereas in TiO_2 flux system, flux no1 gave the better results.*

Keywords: *TiO_2 flux; SiO_2 flux; arc stability; V/I transients; SAW;*

1. INTRODUCTION

SAW uses AC or DC current source. This type of power source generate arc between metal plate and the electrode. The electrode used is continuous fed circular wire consumable one. Flux used in the system is fed with the hoper. The granular flux covers the electrode and metal plate. Arc generated between the electrode and metal plate is not visible in SAW. It serves so many purposes such as shielding and cleaning of molten puddle, protection against sparks and spatter. It also acts as a barrier that holds the heat in and concentrates that heat into the weld area which promotes deep penetration. Due to deep penetration, better bead appearance and superior quality of weld strength, submerged arc welding is most widely used process in heavy industries. In SAW data acquisition system is the best solution to monitor the voltage and current fluctuations. Voltage and current transient were recorded to study the quality of weld. As per the literature review the arc characteristics of submerged arc welding with stainless steel wire were studied by using Analysator Hannover. Probability density distribution curve of arc voltage and welding current were analyzed. Metal transfer modes in SAW and characteristics of stable arc were summarized [1]. A granular flux which is used in submerged arc welding plays an important role it should provide appropriate weld metal composition and exhibit good welding behavior .This can be achieved by maintaining flux ingredients with in the optimal range [2]. Flux for HSLA steel are not readily available there flux composition are not clearly described. Constrained matrix mixture design and extreme vertices design were use to design the flux for study the effect of flux composition on the weld properties [3]. Metal transfer behavior of plasma enhanced shielded metal arc welding was studied by recording the arc signal in real time with the help of high speed data acquisition system. It was analyzed that the pattern recognition of several kinds of metal transfer mode for PESMAW can be ascertained along with accurate measurement of relative important process parameters [4]. Short-circuiting is very common phenomenon in gas metal arc welding. In order to estimate the working parameter and ensure stabile GMAW-P, dynamic behavior of short-circuiting in GWAW-P was studied for varying pulsing parameters [5]. Acoustics signals were processed to obtain time domain and frequency domain descriptors in short circuit gas metal arc welding. The result indicate that the arc sound exhibit distinct characteristics for each welding situation and main source of acoustic waves in short circuit metal transfer mode is arc reignition. It can be easily assessed the arc stability and welding defects with the help of acoustics signals [6]. In advanced gas metal arc welding process the effect of welding process parameters on waveform deposition was studied, the result shows that good weld ability, good mechanical joint properties and acceptable process efficiency could be obtained for thin sheets through advanced power source regulation, especially over short circuiting, controlled polarity and electrode wire motion[7]. The energy entropy can be used to evaluate the stability of arc in square wave alternating current submerged arc welding. Welding current signal in different frequency and duty cycles and comparing with the arc stability and quality of weld shaping [8]. In gas metal arc welding the acquired welding arc sound signal along with current and voltage signal were analyzed in time domain and frequency domain to correlate them with the various process parameters and metal transfer modes [9]. On line quality monitoring in short-circuit gas metal arc welding was used to study the metal transfer and stability of arc with the help of recording of voltage and current data. To produce the welded joint of smooth weld quality the process should be stable. This allow metal to flow uniformly from electrode to work piece. Short circuit frequency when match with the oscillation frequency optimal process stability occurs. This condition should satisfy the following point such as maximum short circuit rate, minimum standard deviation of short circuit rate, minimum mass transfer per short-circuit and minimum spatter loss[10]. In the present standard deviation of current and voltage signal were used to analyze the arc behavior of both type of flux system. The stability of arc for both flux system was examined by the use of MATLAB software.

2. METHOD OF FLUX DESIGN

In present work three factors were selected for the design of flux with their three levels. Taguchi design is a simple and systematic method that can reduce number of experiments to an optimal level because of this reason it was adopted. Degree of freedom for each factor is one less than level of a factor. In present work total degree of freedom for all three factors becomes six. Two degree of freedom is assigned for each three factor, and two degree of freedom is assigned to error term, total degree of freedom becomes eight. So L9 orthogonal array was selected which has nine numbers of runs. Level of flux constituents NiO,MnO and MgO is shown in table 1.

3. METHOD OF FLUX PREPARATION

Above analysis suggest L9 orthogonal array, 9 fluxes each for SiO_2 and TiO_2 based material were prepared. The Main three constituents that vary in the flux as per L9 orthogonal array is shown in table 2. Other constituents of flux that were kept constant are shown in table 3 and 4 for each type of flux. Total 2kg of flux was prepared for each combination by the agglomeration method. All the constituents were dry mixed first in a big container with ten steel balls of 10mm diameter for half an hour. Potassium silicate was heated up to 50^0c, sprayed into the mixture (500gm per 1000ml). Same mixture was then thoroughly mixed again for half an hour. This process was repeated again and again until the binder potassium silicate and other constituents form the granules. This mixture was dried at room temperature for 48 hrs and then it is baked in muffle furnace at approximately 650°C for 4 hours. After cooling, the mixture was passed through the sieve of required size to remove the dust from the flux and kept in air tight containers. The flux was baked again before the use up to 400°C.

Table 1: Flux constituent's level

Sr. No.	Design matrix		
1	60	50	85
2	60	70	95
3	60	90	105
4	80	50	95
5	80	70	105
6	80	90	85
7	100	50	105
8	100	70	85
9	100	90	95

Table 2: L9 Orthogonal array Design matrix

Factors	Code	Level 1	Level 2	Level 3
NiO (gms)	A	60	80	100
MnO (gms)	B	50	70	90
MgO (gms)	C	85	95	105

4. EXPERIMENTAL PROCEDURE

On a constant DC voltage submerged arc welding machine, which has the provision for automatic wire feed rate and welding speed. Bead on plate arrangement was used to test the condition of weld.

Table 3: Composition of siO_2 based flux

Constituents	Al2O3	SiO2	CaO		CaF2	K2 SiO2
Wt (%)	14.85	28	27.5		7.5	2:1 ratio

Table 4: Composition of TiO_2 based flux

Constituents	Al2O3	TiO2	CaO		CaF2	K2 SiO2
Wt (%)	14.85	28	27.5		7.5	2:1 ratio

Table 5: Welding Condition Parameters

Parameter	Unit	Value
Open Circuit Voltage	V	34V
Current	A	500
Trolley Speed	cm/min.	20
Electrode stick out		2.5mm.
Type of Flux		TiO2 and SiO2 Based

The low carbon steel plates of grade (IS-2062A) were mechanically cleaned with a brush, to remove the rust from the surface, before the welding was performed. The welding conditions are as shown in the table 5, kept constant throughout the experiment. Single layer weld passes were made for the all 9 fluxes each of SiO_2 and TiO_2 based at 34Volt. Voltage and current transient were recorded for all type of fluxes with the help of high speed data acquisition system.

5. RESULT AND DISCUSSION

A high speed data acquisition system that has the provision for recording the data at two different channels at a time; two properties can be recorded in real time. This high speed system can record the voltage and current reading as 1000 samples per seconds. In our case the setting was done to record 200 samples per seconds for approximately one to two minutes time. The recorded samples of voltage and current were used to plot the graph of time v/s voltage and time v/s current.

Table 6: Std. deviation of voltage for SiO_2 flux

S. No.	std dev for voltage 0 to 4 sec	std dev for voltage 4 to 8sec	std dev for voltage 30 to 34 sec	std dev for voltage 60 to 64 sec
1	0.8413	0.6772	0.4995	0.4923
2	0.3881	0.4365	0.3718	0.6753
3	1.99	0.4549	0.371	0.3951
4	0.398	0.4093	0.3648	0.3417
5	0.3914	0.3986	0.4659	0.4614
6	0.5142	0.5045	0.4578	0.4718
7	0.4509	0.694	0.5869	0.6772
8	0.4531	0.439	0.5479	0.4461
9	0.4387	0.4828	0.4235	0.4051

Table 7: Std. deviation of voltage for TiO_2 flux

S. no.	std dev for voltage 0 to 4 sec	std dev for voltage 4 to 8sec	std dev for voltage 30 to 34 sec	std dev for voltage 60 to 64 sec
1	0.4657	0.4781	0.4461	0.4448
2	0.5171	0.5553	0.632	0.6488
3	0.5599	0.5276	0.5338	0.555
4	0.5503	0.6804	0.5396	0.6472
5	0.6122	0.6297	0.4839	0.6642
6	0.5657	0.6726	0.625	0.5101
7	0.435	0.5722	0.5301	0.5228
8	0.5243	0.5189	0.6096	0.5506
9	0.7252	0.7311	1.2074	2.0107

For both type of flux system the example of flux no1 and flux no 4 were used to plot the graph. Fig 1 represents the voltage and current transient for SiO_2 flux no1. It is clear from the Fig. that for the first 20 sec arc is not so stable. Fig 2 which represent flux no 4 of SiO_2 flux arc is stable up to 80 sec and it becomes unstable for 10 sec after that.

Fig 3 and 4 represent the TiO_2 flux no 1 and 4 respectively. It is very much clear from these graph that arc is very much unstable for entire duration. To further study the arc stability in details, time of welding is divided into four segments such as, period of arc initiation, i.e. from 0 to 4 sec. Period of arc propagation i.e. 4 to 8 sec. Period of arc stability i.e. 30 to 34 sec. Period of arc smoothness i.e. 60 to 64 sec. From these graphs and with the use of statics of MATLAB standard deviation was calculated for the different duration of the weld. The result shown in table 6, 7 is the standard deviation of voltage for both type of flux. Similarly standard deviation of current is shown in table 8, 9 for both type of flux.

Table 8: Std. deviation of current for SiO_2 flux

S. no.	std dev for current 0 to 4 sec	std dev for current 4 to 8 sec	std dev for current 30 to 34 sec	std dev for current 60 to 64 sec
1	102.2741	75.7141	54.595	53.4046
2	42.5898	49.0745	39.314	76.4153
3	223.0649	49.3521	39.8803	42.0322
4	42.1878	43.7351	35.587	37.2618
5	40.0025	42.7616	51.2681	50.4313
6	59.4146	57.5797	49.6041	51.4527
7	49.5966	78.9987	64.123	74.4542
8	50.8456	49.3837	62.7179	50.7078
9	55.3457	60.973	50.9201	47.0759

Table 9: Std. deviation of current for TiO_2 flux

s. no.	std dev for current 0 to 4 sec	std dev for current 4 to 8sec	std dev for current 30 to 34 sec	std dev for current 60 to 64 sec
1	51.4372	52.8071	48.3465	47.6335
2	57.4196	62.9831	72.7865	73.8168
3	62.3569	59.5071	59.6197	61.4753
4	66.1813	81.5004	60.2805	75.1816
5	71.0582	75.8302	53.491	75.4993
6	64.2163	77.6959	70.3157	55.977
7	48.3932	69.3162	62.5396	61.2679
8	57.5375	58.8692	67.1588	60.8915
9	87.2207	83.8575	139.9316	231.7152

This data is used to further check the stability of arc for all type of flux in details. Histogram is used to plot the graph of standard deviation of voltage and current. Fig 5 displays the result of all fluxes standard deviation for different duration of weld. It is clear from the Fig. that flux no 4 is most stable as compare to other fluxes. Fig 6 it is clearly visible that flux no1 is most stable flux for all duration of weld. Same is justified from fig 7 and fig 8.

The duration in details can also be used to plot the graph of voltage and current as shown in fig 9 and 10 for SiO_2 flux and fig 11 and 12 for TiO_2 flux. These diagrams are very useful to study the metal transfer mode for all the fluxes.

Fig 9 is the expansion of graph in fig.1.From this diagram it is evident that the metal is being transferred to the molten pool from the electrode. Fluctuation in the voltage and current shows that drop by drop metal is being transferred to the pool.

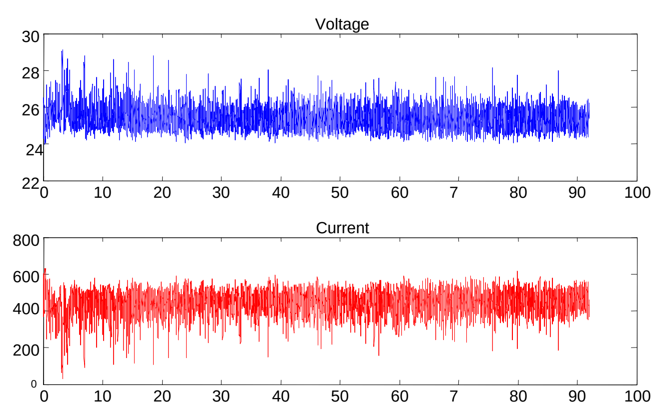

Fig. 1: V and I transient for Sio_2 flux 1

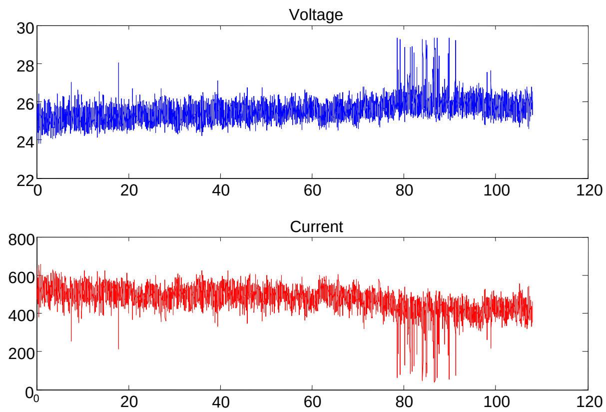

Fig. 2: V and I transient for SiO_2 flux no 4

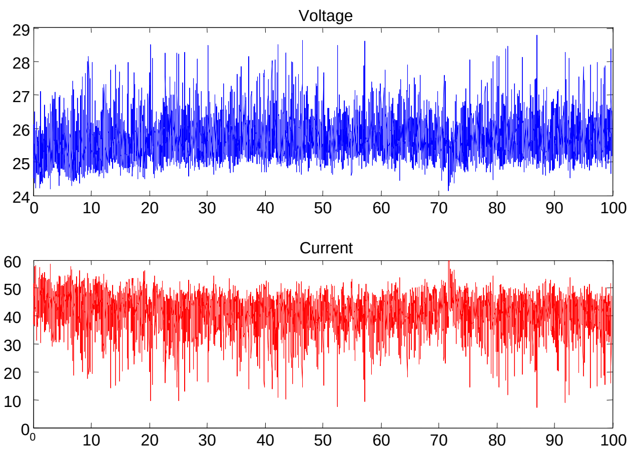

Fig. 3: V and I transient for TiO_2 flux no 1

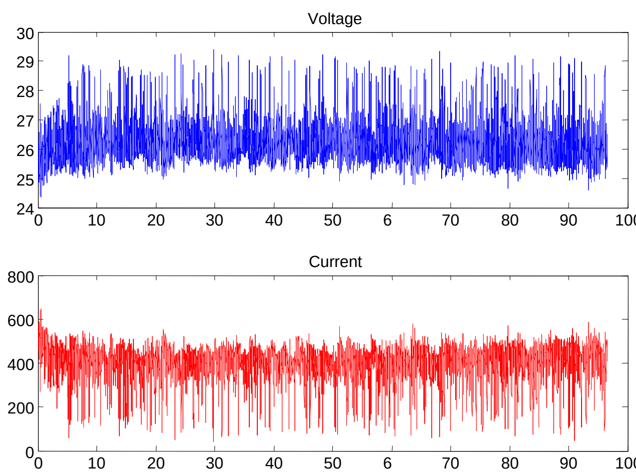

Fig. 4: V and I transient for TiO_2 flux no 4

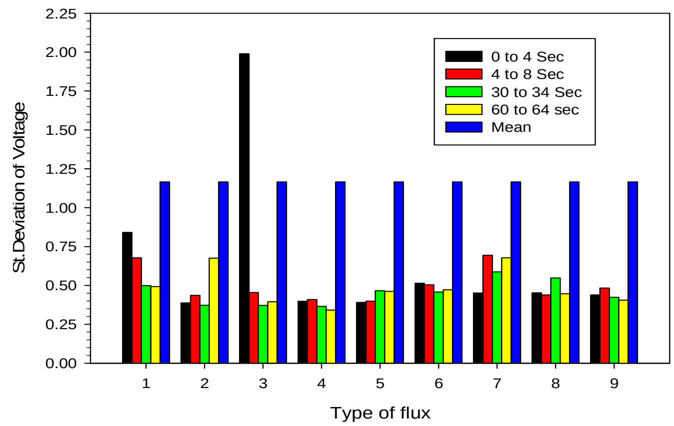

Fig. 5: Std. deviation of voltage for SiO_2 flux

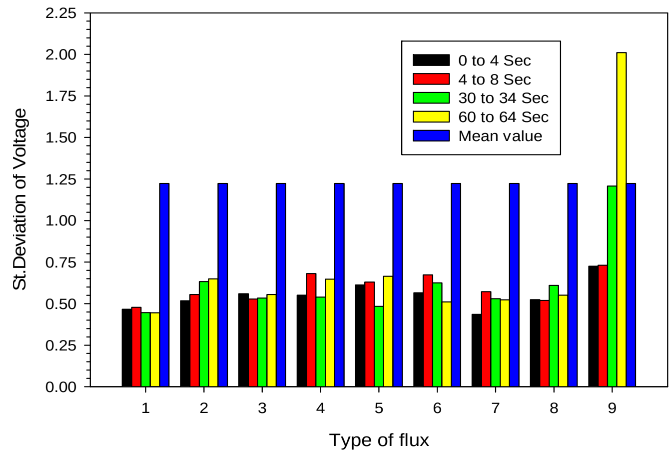

Fig. 6: Std. deviation of voltage for TiO_2 flux

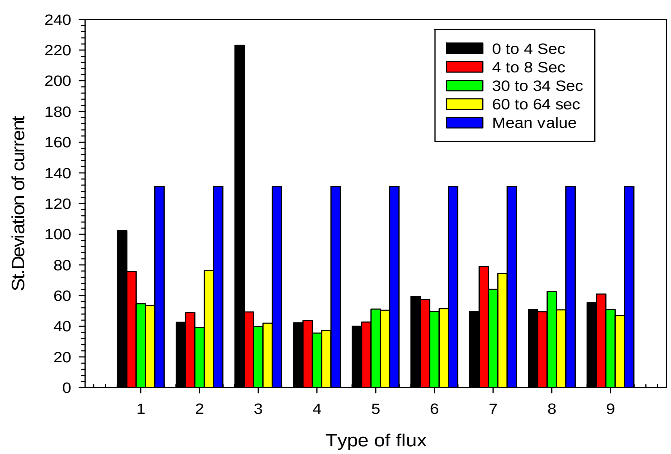

Fig. 7: Std. deviation of current for SiO_2 flux

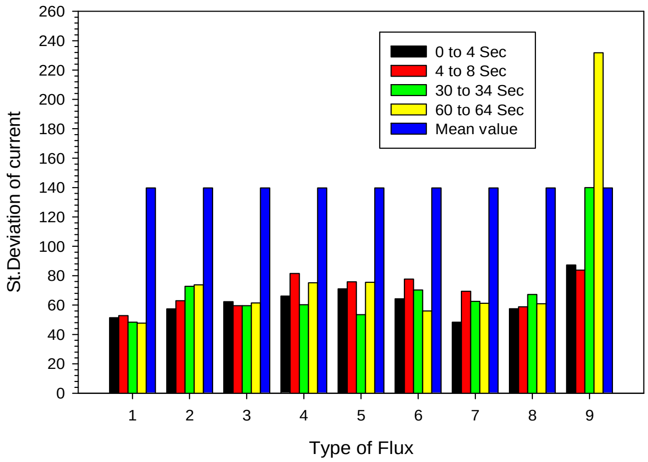

Fig. 8: Std. deviation of current for TiO_2 flux

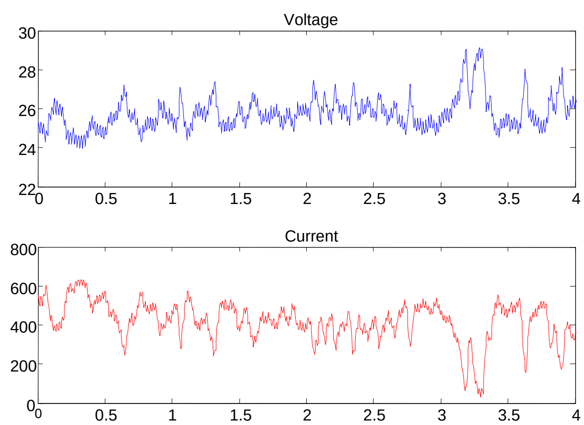

Fig. 9: V and I transient for 0 to 4 sec for SiO_2 flux no 1

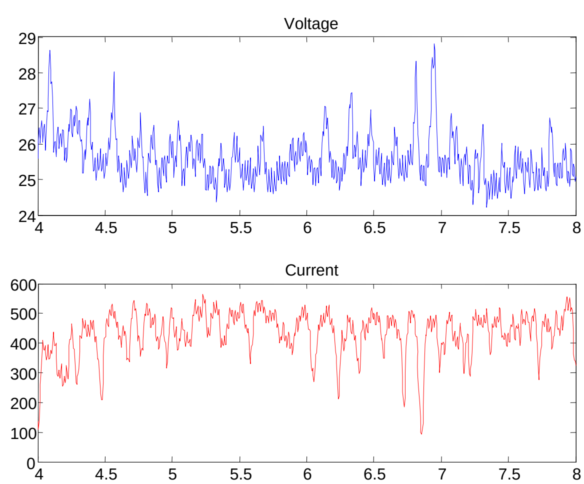

Fig. 10: V and I transient for 4 to 8 sec for SiO_2 flux no 1

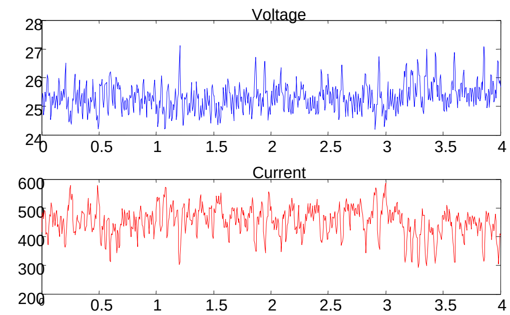

Fig. 11: V and I transient for 0 to 4 sec for TiO_2 flux no1

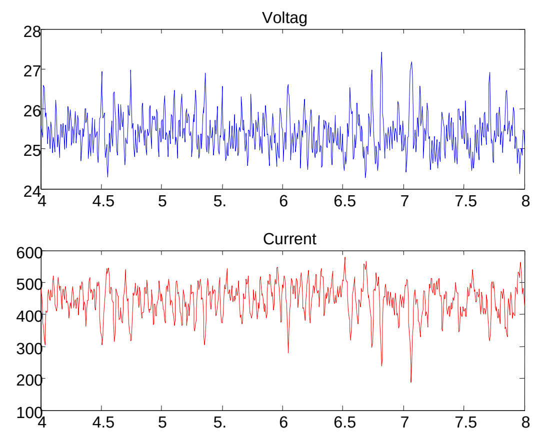

Fig. 12: V and I transient for 4 to 8 sec for TiO_2 flux no1

6. CONCLUSION

The following conclusion can be made

(1) SiO_2 flux system is more stable as compared to TiO_2 based flux system.
(2) Flux no 4 is most stable in SiO_2 flux system and flux no 1 is most stable for TiO_2 based flux system. Clearly evident from the histogram .
(3) On line monitoring of the weld can be very use full to detect the weld defect by checking the fluctuation in voltage and current reading.
(4) Metal transfer mode can also be detected with the recorded data.
(5) Voltage and current transient can be used to study the arc behavior in submerged arc welding as in this type of welding arc is not visible.

7. ACKNOWLEDGEMENTS

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