Analysis of Some Basic Coated MMAW Electrodes Based on Statistical Analysis, Mechanical Weld Properties and Hydrogen Content

By
Dr. B.C.Sharma
Assistant Professor, G.B.Pant Engineering College,
Pauri (Garhwal), Uttaranchal-246001,India
E-mail: bc_sharma@yahoo.com
Tel (+91)1368-228183, Fax: (+91) 1368-228155

Abstract

Experimental investigations have been carried out to study the behaviour of basic type of coated electrodes (IS:E614514 HJ, AWS: E7018,DIN: E5144B 1026) of different sizes produced by different manufacturers for evaluation of process stability, weldment mechanical properties and diffusible hydrogen content .Time analysis, voltage analysis and current analysis have been carried out using an 'Analyser Hannover'. This is a digital measuring and analyzing system. The time analysis does not indicate any definite trend so results have been interpreted on the basis of voltage and current analysis. The experimental results reveal that the arc stability has no definite trend for the electrodes produces by a particular manufacturer. However, relatively better arc stability is associated with the electrodes of particular manufacturer depending upon the size of electrode. The melting rate (gm/J) increases with the increase in the electrode diameter. The mechanical testing of the weldments indicate that all the electrodes which have been used, confirms to the IS, AWS, ISO and DIN standards i.e. they met the quality and requirement of the code. Higher impact strengths are associated with the electrode which yield low diffusible hydrogen contents.

1. INTRODUCTION

Manual metal arc welding was the first welding process after which other welding processes were developed, that we know today. In spite of the development of various sophisticated welding processes, the MMAW has its own identity in the welding industry. MMAW is the most widely used welding process for joining the metal parts, mainly, because of its versatility [1]. The mechanical and the metallurgical properties of the weld depend on the type of the electrode to be used and the type of the covering. Hydrogen is introduced into the weld by absorption in the molten pool and diffusion subsequently occurs into the heat affected zone (HAZ).In general, hydrogen is quite soluble in molten metal and is readily picked up in the weld metal during welding. In general, more the hydrogen present in the metal greater is the risk of cracking. Thus hydrogen is most powerful promoter of embrittlement.

A stable welding operation should have smooth burning arc with small change in arc length, uniform metal transfer, low spatter loss and rapid re-ignition after every shortest and zero current points in A.C. welding.

Statistical method have been developed for evaluating the welding process stability and microprocessor controlled measuring system is very helpful in analyzing the welding voltage and current waveform, metal transfer behavior and thus determine the welding process stability. The statistical analysis gives reproducible information and criteria about the metal transfer behavior of different covered electrodes. The obtained criteria can be used for monitoring the quality of the electrode during production and for further developing special characteristics of the metal transfer behavior. Suban and Tusek [2] describe several methods used for arc stability in MIG/MAG welding.

In this paper experimental investigations have been carried out to evaluate the arc stability, mechanical properties and diffusible hydrogen contents for some basic type of electrodes of different types of electrodes.

2. STATISTICAL ANALYSIS

The studies carried out regarding metal transfer and arc stability using short circuit counter by McMaster et al. [3], lot of further development have taken place toward studying the stability of the welding process using the method of statistical analysis of the voltage and current waveforms during welding.

Such studies are based on the fact that variations occur in one or more welding parameters because of different factors such as fluctuations in the line voltage, characteristic of the process i.e. variation in the arc length and heat input to the work piece etc. These shall lead to the changed welding condition and thus the fluctuation in the welding parameters like the arc voltage and welding current, are generated. Such variations can be used to analyze the welding process. As the voltage time fluctuation of an arc welding process is not deterministic, but a stochastic signal so the statistical theory has to be applied to describe and characterize such function.

Sunnen [4] also studied the stability of the welding process by counting the number of arc voltage peaks after re-ignition of the arc. Voltage cumulative graphs are also obtained using the technique of micro-photometry to determine the stability of the process.

It has been reported that the electrical signals can be used for the classification and analysis of the arc welding process. The statistical analysis of voltage and current signals can be used for the investigation into the stability of the welding process, evaluation of power sources, survey and control during the welding and judging the skill of the welding [5-7]. The information about the stability of the process is readily obtained from the amplitude density distribution through measurement and can be utilized in controlling the welding process [8].

The application of the microcomputer can provide a quick qualitative assessment of the welding arc stability. The voltage setting which produces greatest regularity in short circuiting event in dip mode of metal transfer, also produce satisfactory weld bead profiles [9, 10]. However, it has been found in addition to welding voltage, current and short circuiting frequency analysis, the arc burning time distribution analysis is also necessary to determine the stability of the process. The analysis based on only short circuiting frequency distribution is insufficient to define the stability of welding process [11].

It has been reported that the coefficient of variation for the short circuit mean time eventually arc burning mean time could represent a suitable criteria for the stability of welding process [12]. For shielded metal arc welding electrode, it has been reported that the standard deviation of the welding voltage values can be used as a criteria for the evaluation of the stability of the welding process [10, 13, 14].

3. EXPERIMENTAL SET UP

The block diagram of the experimental set up is shown in Figure 1. The electronically controlled feeder unit has been for feeding the electrode at constant arc length. Mild steel plates of size 200 x 40 x 10 mm have been used for depositing the weld beads. The welding has been done for about 60 seconds. Welding time and electrode length before and after the welding have been recorded for determining the welding rate. Welding speed of 22 cm/min has been selected for depositing the weld. Welding current and voltage for each electrode have been recorded separately. The welding voltage has been measured between the electrode holder and the work piece with the help of digital voltmeter. A voltage signal proportional to the welding current has been obtained from a high frequency shunt for the measurement of the welding current. A Thyristorised welding power source (Thyroarc 402) has been used as the welding power source. An electronic control panel is used to adjust the arc length of obtaining the best possible bead.

Similar type of electrode manufactured by Advani Oerlikon Ltd. (M_1), D&H Secheron Electrode Pvt. Ltd.(M_2), Modi Arc Electrode Co. (M_3) have been used. The specification of the electrode used for the above investigation are:

TYPE : BASIC
CODE : AWS E7018
IS : E 614514 HJ
DIN : E144B 1026
LENGTH : 450mm
DIAMETER : 3.15,4 and 5 mm

3.1 Sampling and data recording

The 'Analyser Hannover' has been used for statistical analysis of voltage and current and current waveform during welding Figure 2 shows the controlling, monitoring and analyzing system used. The other equipment used for the experimental and analysis are given in Table 1 with the purpose.

Analayser Hanover which is a digital measuring and analyzing system is able to classify electronically pulse width in steps of .1×n ms in 256 classes and stores the frequencies in the memory. The value of n is an integer, 1 or more. The classifications can be done for both the short circuiting time (t_1) and arc burning time (t_2)

Frequency of sampling is about 85 KHz and data of more trials, each with one million samples have been overlapped in each case. The

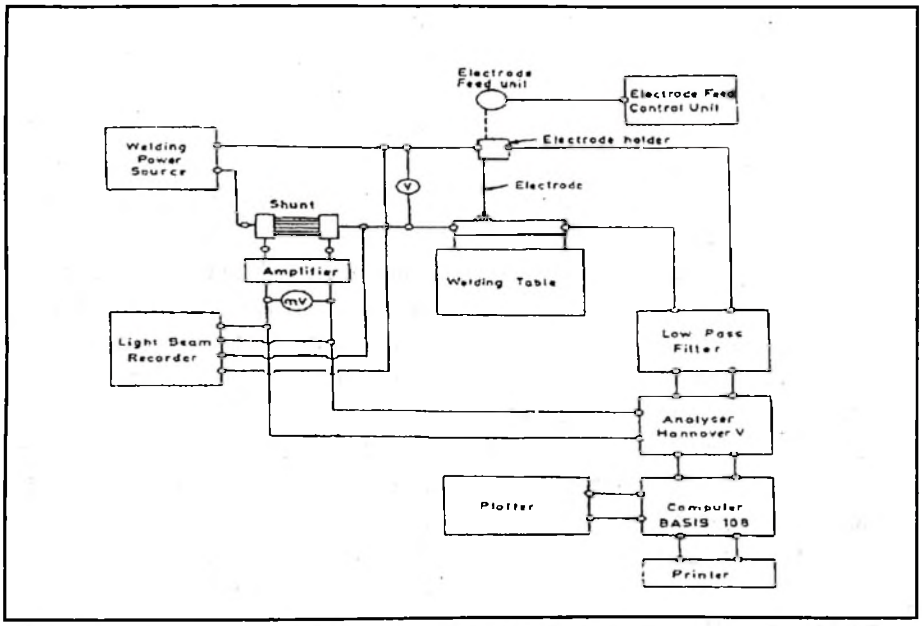

Figure 1: Block diagram of experimental setup

Table 1: Equipment used for experimental investigation with purpose

S.No.	Equipment	Purpose
1.	Basis 108 128KB computer	Data collection control and analysis
2.	Annalyser Hannover uP-Ah-V Digital measuring and Analysing system	Recording of instantaneous values of arc voltage and welding current
3.	Siemen Oscillofil C1400 Light beam recorder Paper speed, 25-100 mm/sec.	Recording current and voltage oscillograms.
4.	KEITHTHLEY MODEL 177 MICROVOLT DMM, digital voltmeter, DC voltage range, 2mV-1200V	For recording welding voltage and current values
5.	Electrode feeding setup Input supply 220 V, 50Hz.	To feed MMAW electrode for constant arc length.
6.	Thyristorised welding rectifier Make: Advani Oerlikon Model: Thyroarc 402 Range : 10 – 400 A Input Supply 415 v, 35 Amp. OCV – 80V Weight: 290 Kg.	Welding power source
7.	DC Generator Make : Kjelberg Type: KW 510 VC 01, 35 Current Range: 80-500 A Voltage range: 180-40V	Welding power source

Figure 2: Figure showing Analyser Hanover, Computer and Printer

sampling data has been done when the welding process is stabilized i.e. normally 10 seconds after the start of the welding. After completion of the data sampling these data have been transferred to computer for storage on the disc for the further analysis.

Sampling variables which have been selected for the statistical analysis of arc voltage, welding current, short circuiting and arc burning durations are shown in Table 2.

Table 2: Selected welding variables for arc, welding and time analysis

S. No.	Type of Analysis	Specification
1.	Arc voltage Analysis	
	a. Number of samples	10,00,000
	b. Class width	0.5 V
	c. Duration of measurement	11.75 sec
2.	Welding Current Analysis	
	2.1 Number of samples	10,00,000
	2.2 Class width	4 & 8 A
	2.3 Duration of measurement	11.75 sec.
3.	Time analysis	
	3.1 Class width for T1 (Short Circuit time)	0.5
	3.2 Class width for T2 (Arc Burning time)	1.10
	3.3 Threshold voltage	10 V
	3.4 Duration of measurement	10 sec.

3.2 Electrode Testing

Electrode testing is carried out according to the German standards (DIN 1913 part 2 May, 1976) 'Filler electrodes for joint welding of unalloyed and low alloyed steels, testing of filler electrodes, weld metal specimens'. Basic electrodes manufactured by three manufacturers of diameter 4 mm and 450mm lengths have been used for electrode testing. Electrode are dried at 250°C for one hour and then kept at 100°C for 2 hour before being used for welding. Mild steel plates of 280 x 150 x 20 mm and backing strip of 280 x 30 x 10 mm are taken. The plates have been tacked together at an angle of about 30° in order to compensate the shrinkage. Weld metal is deposited in several layers between two plates unit the groove is filled. One tensile and three impact specimens for each set has been taken. The position of tensile and impact test specimen in the test piece is shown in Figure 3. Tensile test bar has been stored in an electrically operated furnace for about 12 hours at temperature of 250°C, to remove hydrogen from the weld metal. The tensile bar was has cut from the test piece by machining to produce the standard tensile test specimen dimension as per German standard and is shown in Figure 4(a).The tensile testing have been carried out on 60 KN hydraulic ultimate testing machine and yield load, ultimate strength, elongation and reduction in diameter have been recorded. The impact test specimens were taken across the weld metal deposited. The position and dimension of the impact test specimen is according to German standard and is shown in Figure 4(b). The notch is placed vertically in TL direction which is the weakest direction. The notch impact bending test has been carried out on **FTM notch impact test machine** absorbed energy, non crystalline spot and lateral expansion have been recorded at different temperatures ranging from -60 to 20°. The low temperature testing of specimen has been carried out by dipping the specimen in liquid nitrogen.

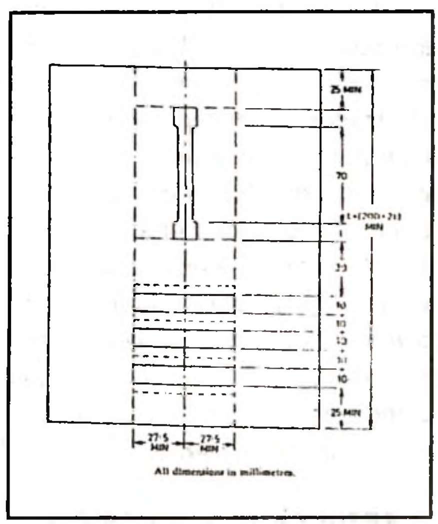

Figure 3: Position of Tensile and Impact test specimen in the test piece

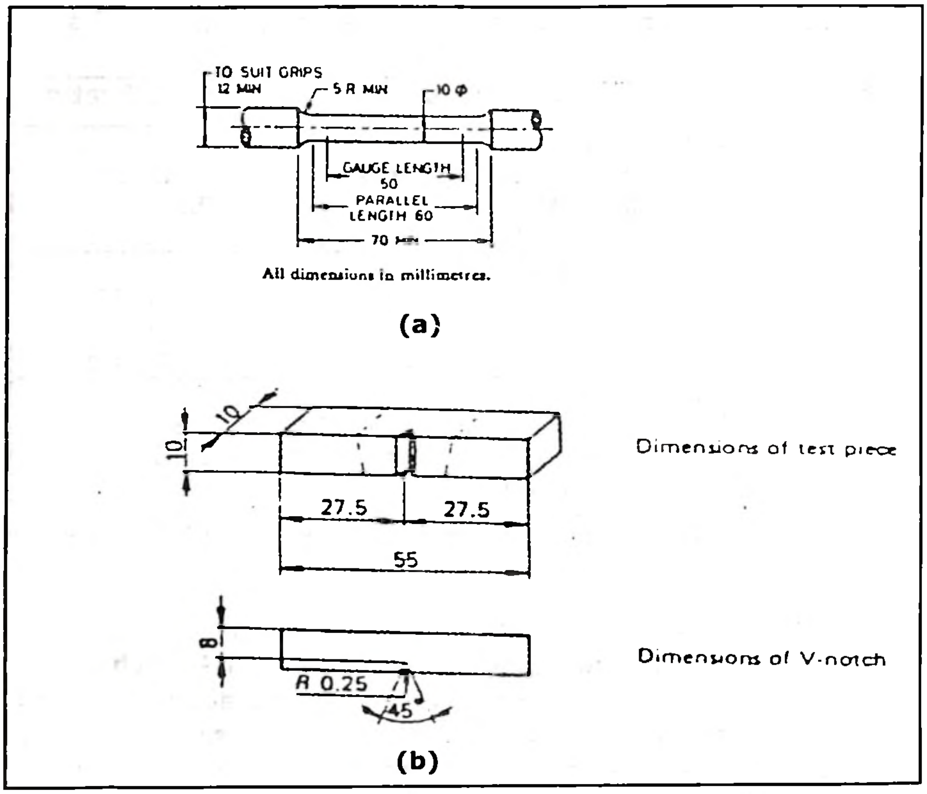

Figure 4: Dimensions of Tensile and Impact test specimen

3.3 Measurement of diffusible hydrogen

The two methods used for measuring the diffusible hydrogen are glycerin method and mercury method. The 4 mm diameter electrodes produced by different manufacturer are used for laying weld bead. The electrodes are dried at 250°C for 1 hr and keep at 100°C for about 2 hr. The standard value of hydrogen obtained by glycerin method is converted into the standard value of hydrogen using mercury method and the results are compared accordingly.

4. RESULT AND DISCUSSION

4.1 Statistical analysis

Figures 5 and 6 shows the representative probability density distribution function (PDDF) for the instantaneous values of welding voltage and current. Figures 7 and 8 shows the representative frequency distribution of the short circuiting and arc burning time respectively. Figures 9 and 10 shows the voltage and current oscillograms for typical welding conditions for different electrodes. From Tables 3 and 4 it is observed that the values of standard deviation for voltage and current analysis are lowest for 3.15 electrode produced by manufacturers. For 4 mm electrodes the lowest standard deviations for the voltage and the current analysis corresponds to the electrodes produced by manufacturer M_1, where the coefficient of variations are also lower as compared to the other manufacturers. For 5 mm electrodes the standard deviations and coefficient of variations for voltage and current analysis are lower for the electrodes produced by the manufacturer M_2, in this case also coefficient of variations are also lower for the same electrodes. Table 5 gives the various statistical parameters for time analyses for different sizes of electrode produced by manufacturers. From Table 5 the relative short circuit time and the arc burning time are practically same for all sizes of electrodes produced by different manufacturers. However, short circuiting frequency and reduces with the increase in the size of electrodes. Relative arc burning time is of the order around 96% so it seems that almost all cases the metal transfer explosive transfer and very little by dip i.e. short circuit mode of metal transfer . In almost all the cases, it has been observed that very large number of short circuit have less than 1ms short circuit time. This indicates that during the large no. of short circuit no metal transfers but these occur only due to moment of molten weld pool and the droplet at that electrode tip making and breaking the contact as the number of short circuit are very low as the main short circuit times are also very low in comparison to mean arc burning time.

Table 3: Voltage Analysis for different sizes of electrodes

	Electrode Size →	3.15 mm			4 mm			5 mm		
S. No	Manufacturer →	M_1	M_2	M_3	M_1	M_2	M_3	M_1	M_2	M_3
1.	Mean Voltage (V)	21.05	21.89	21.93	21.08	21.51	20.65	-	22.00	20.49
2.	Standard deviation (V)	4.72	4.94	4.65	4.67	5.06	4.84	-	4.79	5.07
3.	Cofficient of Variation (%)	22.40	22.60	21.20	22.20	23.52	23.40	-	21.80	24.70

Table 4: Current Analysis for different sizes of electrodes

	Electrode Size	3.15 mm			4 mm			5 mm		
S.No	Manufacturer	M_1	M_2	M_3	M_1	M_2	M_3	M_1	M_2	M_3
1.	Mean Current (A)	120.81	120.45	119.20	161.49	162.28	162.29	-	202.99	204.83
2.	Standard deviation (A)	28.30	28.53	27.94	27.51	28.31	27.53	-	26.9	27.94
3.	Coefficient of Variation (%)	23.4	23.7	23.4	17.0	17.4	17.0	-	13.3	13.6

Table 5: Time Analysis for different sizes of electrodes

	Electrode Size	3.15 mm			4 mm			5 mm		
S.No	Manufacturer	M_1	M_2	M_3	M_1	M_2	M_3	M_1	M_2	M_3
Short circuit time distribution										
1.	S.C, Frequency (sec -1)	13.6	12.7	9.8	9.8	9.6	8.8	-	5.90	6.60
2.	Mean S.C. time (ms)	3.18	3.62	4.32	3.78	5.06	4.30	-	5.29	6.23
3.	Standard deviation (ms)	3.60	3.84	4.22	5.07	5.87	5.79	-	7.85	8.19
4.	Relative S.C. Time (%)	4	5	4	4	5	4	-	3	4
Arc Burning time distribution										
1.	Mean arc burning time (ms)	70.02	75.2	97.73	97.92	98.91	107.4	-	161.47	132.28
2.	Standard deviation (ms)	67.1	67.97	82.59	95.59	85.97	109.59	-	157.54	125.24
3.	Relative arc burning time (%)	96	95	96	96	95	96	-	97	98

So, it was very difficult to draw any conclusion firm time analysis for different sizes of electrodes produced by different manufacturers.

Therefore, within the range of investigation it can be concluded that the arc stability for E7018 (IS: E614514 HJ) basic coated electrodes, can be evaluated on the basis of statically analysis of the welding voltage and current waveforms during welding. Further no definite trend has been observed with respect to particular manufacturers of all sizes of the electrodes. Relatively better arc stability has been achieved for a particular electrode produced by a particular manufacturer upon the size of the electrode.

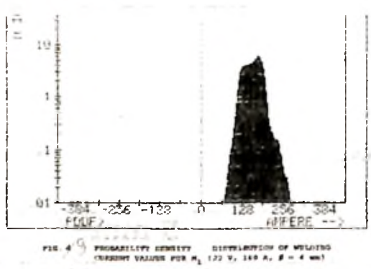

Figure 5: PDDF for welding arc voltage values for M_1 (21V, 157 A, Φ= 4 mm)

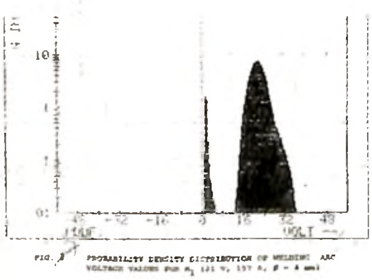

Figure 6: PDDF for welding arc voltage values for M_1 (22V, 160 A, Φ= 4 mm)

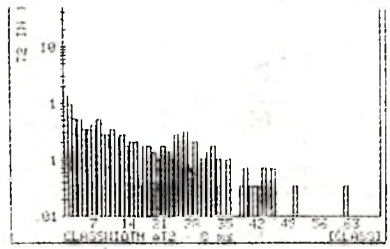

Figure 7: Frequency distribution for short circuiting time for M_1 (22V, 160 A, Φ= 4 mm)

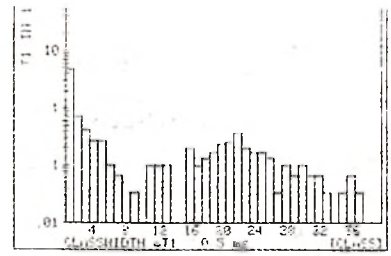

Figure 8: Frequency distribution for arc burning time for M_1 (22V, 160 A, Φ= 4 mm)

Figure 9: Voltage and current oscillogram for M_1 (21V, 157 A, Φ= 4mm), paper speed = 100 mm/sec.

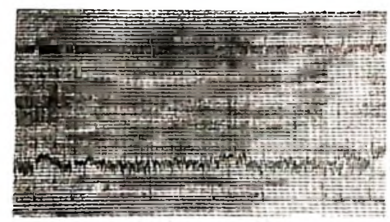

Figure 10: Voltage and current oscillogram for M_2 (22V, 160 A, Φ= 4mm), paper speed = 100 mm/sec.

4.2 Melting rate

The melting rate of different sizes of basic electrodes (AWS: E7018, IS: E614514 HJ, DIN: E5144B 1026) produced by various manufacturers have been calculated and shown in Table 6. The data corresponds to the average of about ten values in each case. The melting rate has been calculated in mg/A-sec and mg/J because of difference in welding voltages in case of different sizes of electrodes.

From the Table 6 it can be seen that:

- The melting rate increases with the increase of electrode diameter.
- For 3.15 mm electrode the melting rate is higher for electrode produced by manufacturer M_2, however for both 4 and 5 mm electrodes the melting rate is higher for the electrodes produced by manufacturer M_3.
- The difference in the above mentioned melting rates are not appreciable except in case of 4mm electrodes where variation

Table 6: Melting rates for different sizes of electrodes produced by different manufacturers

Manufacturers	M_1	M_2	M_3	M_1	M_2	M_3
Electrode size in mm	mg/A-sec			mg/J		
3.15	2.0	2.1	2.0	9.1×10^{-2}	9.2×10^{-2}	8.9×10^{-2}
4	2.11	2.25	2.31	9.7×10^{-2}	10.2×10^{-2}	10.9×10^{-2}
5	-	2.3	2.69	-	10.2×10^{-2}	12.3×10^{-2}

is of the order of around 13% between minimum and maximum melting rate in mg/J.

4.3 Mechanical Properties

4.3.1 Tensile testing:

Tables 7 give the results of tensile tests. This table gives the yield strength, ultimate tensile strength, % elongation, % area reduction for all weld metal. It can be clearly seen that yield and ultimate tensile strength are highest for electrodes produced by manufacturer M_1 and lowest for electrodes produced by manufacturer M_2. It can also be seen that the toughness measure such as % elongation at fracture and % reduction of area follows a reverse trend i.e. higher toughness for M_2 and lowest for M_1.

Figure 11 shows the variation of percentage elongation at fracture to the ultimate tensile strength. This shows the percentage elongation at fracture reduces with the increase in the ultimate tensile strength. Figure 12 shows the variation of % reduction of area with the ultimate tensile strength. The above figure also shows that higher the ultimate tensile strength lower is the % reduction of area.

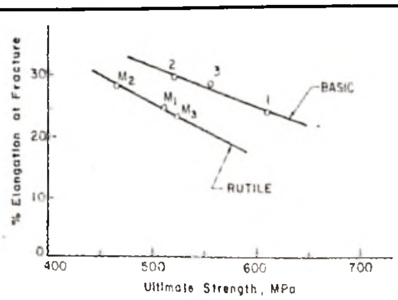

Figure 11: Variation of %age elongation at fracture with ultimate strength.

Table 7: Tensile test results for different manufacturers

Manufacturer	Yield Strength (MPa)	Ultimate Strength (MPa)	Elogation at fracture (%)	Reduction of area (%)	Remarks
M_1	541.13	611.15	24.4	69.20	Cup and cone fracture
M_2	444.86	521.3	29.84	74.20	Cup and cone fracture
M_3	477.46	556.4	28.78	71.91	Cup and cone fracture

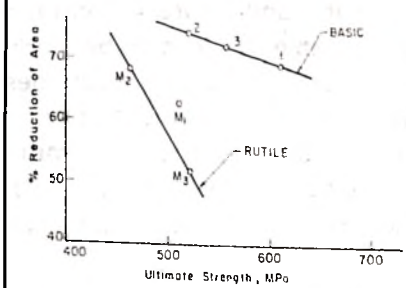

Figure 12: Variation of %age reduction of area with ultimate strength

Experimental results of rutile electrodes from the same manufacturer (IS: E317412, AWS: E6013, DIN: E4322 RR 622) are also given in the Figures 11 and 12 for the purpose of comparison. The trend is same as that of basic electrodes except that the values of percentage reduction of area and % reduction of area are lower as compared to basic electrode for a particular value of ultimate tensile strength.

Figure 13 shows a plot of ultimate tensile strength (σ_u) v/s yield strength (σ_y). The ratio σ_y / σ_u is found to be 0.876 which is a relatively high value, while this ratio is 1 for brittle material and 0.7 for a typical ductile material such as mild steel.

Figure 14 shows the principal behaviours of yield strength, ultimate tensile strength and % elongation for electrodes produced by various manufacturers are taken. The figure indicated that the basic electrodes are superior to rutile electrodes because of higher tensile strength.

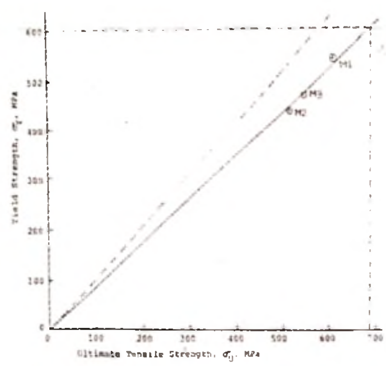

Figure 13: Variation of ultimate tensile strength with yield strength

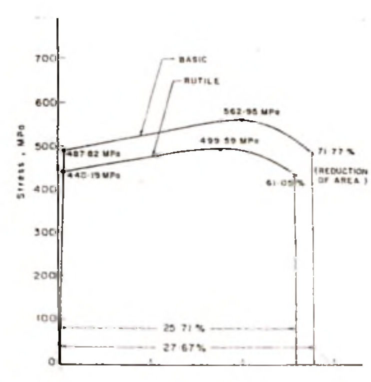

Figure 14: Principal behaviour of Rutile and basic electrode

From Table 7 it can be seen that all the electrodes which have been tested satisfy the requirements as per standards which are given below:

Minimum Ultimate Tensile Strength: 510 N/mm^2
Minimum Yield Strength : 380N/mm^2
Minimum % elongation : 24

4.3.2 Impact testing:

At different temperature (-60°C to 20°C) variation is absorbed energy, % non crystalline spot and lateral expansion for different manufacturers has been taken and are shown in Figure 15 (a) to (c) respectively.

Table 8 gives the average values of absorbed energy, % area of non-crystalline spot and lateral expansion for impact test carried out at different temperatures for different manufacturers. From the above Table 8, it can be early interpreted that all the electrodes satisfy the requirement of different standards i.e. the minimum required energy at -30° C is 47 J, whereas the average absorbed energies at -30° C are 107, 107 and 87 Joules for electrodes produced by manufacturers M_1, M_2 and M_3 respectively. Further, the area of non-crystalline spot and % lateral expansion is also higher for electrodes produced by M_1. This further confirms that M_1 is having better impact resistance as compared to the electrodes produced by M_2 and M_3.

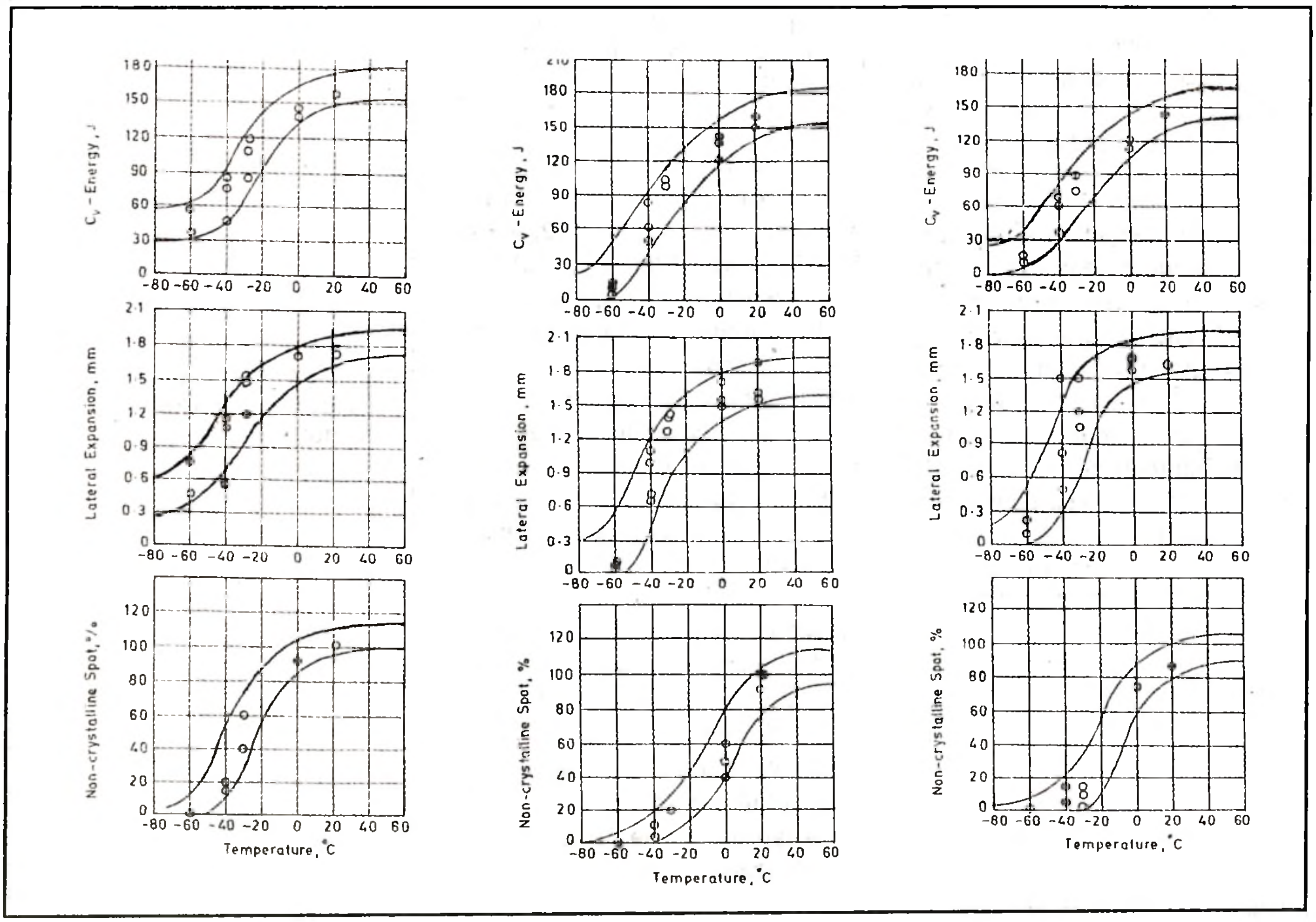

Figure 15: Impact test results for 4 mm Basic electrode produced by manufacturer M_1, M_2 and M_3 respectively

Table 8: Absorbed energy (J), Non crystalline spot (%) and Lateral expansion (%) for electrodes of different manufacturers at different temperatures

Test Temp. (°C)	M_1			M_2			M_3		
	Absorbed energy (J)	Non-crystalline spot (%)	Lateral Expansion (%)	Absorbed energy (J)	Non-crystalline spot (%)	Lateral Expansion (%)	Absorbed energy (J)	Non-crystalline spot (%)	Lateral Expansion (%)
-60	49.5	0	0.53	14	0	0.11	13	0	0.15
-40	71.8	17	0.90	66.6	7	0.90	57	7	0.92
-30	107	47	1.40	107	20	1.40	87	11	1.20
0	141.5	90	1.75	131	50	1.60	117	75	1.65
+20	160	100	1.75	165	93	1.70	146	85	1.65

4.4 Diffusible Hydrogen Contents:

Diffusible hydrogen contents have been determined by both Glycerin and Mercury methods. The diffusible hydrogen contents determined by Glycerin method has been also converted to standard value.. Table 9 gives the values of the diffusible hydrogen contents obtained by Glycerin and mercury methods. From these tables it can be seen that lowest contents of diffusible hydrogen are associated with electrode produced by manufacturer M_1 where highest impact strength have been obtained. This indicates that the higher the contents of the diffusible hydrogen lower the impact strength of the weld metal.

Further, in the case of basic coated electrodes it seems that higher impact strength are associated with higher ultimate tensile strength in spite of the fact that the both percentage reduction in area and the percentage elongation at fracture are lower with the higher ultimate tensile strength. In the previous work with rutile electrodes, it has been reported that higher tensile strength are associated with lower impact strength. However, in basic coated electrodes the trend is reverse. This may be perhaps due to the reason that weld metal deposited by rutile electrodes, may have micro voids which reduce the tensile strength, but may act as crack arresters and offer resistance to fracture during impact testing leading to higher absorbed energy.

Table 9: Diffusible Hydrogen Contents for electrodes of different manufacturers using glycerin and mercury method

Manufacturer	Glycerin methods			Mercury Method	
	Vs (ml/100 gm)	Vs (when converted to Standard value of Mercury methods) (ml/100 gm)	Average	Vs (ml/100 gm)	Average
M1	3.50	6.94	8.8	12.0	11.90
	6.43	11.50			
	4.61	8.66		11.8	
	4.30	8.12			
M2	4.50	8.56	9.4	12.4	12.70
	4.96	9.20			
	5.54	10.11		13.0	
	5.50	9.70			
M3	6.85	12.15	15.6	20.30	18.90
	11.0	18.45			
	9.7	16.60		17.50	
	8.9	15.35			

6. CONCLUSIONS

On the basis of experimental investigations the following conclusions are drawn:

- No definite trend exists with respect to arc stability with the basic electrodes (IS: E614514HJ, AWS: E7018) produced by various manufacturers. However, better arc stability has been observed for electrodes produced by manufacturers M_3, M_1 and M_2 for electrodes sizes of 3.15, 4 and 5 mm respectively.
- The arc stability has been evaluated on the basis of current and voltage analysis for the above mentioned electrodes because of the fact that time analysis does not indicate any definite trend. Time analysis is also not suitable for these electrodes because relative arc burning time is practically 96% in all cases.
- The melting rate per unit of energy supplied, increases with the increase of the size of electrodes produced by all manufacturers.
- All the electrodes which has been tested, satisfy the requirements of the IS, AWS, DIN & ISO standards.
- Higher ultimate tensile strength and toughness have been obtained with basic coated electrodes as compared with rutile type electrodes (IS: E317412, AWS: E6013, DIN: E4322 RR622) which is an establish fact.
- Within the range of experimental investigations no direct correlation has been found between the arc stability and the mechanical properties of the weld metal in case of above mentioned basic type of electrodes. It seems that arc stability may affect more to the metal transfer and bead geometry rather than the metallurgical character of the weld metal. It is difficult to draw any definite conclusions; however, extremely poor arc stability may affect the metallurgical character of the weld metal and thus the mechanical properties.

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