# The Influence of Electrode Polarity and Welding Current on Mechanical Properties of Submerged Arc Weld

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An experimental study has been made on the effect of electrode polarity on macrostructure and mechanical properties of multipass submerged arc welds. The influence of welding current with two polarities has been studied. The welds are made by using C-Mn filler wire and basic flux. Weld deposites were characterised on the basis of tensile properties, hardness measurements and charpy impact toughness. The study of macro structure of weld deposites shows that the amount of reheat refined weldmetal increases with decreasing welding current with DCEP than that observed with DCEN. Hardness survey on the transverse section along the vertical line of the weld deposite revealed that higher hardness occured in the coarse micro structural region than the reheat refined region of the weld deposite. The charpy V-notch impact results show better toughness in the welds deposited at lower level of current with DCEP than that observed at DCEN. Yield strength and ultimate tenslile strength are higher with DCEN than that observed in case of DCEP.

## INTRODUCTION

The Submerged arc welding (SAW) is a process where during welding the arc is shielded by a blanket of granular fusible flux placed over the welding area. This welding process provides a good quality of deposited weld metal due to shielding of arc by flux, higher deposition rates, smooth surface and high electrode utilisation. The mechanical properties of submerged arc weld joints are governed by proper selection of the welding parameters such as welding current, arc voltage and travel speed. A variation in these parameters changes the heat input and consequently affects the deposition rate, geometry and penetration (1,2,3). SAW may be done either by a Direct current (DC) or Alternating current (AC) power source (1,2). However direct current gives better control over the bead shape, penetration and welding speed. The SAW is normally carried out by direct current reverse polarity (Electrode positive, DCEP) because under a given set of other welding parameters, it gives more penetration in combination with good bead shape than that observed with direct current straight polarity ( Electrode negative DCEN ) is used. However, under a given set of welding parameters, a change in electrode polarity from DCEP to DCEN is found to increase the deposition rate (2,4,5,6)

In multipass welding, the weld deposit undergoes multiple thermal cycles due to reheating by the subsequent welding passes. As such, in multipass welding process the weld deposit develops a number of zones having different microstructures modified from its dendritic cast structure. The welding parameters influence the bead geometry and heat input which in turn decide the extent to which the thermal cycle of subsequent beads causes development of different heat treated regions in the previously deposited and solidified weld beads (7,10). The increase in extent of the reheat refinement of microstructure has been found to improve mechanical properties of the weld deposit obtained in multipass welding process (8,9,10).

As may be inferred from the above, for a given set of welding parameters, the increase in deposition rate is more with DCEN as compared to with DCEP and hence from the economic point of view DCEN is appropriate for use in multipass SAW process. However acceptability of this process is dependent on its capability to produce a sufficient amount of "reheat refined zone" in weld deposit so that the required mechanical properties of the weld can be achieved. However, the current literature survey reveals no such systematic investigation which can throw light on the effect of various welding parameters on the characteristics of weld beads deposited under different polarities in multipass SAW process. Keeping in view the above shortcome in this paper, an effort has been made to study the effect of current on the macrostructure and mechanical properties of multipass weld deposit under DCEP and DCEN.

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## 2. EXPERIMENTATION

### 2.1 Plate Preparation and Welding

A 40 thick mildsteel plate was cut into piece of size 350 mm x 120 mm. To obtain a flat surface after butt welding of the two plates by accomodating the bending during welding, the job was prepared by resting them on a 12 mm thick mildsteel base plate as shown schematically in Fig.1. The plates were welded by multirun Submerged Arc Welding process, using a 4 mm diameter copper coated mildsteel electrode wire. A basic flux of type LW 710 having chemical composition as given in Table 1, was used in this investigation. The welding was carried out at different welding currents with the arc voltage and travel speed kept constant as may be seen from Table 2.

### 2.2 Hardness Distribution

The Vicker's hardness HV5 of the weld deposit was measured on the etched transverse section of the weld. The hardness measurement was carried out along the centre line of the weld, starting from the top of reinforced bead region upto the bottom of the weld.

**Table 1. Composition of welding flux LW 710.**
**Agglomerted, Fluoride basic flux**
**Basicity index : 3.1**
**Maximum current : 400 A**

| Grade | Chemical composition (Wt %) | | | |
|---|---|---|---|---|
| | $Sio_2$ + $Tio_2$ | Cao + Mno | $Ai_2o_3$ + Mno | Ca $F_2$ |
| LW 710 | 15% | 35% | 20% | 25% |

**Table 2. Welding Parameters**

**Process** : **Submerged Arc Welding**
**Travel speed** : **40 cm/min**
**Electrode extension** : **30 mm**
**Flux** : **Agglomerted, Flouride basic flux**
**Filler wire specification** : **Class As 4, Grade A.**
**Interpass Temperature** : **175 - 20°C**

| Weldment No. | Welding Current Amp. | Arc V | Electrode Polarity |
|---|---|---|---|
| 1. | 500 | 28 | DCEN |
| 2. | 500 | 28 | DCEP |
| 3. | 700 | 28 | DCEN |
| 4. | 700 | 28 | DCEP |

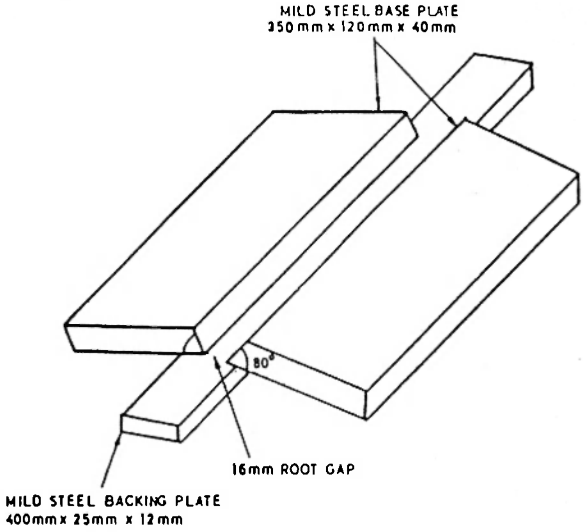
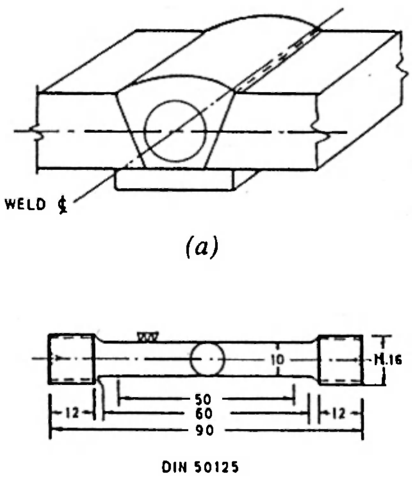


**Fig. 1.** *Weld preparation and test plate assembly*



(a)

(b)

**Fig. 2.** *Location and directions of all weld metal tension specimen*
*(a) Location*
*(b) Dimensions*

During the hardness measurement, the Vicker's hardness indentation has been made in such a way that the behaviour of different microstructural regions coming in the part of measurement can be revealed. After hardness measurement. the specimens are observed under an optical microscope and the position of the indentations with reference to the top boundary and the extent to which different microstructural regions are present across the measurement path were estimated.

### 2.3 All-Weldmetal Tensile Test

The tensile test specimens as shown in Fig 2, conforming to DIN 50125 were machined from the weldmetal along the longitudinal direction of the deposit. The tensile test was carried out on an universal testing machine. The load Vs elongation plots were obtained and the yield strength, ultimate tensile strength, percentage elongation and percentage reduction in area of the weldmetal were estimated.

### 2.4 Charpy V-Notch Impact Test

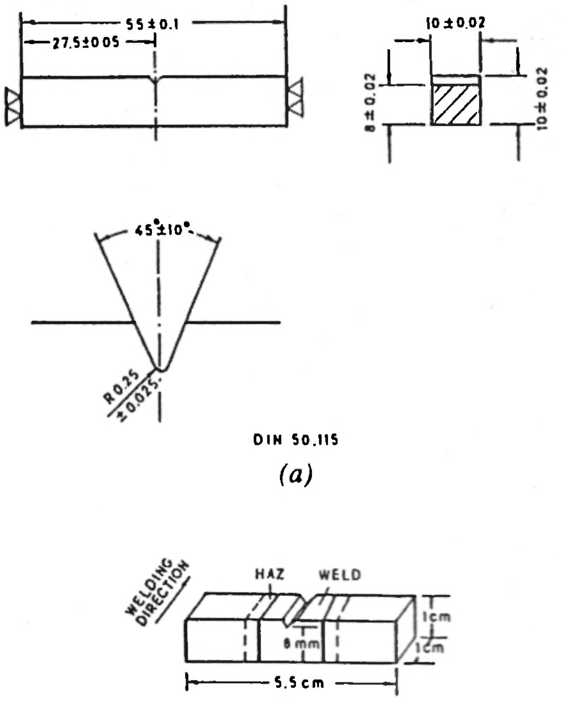
For the charpy impact test, sample of weldmetal having an orientation perpendicular to the welding direction were machined conforming to DIN 50115 as shown schematically in Fig. 3. The v-notch was prepared at the centreline of the weld. The charpy specimens were tested at -60 deg. C, -40 deg. C, -20 deg. C, 0 deg. C and room temperature. To obtain subzero temperature of the specimen, liquid nitrogen was used. Before breaking the specimen under impact loading, the temperature of the specimen was continuously measured with the help of a surface sensor attached to a digital thermometer and the test temperature was controlled with an accuracy of +/- 2 deg. C at -60 deg. C, -40 deg. C, -20 deg. C, 0 deg. C and room temperatures.

## RESULTS AND DISCUSSION

In multipass welding process, the earlier weldbead undergoes a heat treatment caused by the reheat thermal cycle imposed by latter deposition. As a result, a part of the dendritic microstructure of earlier weldbead gets transformed and refined. The extent of this reheat refinement depends on the bead geometry, amount of deposition and bead penetration. It has been observed that at a given welding parameter the change in polarity from DCEP to DCEN increases the weldmetal deposition rate and bead height but reduces the penetration and bead width (2,4). As such, in multipass welding process at a given welding current, arc voltage and travel speed, the use of DCEN reduces the extent of reheat refinement in earlier bead than that observed in case of DCEP (Figs. 4, 5).

At any electrode polarity of DCEN and DCEP during the deposition of weldbead at a given arc voltage of 28 V, the extent of reheat refinement of the weldmetal macrostructure has been found to be significant at a lower welding current of 500 A than that observed with a higher welding current of 700 A (Figs. 4, 5). This is due to decrease in welding current.

The observed trend showing a comparatively higher hardness in the coarse microstructural region ( cast-columnar) in comparison to that observed in the reheat refined region ( Figs. 6, 7) may be attributed to the heat treatment of a certain region of the earlier deposited weldbead by the subsequent run. During deposition of the later bead on the earlier one, a region of the earlier bead nearer to the later one is subjected to a heat treatment due to a rise in the temperature of this region above the recrystallization temperature. This causes the recrystallization and refinement of coarse columner structure of the earlier bead which reduces its hardness from that of the columnar one ( 8, 9).



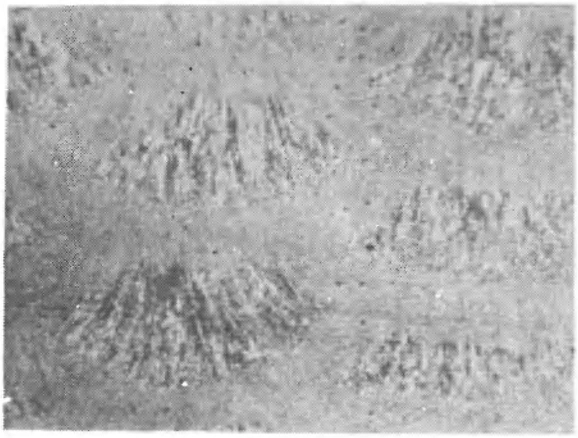
(a)

(b)

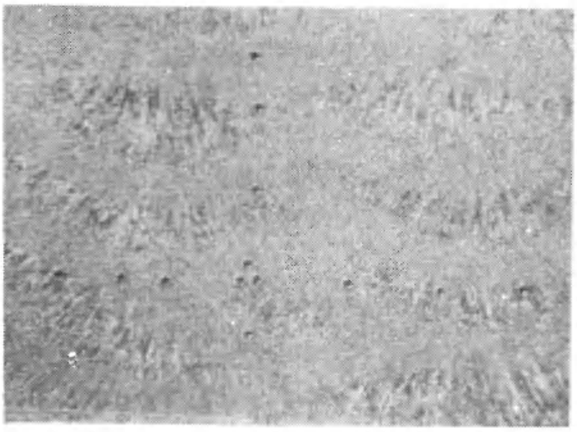
**Fig. 3.** *Dimensions and location of charpy V-Notch specimen*
*(a) Dimensions*
*(b) Location of V-Notch*

For both the welding parameters (welding current 500 A and arc voltage 28 V & welding current 700 A and arc voltage 28 V), a relatively higher average hardness of the weldmetal is observed in case of DCEN than that observed in case of DCEP (Table 3). This may be attributed to the higher deposition rate and also the lower amount of reheat refined weldmetal in case of DCEN as compared to that of DCEP.

It has been observed that the uppershelf energy of the weldmetal is less and impact transition temperature at a particular impact energy is more with DCEN than that observed with DCEP (Figs. 8, 9). This is because in case of DCEP, the extent of reheat refined metal is more than that in case of DCEN (Figs. 4, 5).

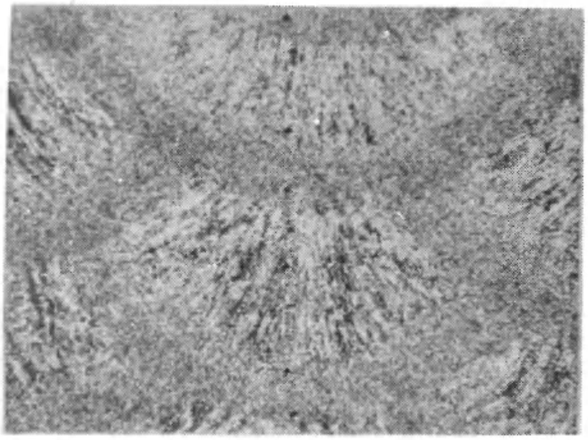


*(i) DCEN*

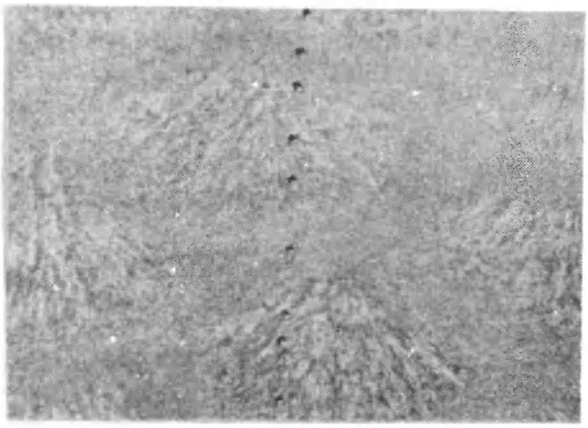


*(i) DCEP*

**Fig. 4.** *Macrostructure of middle region of multi-pass weld deposit at 500 A, 28 V (i) DCEN (ii) DCEP X 2, enlarged 2.5 times.*



*(i) DCEN*



*(i) DCEP*

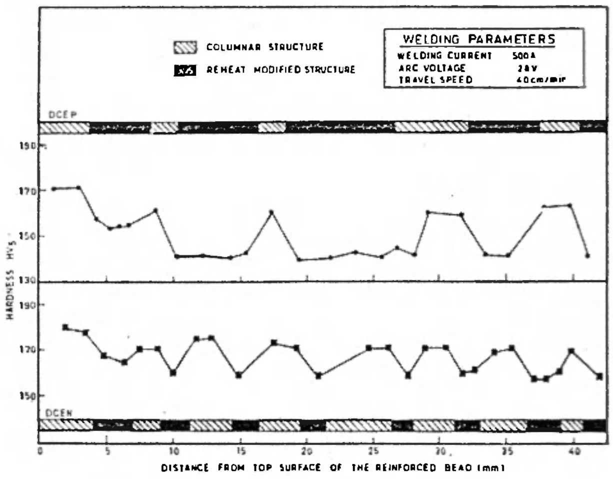
**Fig. 5.** *Macrostructure of middle region of multi-pass weld deposit at 700 A, 28 V (i) DCEN (ii) DCEP X 2, enlarged 2.5 times.*

**Table 3. Welding parameters - Average hardness in the weldmetal**

| Welding Current (Amps) | Arc Voltages (Volts) | Average Hardness of the weldmetal HV5 | |
|---|---|---|---|
| | | DCEN | DCEP |
| 500 | 28 | 166.90 | 148.16 |
| 700 | 28 | 156.00 | 140.22 |

**Table 4. Tensile properties of submerged arc weld deposits**

| Welding Current | Arc Voltage Voltage (volts) | Heat input Kj/mm | Yield stength N/mm | | Ultimate Tensile strength | | % Elongation | | Reduction in cross sections arca | |
|---|---|---|---|---|---|---|---|---|---|---|
| 500 | 28 | 2.1 | 340.25 | 330.29 | 440.99 | 413.0 | 27 | 31.4 | 41 | 43 |
| 700 | 28 | 2.9 | 365.72 | 356.80 | 452.75 | 420.87 | 23.2 | 26.90 | 40 | 42 |



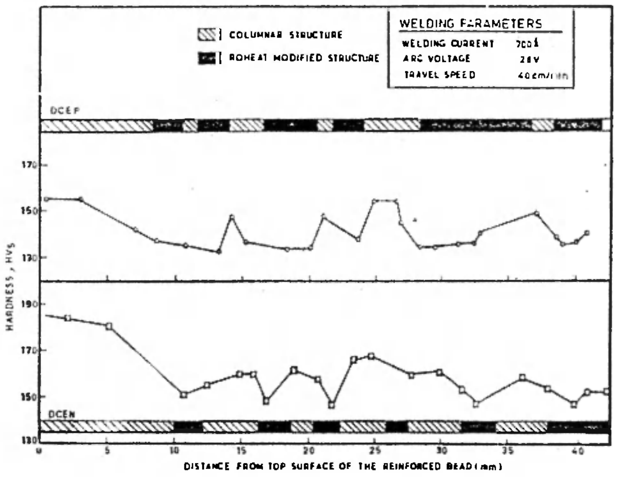
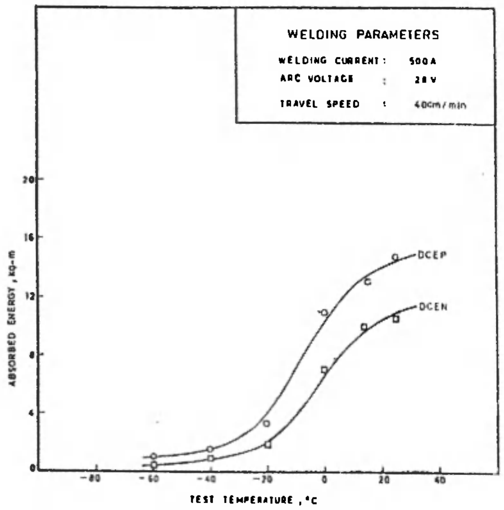


**Fig. 6.** *Hardness distribution from top to bottom along the centre line of the weld measured in the transverse section of the weldment*

**Fig. 7.** *Hardness distribution from top to bottom along the centre line of the weld measured in the transverse section of the weldment*



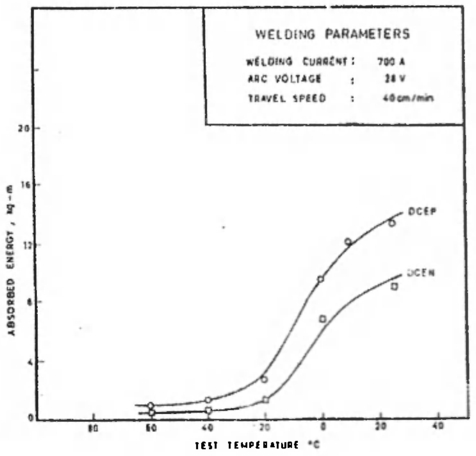


**Fig. 8.** *Charpy v-notch impact test results*

**Fig. 9.** *Charpy v-notch impact test results*

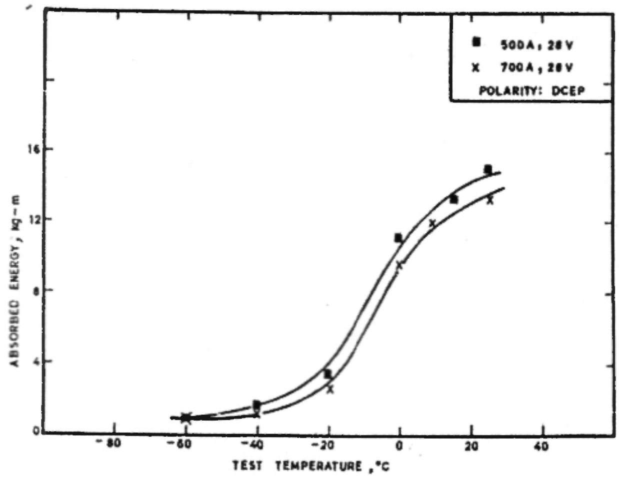


**Fig. 10.** *Charpy v-notch impact test results*

Impact transition temperature (ITT) depends upon the amount of reheat refined zone in the weldmetal. The I.T.T. decreases with increase in the amount of reheat refined zone in the weldmetal. The amount of reheat refined weldmetal increases with a decrease in welding current (Figs. 4, 5 ).

With a change in current from 500 A to 700 A at an arc voltage of 28 V, there is a decrease of 1.8 kg.m in the uppershelf energy with DCEP ( Fig. 10). This is due to the reduction in the amount of reheat refined weldmetal in the weld deposit.

Yield strength and ultimate tensile strength of the weldmetal are higher with DCEN than that with DCEP. But the percentage elongation and percentage reduction in cross sectional area are less with DCEN than that observed with DCEP (Table 4). This is because of the increase in deposition rate and bead height reduction in penetration and bead width with DCEN compared to DCEP. The deposition rate and bead geometry directly reflect the amount of reheat refined weldmetal. The amount of reheat refined weldmetal is more in case of DCEP than that observed in case of DCEN (Figs 4, 5).

Yield strength and ultimate tensile strength decrease & percentage elongation and percentage reduction in cross-sectional area increase with a decrease in welding current from 700 A to 500 A (Table 4). This is because the welds deposited at lower level of current tend to heat treat ( due to deposition rate) more of the previously deposited structure in relation to the amount of columnar structure they create.

## CONCLUSION

(1) At a given welding parameter, the use of electrode negative polarity (DCEN ) reduces the extent of reheat refinement in earlier bead than that observed in case of electrode positive polarity (DCEP ).

(2) At any electrode polarity, higher amount of reheat refinement regions in the weldmetal can be obtained with a decrease in welding current.

(3) In multipass welding, comparatively higher hardness occurs in the coarse microstructural region (cost-columnar ) than that in the reheat refined region of the weld deposit at any given welding parameter.

(4) Impact transition temperature of the weldmetal decreases with a change in electrode polarity from DCEN to DCEP.

(5) Yield strength and ultimate tensile strength are higher with DCEN than that with DCEP. But percentage elongation and percentage reduction in cross- sectional area are less with DCEN than that observed with DCEP.

(6) Yield strength and ultimate tensile strength decrease & percentage elongation and percentage reduction in cross-sectional area of the weldmetal increase with a decrease in welding current.

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