# Evaluation of Heat Input Variation on the Mechanical Properties of ASTM A300 Steel at the Heat Affected Zone

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**Abstract— This work investigated the effect of heat input variation on the mechanical properties of ASTM A300. Three welds were made with varying voltages and currents by using Flux Core Arc Welding (FCAW) process and the heat input was computed. Nine test specimens were prepared using API 1104 standard. The specimens were subjected to tensile test, impact test and hardness test. Analysis of variance (ANOVA) was used to determine effect of the various heat input on the mechanical properties of ASTM A300 obtained at the heat affected zone. The result obtained showed that heat input has significant effect on the tensile strength, toughness and hardness of ASTM A300 steel.**

**Index Terms — Heat Input, Heat Affected Zone, Mechanical Properties, ASTM A300 Steel**

## I. INTRODUCTION

Steels and its alloys are important materials in the fabrication and construction of structures used in the oil and gas facilities. Welding process is one of the most important techniques and cost effective means of joining steel structures. Weld integrity and strength are important factors in steel structure performance and sustainability when in service. The heat affected zone (HAZ) which is the volume of material at or near the weld metal when exposed to high temperature is an important factor to consider in the determination of mechanical properties, weld strength and performance evaluation of steel at the weld region. Attempt has been made by several researchers in the evaluation of heat input on the mechanical properties of various steels [1-9]. Relatedly, the influence of thermic conditions on the mechanical properties of heat affected zone of steels and the relationship between the heat cycle and the absorbed energy has been studied [10-13]. The American Standard for Testing and Materials (ASTM) A300 steel is used in the oil and gas industries for pipeline transportation [14]. Hence, this study seeks to evaluate heat input variation on the mechanical properties of ASTM A300 at the heat affected zone.

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## II. METHOD

### A. Material Specifications

The steel material was acquired from Big Finger Oil Services Limited, Warri, Nigeria and the chemical analysis test was conducted (using Angstron spectrometer with model number V-950) at Standard Organization of Nigeria, Enugu, Nigeria, to determine the type of steel. In accordance to ASTM steel designation, this steel falls into low temperature carbon steels grade represented within the A300 series as shown in table 1.

Table 1: Chemical Analysis of ASTM A300 steel

| | Constituent (Percentage in Weight) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Element | Fe | C | Si | P | S | Cr | Co | Mn | Cu | Al | W |
| Composition | 98.8 | 0.16 | 0.17 | 0.16 | 0.01 | 0.2 | 0.004 | 0.64 | 0.12 | 0.03 | 0.05 |

### B. Welding Procedures

In order to investigate the mechanical properties, the specimens were prepared according to API 1104 standard.


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Six (6) plates measuring 304.8mm × 152.4mm × 12mm were cut to shape, bevelled and butt welded using Flux Core Arc Welding (FCAW) process, with 1.2mm diameter mild steel filler wire at varying travel speed and arc voltages using ESAB AB welding machine with serial number 917-008-3060. DCEN welding polarity was employed while the gas flow rate was kept at 20. Figure 1 shows a sample of the butt welded plate using the FCAW process.

Fig.1. Sample of Butt welded plate using FCAW

The welding parameters for the three (3) categories of welds, heat inputs and welding speed are shown in tables 2 and 3. Twenty-seven (27) samples of test specimens were obtained from these welds. Nine (9) standard specimens from each weld were machined for tensile, impact and hardness tests, respectively.

Table 2: Welding Parameters for the welds.

| **Weld (Volts)** | **Bead Number** | **Welding Current (A)** | **Weld Time (S)** |
|---|---|---|---|
| 24.2 | Root Run | 137 | 45 |
| | Hot Pass | 138 | 52 |
| | Capping | 139 | 55 |
| 25.3 | Root Run | 140 | 63 |
| | Hot Pass | 139 | 65 |
| | Capping | 142 | 61 |
| 26.3 | Root Run | 143 | 67 |
| | Hot Pass | 143 | 65 |
| | Capping | 143 | 66 |

Table 3: Table of the Various Heat Inputs

| **Arc Voltage (Volts)** | **Arc Current (A)** | **Welding Speed (mm/s)** | **Heat Input (KJ/mm)** |
|---|---|---|---|
| 24.2 | 104 | 4.89 | 0.675 |
| 25.3 | 138 | 4.77 | 0.744 |
| 26.3 | 143 | 4.55 | 0.827 |

C. Testing Procedure

The welded specimens were subjected to the three (3) mechanical tests namely tensile, hardness and impact. The tensile test was carried out with Enerpac Tensile Testing Machine, model number EEM-421E. Brinell hardness test was done using TQ Universal Testing Machine with model number SM100 and the Impact test (Charpy) was carried out with Brooks impact testing machine with model number MAT21/1T3U. Figures 2, 3 and 4 are the specimens for the tensile, impact, and hardness test, respectively.

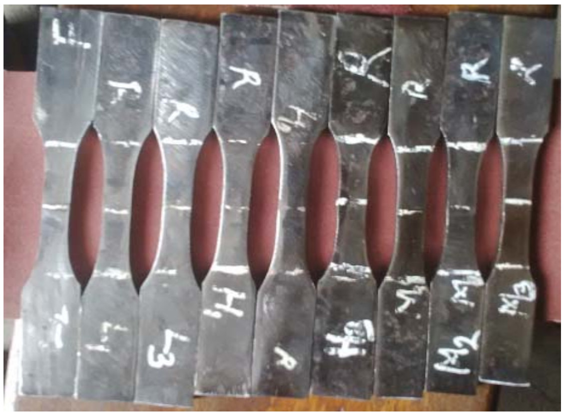

Fig. 2. Diagram of Tensile Test Specimen

Fig.3. Impact Test Specimen

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Fig. 4. Hardness Test Specimen

## III. RESULTS AND DISCUSSIONS

The results for tensile strength, percentage elongation, and percentage reduction of ASTM A300 are plotted in figures 5, 6 and 7, respectively. It was observed in figure 4, that increase in heat input decreases the tensile strength at the heat affected zone of the weldment. Hence, heat input has effect on the tensile strength of ASTM A300. However, the percentage elongation and reduction in area increases and the heat input increases as shown in figures 5 and 6. Also, the impact strength (toughness) and hardness of the ASTM A300 at the HAZ increases as the heat input increases as shown in figures 8 and 9.

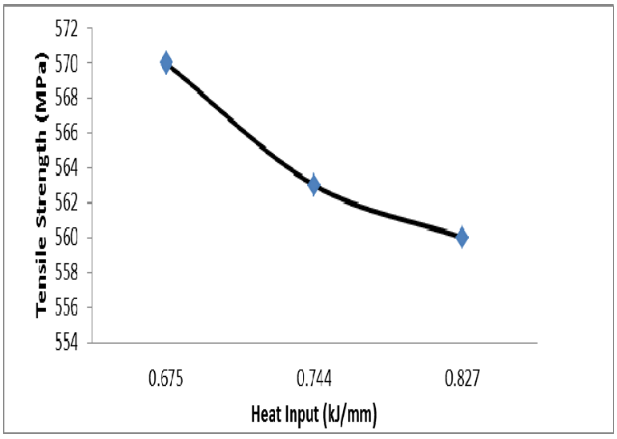


Fig.5. Plot of Heat Input vs. Average Tensile Strength

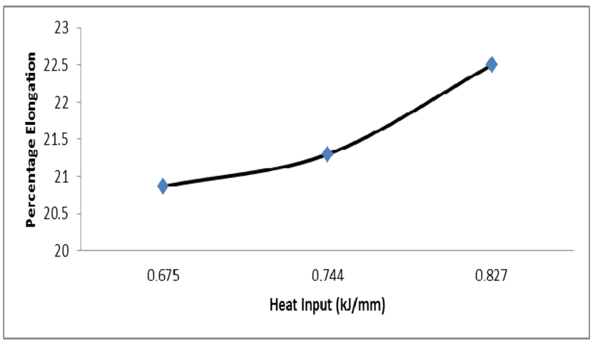


Fig.6. Plots for Energy input vs. percentage Elongation

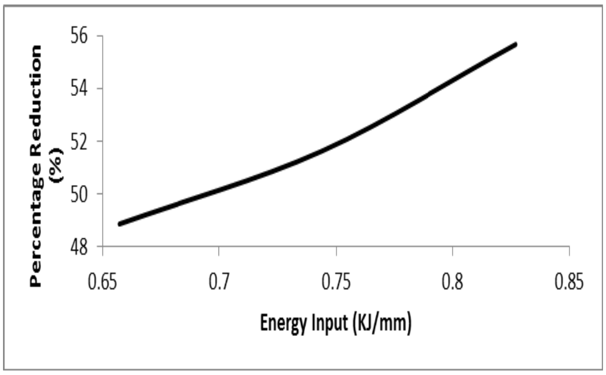


Fig.7. Plots for Energy input vs. percentage Reduction in Area

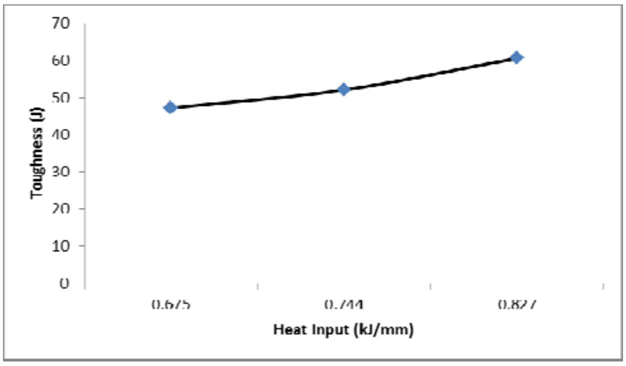


Fig. 8. Plots for Energy input versus Toughness

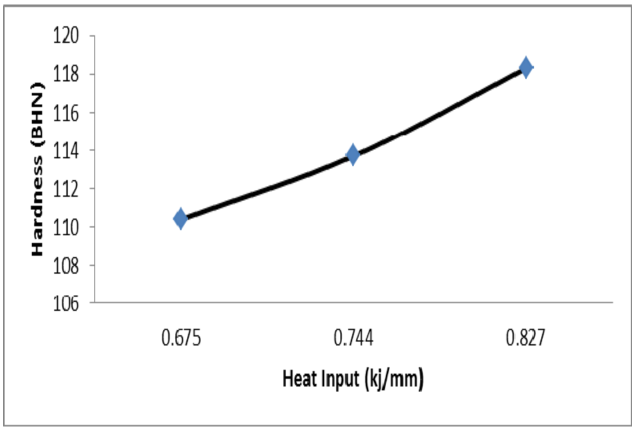


Fig.9. Plots for Energy input vs. Hardness

To ascertain if there were variances in the test samples, the results from experiment were analysed using a 2 way ANOVA. Additionally, regression models were obtained for all the variables investigated using Microsoft excel 2010 version. From figure 5, the regression model is obtained in equation 1 as;

$$Y = 574.33 - 5x \quad (1)$$

where, Y is the average tensile strength (MPa)

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x is the heat input (kJ/mm)

Also, the coefficient of determination $R^2$ is 0.95, which indicate that there is close relationship between heat input and tensile strength and that the model can adequately predict tensile stress for a given heat input. The ANOVA table for the tensile strength of the different test samples is shown in Table 4. The P-values for both the variation in heat input and variation in samples are lesser than 0.05, which means that the effect of energy input on the average tensile strength is significant.

Table 4: ANOVA analysis of the Tensile Strength for the Different test Samples

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---|---|---|---|---|---|---|
| Energy Input | 0.0035 | 2 | 0.0017 | 1.3684 | 0.3525 | 6.9442 |
| Samples | 0.0019 | 2 | 0.0009 | 0.7368 | 0.434 | 6.9442 |
| Error | 0.0051 | 4 | 0.0013 | | | |
| Total | 0.0104 | 8 | | | | |

The regression and experiment plot for input energy versus average values of the impact strength (toughness) is shown in figure 8, and the regression model is given in equation 2.

$$Y = 87.322x - 12.075 \quad (2)$$

where, Y is the impact strength (toughness) in J

x is the heat input (kJ/mm)

With an $R^2$ of 0.99, the heat input accurately predicts toughness value at the heat affected zone. Table 5 is the ANOVA table for the different samples investigated. It was observed that the values of toughness are affected by the input energy having P-value less than 0.05.

Table 5: ANOVA Table for the Notch Toughness Values for the Different test Samples

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---|---|---|---|---|---|---|
| Energy Input | 18289.6 | 2 | 9144.8 | 20.684 | 0.008 | 6.94 |
| Samples | 258.7 | 2 | 129.4 | 0.292 | 0.461 | 6.94 |
| Error | 1768.4 | 4 | 442.1 | | | |
| Total | 20316.7 | 8 | | | | |

Also, figure 9, is the regression and plot of input energy against the average values of Brinell hardness. The regression model shown in equation 3 accurately predicts values of Brinell test, having $R^2$ of 0.99.

$$Y = 52.089x + 75.136 \quad (3)$$

where, Y is the Brinell hardness in BHN

x is the heat input (kJ/mm)

Table 6 is the ANOVA table for the Brinell hardness values. It can be deduced that the hardness of the material is affected by the input energy of the welded joint at the heat affected zone, having P-value less than 0.05.

Table 6: ANOVA Table for the Notch Toughness Values for the Different test Samples

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---|---|---|---|---|---|---|
| Energy Input | 0.137 | 2 | 0.069 | 9.012 | 0.033 | 6.94 |
| Samples | 0.02 | 2 | 0.01 | 1.325 | 0.362 | 6.94 |
| Error | 0.03 | 4 | 0.008 | | | |
| Total | 0.188 | 8 | | | | |

The experimental test and analysis of variance (ANOVA) adopted in this study in assessing the impact of heat input on the mechanical properties of ASTM A300 at heat affected zone indicate that heat input could affect the mechanical properties of ASTM A300 steel.

## IV. Conclusion

In this study, the heat input variation on the mechanical properties, namely; tensile strength, percentage elongation, percentage reduction, impact strength and hardness of ASTM A300 at the heat affected zone of welded joint has been examined. It is observed that heat input at the heat affected zone of ASTM A300 during welding could significantly affect the tensile strength, percentage elongation, percentage reduction, impact strength and hardness of ASTM A300.

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