

Comparative Analysis of Tensile Strength and Percentage Elongation in Submerged Arc Welding Using Different Slag-Flux Ratios

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ABSTRACT: The research includes the experimental results of Submerged Arc Welding in terms of tensile strength and percentage elongation conducted on mild Steel work piece. The six experiments were conducted with different slag-flux percentage to study its effect on output parameters of interest. The design of Experts software was used to analyze the data. The selected process variable i.e. slag percentage in slag-flux mixture was varied up to six levels and one factor design of experiments was selected to design the experiments. Response surface methodology (RSM) was used to develop the regression equation relating response characteristics and process variable. The results were tabulated and regression equations were developed from the experimental data and it shows that as the slag percentage increases tensile strength decreases and tensile strength obtained within 80% slag mixture were found to be above AWS requirement line. The statistical analyses were done with the help of Analysis of Variance (ANOVA).

KEYWORDS: Flux; Mild Steel; Percentage Elongation; Slag; Submerged Arc Welding (SAW); Tensile Strength

I. INTRODUCTION

Submerged arc welding (SAW) is a commonly used arc welding process firstly developed by the Linde-Union Carbide Company. In this process continuously fed consumable solid or tubular (flux cored) electrode is used. The molten weld and the arc zone are protected from atmospheric contamination by being "submerged" under a blanket of granular fusible flux consisting of lime, silica, manganese oxide, calcium fluoride, and other compounds. When the flux is in molten state it becomes conductive, and provides a current path between the electrode and the work. This thick layer of flux completely covers the molten metal thus preventing spatter and sparks as well as suppressing the intense ultraviolet radiation and fumes that are a part of the shielded metal arc welding process (SMAW).

Buochareon et al. [1] had studied the effect of mixture of reused and new flux on chemical composition in weld metal of Submerged Arc Welding process. The ANOVA analysis results showed that averaged hardness was statistically significant different with the probability of rejecting the hypothesis tested of 0.05. It can be concluded that crushed slag can be used to mix with new flux and applied to engineer application with required hardness. New flux can be saved up to 66.66% resulting cost reduction and reducing environmental effect.

Jindal et al. [2] had designed and developed a flux for Submerged Arc Welding of HSLA steel. In this research L8 array of Taguchi Design was used to formulate 8 types of fluxes to vary basicity index (BI) from 1.26 - 2.81. The impact of flux constituents and basicity index on tensile strength, micro hardness and microstructure of the weld metal was also studied in this research. Experiments confirm that ultimate tensile strength increase with increase of basicity index with minimum at 1.26 increases upto 2.33 and then further decreases. On the other hand opposite in case of micro hardness which is highest at 1.26 and minimum at 1.9. Increment of CaO in the flux increases the ultimate tensile strength (UTS) but micro hardness remains unaffected, whereas increment of SiO₂ decreases ultimate tensile strength but micro hardness remains constant. Micro hardness decreases critically with increase of CaF₂.

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Kumar et al. [3] had done a structural and chemical analysis of crystalline phases in developed agglomerated fluxes. Thirty two fluxes were developed by using a mixture of oxides, halides, carbonates, silicates and ferroalloys for SAW. The research was focused on ten (out of thirty-two) fluxes which were examined by X-ray diffraction for different types of oxides formed and changed in oxidation number of metallic centers after doing sintering process at around 850°C. This work also had shown effect of temperature over phase transformation, melting of different compounds and differential thermal analysis (DTA) in range of 1000° to 1400°C. The objective of this study was to know the quantity of ions present (percentage) and melting behavior of developed agglomerated fluxes for submerged arc welding process.

Mercado et al. [4] had examined the effect of flux composition on the microstructure and tensile properties of a submerged-arc welded AISI 1025 steel. Three flux compositions were used with a low-carbon electrode and commercial flux composition was used for comparison. The welding conditions were kept identical. Tension tests were conducted at room temperature. Microstructure and macrostructure of welds were observed with light and SEM. The presence of acicular ferrite was detected for welds of fluxes containing highest content of titanium oxide. It had been observed that the ultimate tensile strengths seem to be influenced by presence of acicular ferrite. The elongation and reduction in area percentages were affected by the inclusion Volume percentage.

Mercado et al. [5] presents a study of the effect of adding TiO₂ in fluxes on the mechanical properties and microstructure of the weld metal formed during Submerged-Arc Welding (SAW) of ASTM A-36 steel plates. Four different fluxes having about 9, 12, 15 and 18% Ti were used with a low-carbon electrode. The observation confirms that the increase in the percentage of acicular ferrite and a decrease in its length were observed with an increase in titanium content. The increment of Ti content in fluxes has also improved the toughness and ductility of the welds.

II. EXPERIMENTAL PROCEDURE

In this research the tensile strength and percentage elongation of specimen during different ratio of flux were taken into consideration. First of all Slag was collected and reprocessed and then it was mixed with fresh flux in different proportion for experimentation. The step by step procedure of work has given below.

2.1: Collection of Slag: The slag was collected from the dump yard of industry which is engaged in production of large diameter cross country pipes using SAW process. This slag generated during the SAW welding process using F7AZ flux & EL8 filler wire. This slag was collected free of cost.

2.2: Processing of Slag: To carry out the experimentation, first of all slag was collected and reprocessed. After that this reprocessed slag has been mixed with fresh flux in different proportions in order to obtain different mixtures of flux. Weld beads were made on M.S plates on random basis to eliminate any schematic error. The experiments were performed at a piping industry in Punjab, India The above slag was crushed and potassium silicate binder (90 ml in 550 grams of crushed slag), aluminum powder as deoxidizer (4% by weight of the crushed slag) and rutile i.e. titanium dioxide powder (5.5% by weight of crushed slag) were added and mixed for time of 10 minutes and then passed through a standard 10 mesh screen to form small pallets. The pellets of the flux were dried in air for 24 hours and then baked in the muffle furnace between 700-750°C for nearly three hours. After cooling, these pallets were crushed and subsequently sieved. After sieving, fluxes were kept in air tight bags and baked again at 300°C before welding.

2.3: Preparation of Base plate: Mild steel plates having size 12×100×200 mm and grade A106-99 were used in this investigation. The plates were cut into defined length with the help of a power hacksaw. The test plates were cleaned using wire brush and emery paper. The chemical composition of the base plate used has been shown in [Table-1](#).

Table- 1: Chemical Composition of Base Plate

| C% | Mn% | Si% | S% | P% |
|-------|------|-------|-------|-------|
| 0.355 | 0.34 | 0.180 | 0.035 | 0.040 |

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2.4: Electrode Wire used : The electrode wire used for the welding was Supermelt Grade-A of 3.15 mm diameter conforming to AWS/SFA A5.17, EL-08; the chemical composition of filler wire has been presented in Table-2

Table- 2: Chemical Composition of electrode wire

| | | | | | |
|-------|-------|-------|-------|-------|-------|
| C | Mn | Si | S | P | Cu |
| 0.078 | 0.479 | 0.016 | 0.015 | 0.021 | 0.267 |

2.5: Flux used : An agglomerated flux and the above prepared flux were used in this investigation. The specification of flux used was AWS/SFA: 5.17 FLUX, F7AZ - EL 8. In this investigation fresh flux was used for only comparison purpose.

2.6: Specifications of Welding Machine: LINCONWELD Submerged Arc Welding equipment has been used in experimental work, whose specifications are given below in [Table-3](#)

Table 3: Specification of SAW Machine

| | |
|--|-----------------|
| Manufacturer | Lincon Electric |
| Current range | 0-1500 Amp |
| Max. Welding Current at 60% Duty Cycle | 1500 A |
| Operating voltage | 0-100V |
| Electrical supply | DC |
| Wire feeder | Automatic |

2.7: Welding Parameters: Welding parameters have been set according to the thickness of base plate 12mm. The parameters used for preparing beads on plate are shown in [Table-4](#)

Table- 1: Welding Parameters

| Parameter | Symbol | Value |
|------------------------------|--------|-------|
| Welding Current (A) | I | 400 |
| Open Circuit Voltage (V) | V | 30 |
| Travel Speed (m/min) | S | 425 |
| Nozzle to Plate distance(mm) | N | 25 |

2.8: Welding Procedure

- a) The Mild Steel Flat of 12mm thickness was used for Welding in this research.
- b) 8 plates of size (200×100×12) mm were cut from the base metal with power hack saw.
- c) In order to have butt joint, required V-groove was made with the help of grinder. The angle of V-groove was kept nearly 60°.
- d) The root gap was kept 3 mm.
- e) Samples were tacked with the help of MIG welding machine. The backing plates of 12 mm thick were also tack welded to these 12 mm thick base plates.
- f) Applying the weld bead by using submerged arc welding machine with different flux-slag mixtures prepared before.
- g) The process of applying the weld bead has been repeated for all six mixtures.
- h) Those tacked plates were removed.
- i) After that specimen were prepared for mechanical Properties testing.

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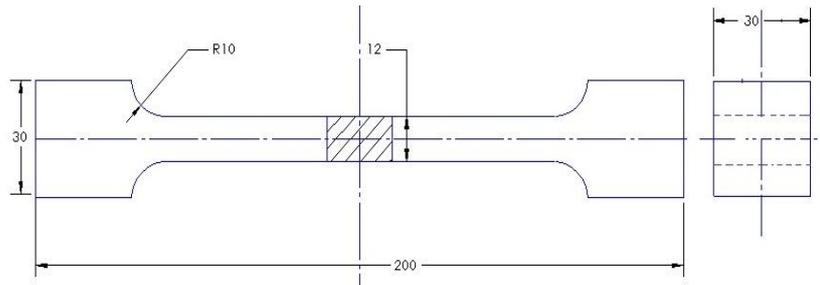


FIGURE-1: ORTHOGRAPHIC VIEW OF SPECIMEN

III. RESULTS AND DISCUSSIONS

The design of Experts Software was used to analyze the data. The selected process variable i.e. slag percentage in slag-flux mixture was varied up to six levels and one factor design of experiments was selected for the design the experiments. The Response surface methodology (RSM) was used to develop the regression equation relating response characteristics and process variable. The six experiments were conducted with different slag-flux percentage to study its effect on output parameters of interest. The results were tabulated and regression equations were developed from the experimental data. The statistical analyses were done with the help of Analysis of Variance (ANOVA).



Fig-2: Photographic View of Testing Specimens

The six experiments were conducted with different slag-flux percentage to study its effect on output parameters of interest. The results were tabulated and regression equations were developed from the experimental data. The statistical analyses were done with the help of Analysis of Variance (ANOVA).

Table- 5 shows values of different response parameters (tensile strength and percentage elongation) for different levels of input variable i.e. different percentage of slag in slag-flux mixture and Table-6 shows corresponding AWS requirement for response parameters.

3.1: Analysis for Tensile strength

Tensile strength is an important parameter of engineering materials that is used in structures and mechanical devices. It is a characteristic that influence the performance of mechanical parts. The Photographic view of Tensile strength Specimen has

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shown in the figure-3 and dimensions of specimen has given in the figure-2. The linear model as shown in table-7 was suggested by response surface methodology using design of experts software.

Table -5: Detail of Response Parameters for different input

| Run | Slag %age in slag-flux mixture (%) | Tensile strength (Mpa) | Elongation (%) |
|-----|------------------------------------|------------------------|----------------|
| 1. | 0 | 548 | 30 |
| 2. | 20 | 495 | 27.5 |
| 3. | 40 | 446 | 26 |
| 4. | 60 | 460 | 27 |
| 5. | 80 | 428 | 25 |
| 6. | 100 | 398 | 19 |

Table- 6: AWS requirement for Response parameters

| Response factor | AWS requirement | Units |
|------------------|-----------------|-------|
| Tensile strength | 420 | MPa |
| %age elongation | 24 | % |

Table -7 Model Summary Statistics for tensile Strength

| Source | Std. Dev. | R-Square | Adjusted R-Square | Predicted R-Squared | PRESS | |
|-----------|-----------|----------|-------------------|---------------------|---------|-----------|
| Linear | 19.06 | 0.8962 | 0.8702 | 0.7687 | 3237.53 | Suggested |
| Quadratic | 18.75 | 0.9247 | 0.8744 | 0.5432 | 6392.95 | |
| Cubic | 14.55 | 0.9697 | 0.9244 | 0.7184 | 3940.63 | |

Table- 8: Analysis of variance (Partial sum of squares)

| Source | S.S | Df | M.S | F -Value | Prob > F | |
|-----------|----------|----|----------------|----------|----------|-------------|
| Model | 12542.41 | 1 | 12542.41 | 34.53 | 0.0042 | Significant |
| A | 12542.41 | 1 | 12542.41 | 34.53 | 0.0042 | |
| Residual | 1453.09 | 4 | 363.27 | | | |
| Cor Total | 13995.50 | 5 | | | | |
| Std. Dev. | 19.06 | | R-squared | | 0.8962 | |
| Mean | 462.50 | | Adj R-Squared | | 0.8702 | |
| C.V. | 4.12 | | Pred R-Squared | | 0.7687 | |
| PRESS | 3237.53 | | Adeq Precision | | 12.164 | |

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Table -7 shows the Model Summary Statistics for tensile Strength suggesting the Linear model due to the less difference of adjusted and predicted values in other sources the difference of adjusted and predicted value are more. As depicted in the Table -8, Model F-value of 34.53 implies that the model is significant. The value of 'Prob > F' less than 0.0500 indicate model terms are significant. The 'Pred R-Squared' of 0.7687 is in reasonable agreement with the 'Adj R-Squared' of 0.8702. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Our ratio of 12.164 indicates an adequate signal.

3.1.1 : Response Surface model for Tensile Strength: Final equation in terms actual factor: Tensile Strength = +529.42857- 1.33857 * slag

The diagnostic checking of the model has been carried out using data from table 9 and the results are presented in figure 3

Table- 9: Diagnostics case statistics for tensile strength

| Standard order | Actual value | Predicted value | Residual |
|----------------|--------------|-----------------|----------|
| 1 | 428.00 | 422.34 | 5.66 |
| 2 | 495.00 | 502.66 | -7.66 |
| 3 | 460.00 | 449.11 | 10.89 |
| 4 | 398.00 | 395.57 | 2.43 |
| 5 | 548.00 | 529.43 | 18.57 |
| 6 | 446.00 | 475.89 | -29.89 |

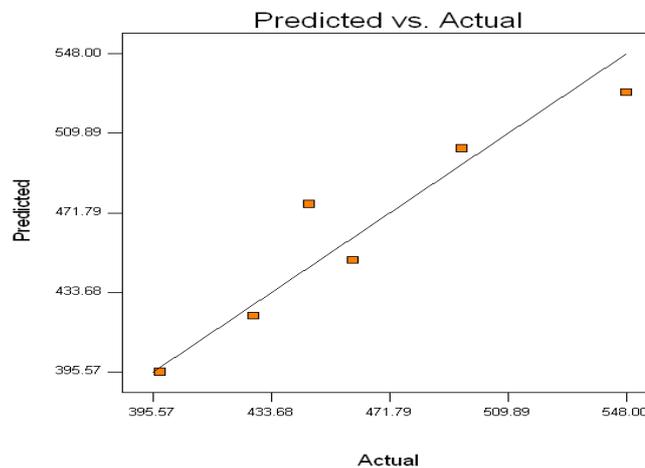


Fig-3: Plot of actual vs. predicted response (tensile strength)

The fig-3 shows the plot of actual versus predicted response of tensile strength and it is clear from the figure that the values are within in the range having small variation from actual values. Two values are above the line and four values are below the line.

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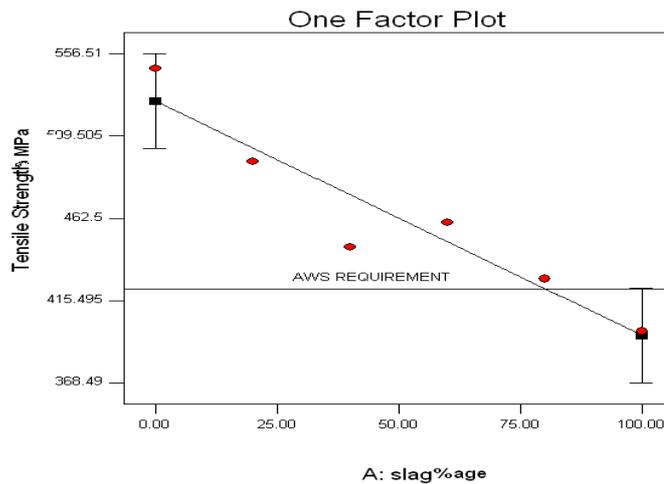


Fig-4: Plot of tensile strength with slag % in flux-slag mixture.

Figure- 4 shows the variation of tensile strength as percentage of slag is varied in slag-flux mixture. It is clear from the figure- 4 that as slag percentage increases tensile strength decrease accordingly. But the values of tensile strength obtained upto 80% slag mix. were found to be above AWS requirement line.

3.2: Analysis of Percentage Elongation

3.2.1: Selection of adequate model for percentage elongation: The cubic model is suggested by response surface methodology in following Tables 10 and Table 11 as per design of experts software.

Table- 10: Sequential Model Sum of Squares for Percentage Elongation

| Source | Sum of squares | df | Mean Square | F Value | Prob > F | |
|--------------|----------------|----------|-------------|--------------|---------------|------------------|
| Mean | 3978.38 | 1 | 3978.38 | | | |
| Linear | 54.03 | 1 | 54.03 | 14.56 | 0.0188 | |
| Quadratic | 4.53 | 1 | 4.53 | 1.32 | 0.3344 | |
| Cubic | 9.57 | 1 | 9.57 | 25.58 | 0.0369 | Suggested |
| Residual | 0.75 | 2 | 0.37 | | | |
| Total | 4047.25 | 6 | 674.54 | | | |

Table- 11: Model Summary Statistics for Percentage Elongation

| Source | Std. Dev. | R-Square | Adjusted R-Square | Predicted R-Squared | PRESS | |
|--------------|-------------|---------------|-------------------|---------------------|--------------|------------------|
| Linear | 1.93 | 0.7845 | 0.7306 | 0.4095 | 40.67 | |
| Quadratic | 1.85 | 0.8502 | 0.7504 | -0.3860 | 95.46 | |
| Cubic | 0.61 | 0.9891 | 0.9728 | 0.7703 | 15.82 | Suggested |

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Table -12: Analysis of Variance for Percentage Elongation (Partial sum of squares)

| Source | Sum of Squares | DF | Mean Squares | F Value | Prob > F | |
|----------------|----------------|----------|--------------|---------------|----------------|--------------------|
| Model | 68.05 | 2 | 34.03 | 124.09 | 0.0013 | Significant |
| A ² | 4.53 | 1 | 4.53 | 16.51 | 0.0269 | |
| A ³ | 63.53 | 1 | 63.53 | 231.67 | 0.0006 | |
| Residual | 0.82 | 3 | 0.27 | | | |
| Cor Total | 68.88 | 5 | | | | |
| Std. Dev. | | | 0.52 | | R-squared | 0.9881 |
| Mean | | | 25.75 | | Adj R-Squared | 0.9801 |
| C.V. | | | 2.03 | | Pred R-Squared | 0.9041 |
| PRESS | | | 6.60 | | Adeq Precision | 29.754 |

Table- 10 shows the Sequential Model Sum of Squares for Percentage Elongation suggesting the cubic model because f-value of cubic model is high as compared to other. Similarly the Table- 11 shows the Model Summary Statistics for Percentage Elongation in which again cubic model has been suggested due to very less standard deviation. As shown in Table- 12, The Model F-value of 124.09 implies the model is significant. There is only a 0.13% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. The "Pred R-Squared" of 0.9041 is in reasonable agreement with the "AdjR-Squared" of 0.9801."Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Our ratio of 29.754 indicates an adequate signal.

3.2.2: Response Surface model for Percentage Elongation

Final equation in terms actual factor: %age elongation = +30.13492 - 0.26402 * slag + 6.33433E-003 * slag² - 4.80324E-005 * slag³

Table-13: Diagnostics case statistics for percentage elongation

| Standard order | Actual value | Predicted value | Residual |
|----------------|--------------|-----------------|----------|
| 1 | 25.00 | 24.96 | 0.040 |
| 2 | 27.50 | 27.00 | 0.50 |
| 3 | 27.00 | 26.72 | 0.28 |
| 4 | 19.00 | 19.04 | -0.044 |
| 5 | 30.00 | 30.13 | -0.13 |
| 6 | 26.00 | 26.63 | -0.63 |

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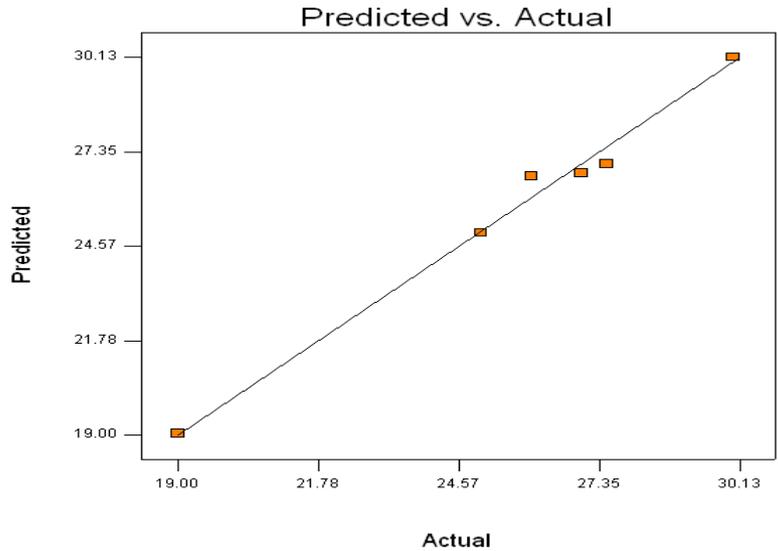


Fig-5: Plot of residual vs. predicted response (% elongation)

The fig-5 shows the Plot of residual vs. predicted response in percentage elongation and it is clear from the figure that the actual and predicted values are closer to each other having small residue.

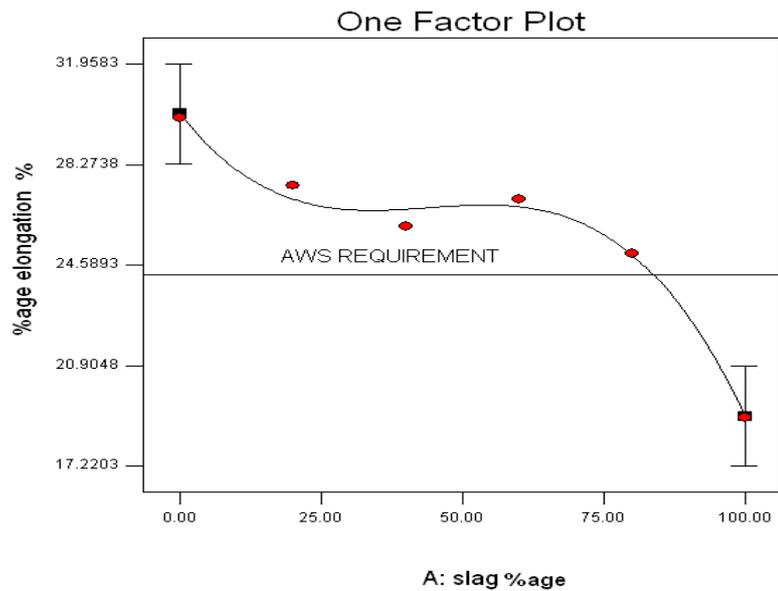


Fig- 6: Plot of impact strength with slag percentage in flux-slag mixture.

Figure -6 shows the variation of %age elongation as percentage of slag is varied in slag-flux mixture. It is clear from the figure 6 that as slag percentage increases %age elongation decreases accordingly. But the values of tensile strength obtained upto 80% slag mix. were found to be above AWS requirement line.

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IV. CONCLUSIONS

From the results the following conclusion can be made.

- 1) It had been confirmed that as slag percentage increases tensile strength decreases accordingly. But the values of tensile strength obtained upto 80% slag mix. were found to be above AWS requirement line.
- 2) Also in the another case it was confirmed that as slag percentage increases %age elongation decreases accordingly. But the values of tensile strength obtained upto 80% slag mix. were found to be above AWS requirement line.
- 3) The results were also confirmed by ANOVA analysis in both cases, which confirms that the amount of 80% slag mixture was useful for mechanical testing.

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