International Journal of Engineering Sciences Paradigms and Researches Vol. 08, Issue 01, October 2013
(An Indexed, Referred and Impact Factor Journal)
ISSN (Online): 2319-6564
www.ijesonline.com

Maximizing Tensile Strength in AISI 50110 (EN 31) Welded Joints using GAS Metal ARC (GMAW) Welding

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Abstract

This research paper is aimed at making an attempt to develop a response surface model to predict tensile strength of inert gas metal arc welded AISI 50110 (EN31) high carbon steel joints. The process parameters such as arc voltage and welding current are studied. The experiments have been conducted based on a two-factor, three-level, and face centred composite design matrix. The empirical relationship can be used to predict and study the effects and behavior of processing parameters on tensile strength of inert gas metal arc welded EN31 high carbon steel joints. Response surface methodology (RSM) has been applied to study the MIG welding process parameters to attain the maximum tensile strength of the joint.

Keywords: *Tensile Strength, AISI 50110 (EN 31), GMAW.*

1. Introduction

The history of joining metals goes back several millennia, called forge welding, with the earliest examples of welding from the Bronze Age and the Iron Age in Europe and Middle East. The ancient Greek historian Herodotus states in The Histories of the 5th century BC that “Glaucus of Chios was the man who single-handedly invented iron-welding." Welding was used in the construction of the iron pillar in Delhi, India, erected about 310 AD and weighing 5.4 metric tons [1].

The Middle age brought advances in forge welding, in which blacksmiths pounded heated metal repeatedly until bonding occurred. In 1540, Vannoccio Biringuccio published De La Pirotechina, which includes descriptions of the forging operation. Renaissance craftsmen were skilled in the process, and the industry continued to grow during the following centuries:

In the 19th century, major breakthroughs in welding were made. The use of open flames (acetylene) was an important milestone in the history of welding since open flames allowed the manufacture of intricate metal tools and equipments. In 1881 a Russian inventor, Benardos demonstrated the carbon electrode welding process. An arc was formed between essentially a moderately consumable carbon electrode and the work. A rod was added to provide needed extra metal. An image of Nikolay Benardos is on a Russian stamp honoring him as the "father of welding." A sketch of a carbon arc torch is shown to his right [2].

Around 1900, A. P. Strohmenger released a coated metal electrode in Britain, which gave a more stable arc. Coated metal electrode was first introduced in 1900 by Strohmenger. A coating of lime helped the arc to be much more stable. A number of other welding processes were developed during this period. Some of them included seam welding, spot welding, flash butt welding, and projection welding. Stick electrodes became a popular welding tool around this time as well. However, alternating current was first commercially utilized by the welding industry only in the 1930's. In 1919, alternating current welding was invented by C. J. Holslag but did not become popular for another decade.

World War caused a major surge in the use of welding processes, with the various military powers attempting to determine which of the several new welding processes would be best. The British primarily used arc welding, even constructing a ship, the Fulagar, with an entirely welded hull. Arc welding was first applied to aircraft during the war as well, as some German airplane fuselages were constructed using the process. Also noteworthy is the first welded road bridge in the world, designed by Stefan Bryla of the Warsaw University of Technology in 1927, and built across the river SludwiaMaurzyce near Lowicz, Poland in 1929 [3].

During the middle of the century, many new welding methods were invented. 1930 saw the release of stud welding, which soon became popular in shipbuilding and construction. Submerged arc welding was invented the same year and continues to be popular today. In 1932 a Russian, Konstantin Khrenov successfully implemented the first underwater electric arc welding. Gas tungsten arc welding, after decades of development, was finally perfected in 1941, and gas metal arc welding followed in 1948, allowing for fast welding of non-ferrous materials but requiring expensive shielding gases. Shielded metal arc welding was developed during the 1950s, using a flux-coated consumable electrode, and it quickly became the most popular metal arc welding process. In 1957, the flux-cored arc welding process debuted, in which the self-shielded wire electrode could be used with automatic equipment, resulting in greatly increased welding speeds, and that same year, plasma arc welding was invented. Electro slag welding was introduced in 1958, and it was followed by its cousin, electro gas welding, in 1961. In 1953 the Soviet scientist N. F. Kazakov proposed the diffusion bonding method.

There were several advancements in the welding industry during the 1960's. Dualshield welding, Innershield, and Electro slag welding were some of the important welding developments of the decade. Plasma arc welding was also invented by Gage during this time. It was used for metal spraying. The French also developed electron beam welding, which is still used by the aircraft manufacturing industries of the United States. Electromagnetic pulse welding is industrially used since 1967. Friction stir welding was invented in 1991 by Wayne Thomas at The Welding Institute (TWI, UK) and found high-quality applications all over the world. All of these four new processes continue to be quite expensive due the high cost of the necessary equipment, and this has limited their applications.

The popularity of MIG welding over other forms of welding is founded on the strides made over close to a century of continuous improvement in the MIG processes and which constitute a central part of the LONGEVITY MIG welder history. As early as the beginning of the twentieth century, innovators in the welding industry were trying various ways of improving the quality of their welds and one process that promised to eliver great sults was MIG welding. MIG is acronym for Metal Inert Gas and it is also referred to as Gas Metal Arc Welding (GMAW). What sets MIG welding apart from the other forms of welding particularly stick and Oxy-Acetylene welding is the fact that the process makes use of inert gas to shield the area being welded from the contamination caused by air and which slows down the welding process and leads to poor quality welds.

Early attempts at using inert gas in MIG welding started bearing fruits in the 1940s and this is an important period in MIG welder history. The actual test for developing a useful MIG welder in the early days consisted in deciding on the gas to use for the creation of the protective shield. Attempts were made with various gases including carbon dioxide, hydrogen, carbon monoxide and argon. Each of these gases had their advantages and disadvantages. Carbon monoxide, for example, was found to be effective but presented serious risks to the welder. Argon used in the early years of the MIG welder history had the disadvantage of being too expensive thereby making MIG welding less cost effective when compared to other forms of welding. With time however, technological advances have enabled the use of semi-inert gases which are less expensive than their inert counterparts and this has made MIG welding more cost effective.

The real breakthrough in the development of a practical MIG welder occurred in 1949 which is an important year in MIG welder history. In that year, three inventors from Airco patented a process for the use of a shielding gas by use of either argon or helium mixed with carbon dioxide. For quite a while, this remained the foremost way of creating protective shields for MIG welders. The next major achievement in MIG welder history took place when the short circuiting MIG welder was developed. This happened in the 1960s and continuous improvement in the MIG welding processes enabled the reduction of spatter produced from MIG welding as well as the use of thinner sized wires. During this important period in MIG welder history, the ideal mixture of gases was established [2].

In the present scenario demand of the joining of similar materials continuously increases due to their advantages, which can produce high tensile strength, deeper penetration, continuous welding at higher speed and small welding defects. In this study Thyristorised power source of TECHNO CRATS ICP 400 is used to join 7mm flat plates of EN31 due to their ability to quick arc start, stick out & crater control, Fresh tip treatment technology (FTT) to eliminates globule formation at the wire tip during weld stop & others advantage. The effect of the process parameters viz. voltage and welding current and focusing position on the weld joint tensile strength has been investigated. Joining of EN31 was considered to be a problem due to the hardness & result in a poor weld. In automotive part industries the EN31 joints have been widely used due to their high vulnerability to rust, machinability and stiffness. GMAW welding is used because of its advantages over other welding techniques like high welding speeds, less distortion, no slag removal required, high weld metal deposition rate, high weld quality, precise operation etc. The demand for producing joints of similar materials has been continuously increasing due to their advantages, which can provide appropriate mechanical properties and cost reduction.

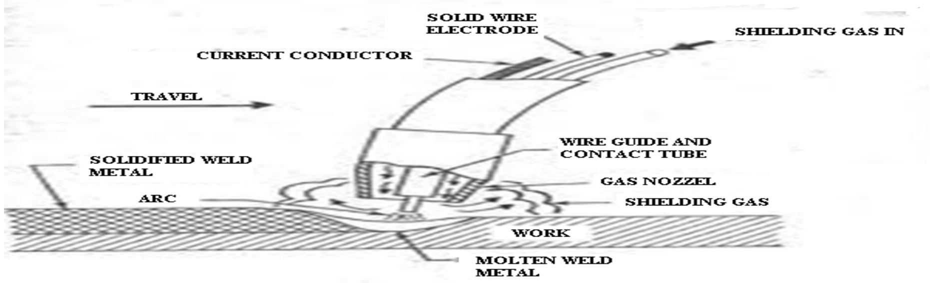
2. Definition of Welding

Welding is a fabrication or joining process that joins materials, usually metals or thermoplastics, by causing coalescence. This is often done by melting the work-pieces and adding a filler material to form a pool of molten material that cools to become a strong joint, with pressure sometimes used in conjunction with heat, or by itself, to produce the weld. Most of the welding techniques utilize heat & pressure for welding joints. Heat may be obtained from electric arc, electric resistance, chemical reaction, friction etc. In other word Welding is a material joining process in which two or more parts are joined together at their contacting surfaces by a suitable application of heat and/or pressure. In some welding process a filler material is added to facilitate coalescence [4].

2.1 MIG Welding Process

Gas metal arc welding (GMAW), sometimes referred to by its subtypes metal inert gas (MIG) welding or metal active gas (MAG) welding, is a semi-automatic or automatic arc welding process in which a continuous and consumable wire electrode and a shielding gas are fed through a welding gun. A constant voltage, direct current power source is most commonly used with GMAW, but constant current systems, as well as alternating current, can be used. Basically the metal transfer in GMAW can be done by three methods, called globular, short-circuiting, and axial spray. Every transfer methods have different properties, advantages and disadvantage.

Before igniting the arc, gas and water flow (if water cooled) is checked. Proper current and wire feed speed is set and the electrical connections are ensured. The arc is struck by any one of the two methods. In the first method current and shielding gas flow is switched on and the electrode is scratched against the job as usual practice for striking the arc. In the second method, electrode is made to touch the job, is retracted and then moved forward to carry out welding. About 15 mm length of the electrode is projected from the torch before striking the arc. During welding, torch remains about 10-12 mm away from the job and arc length is kept between 1.5 to 4 mm. Arc length is maintained constant by using the principles of self-adjusted arc, and self-controlled arc in semi-automatic and automatic welding sets respectively.



(MIG Welding Process)

GMAW was developed and used for welding of aluminum and other non-ferrous materials in the 1940s; GMAW was soon applied to steels because it allowed for lower welding time compared to other welding processes. The cost of inert gas limited its use in steels until several years later, when the use of semi-inert gases such as carbon dioxide became common. Further developments during the 1950s and 1960s gave the process more versatility and as a result, it became a highly used industrial process. Today, GMAW is the most common industrial welding process, preferred for its versatility, speed and the relative ease of adapting the process to robotic automation. The automobile industry in particular uses GMAW welding almost exclusively. Unlike welding processes that do not employ a shielding gas, such as shielded metal arc welding, it is rarely used outdoors or in other areas of air volatility. A related process, flux cored arc welding, often does not utilize a shielding gas, instead employing a hollow electrode wire that is filled with flux on the inside.

As noted, GMAW is currently one of the most popular welding methods, especially in industrial environments. It is used extensively by the sheet metal industry and, by extension, the automobile industry. There, the method is often used for arc spot welding, thereby replacing riveting or resistance spot welding. It is also popular for automated welding, in which robots handle the work pieces and the welding gun to quicken the manufacturing process. Generally, it is unsuitable for welding outdoors, because the movement of the surrounding air can dissipate the shielding gas and thus make welding more difficult, while also decreasing the quality of the weld. The problem can be alleviated to some extent by increasing the shielding gas output, but this can be expensive and may also affect the quality of the weld. In general, processes such as shielded metal arc welding and flux cored arc welding are preferred for welding outdoors, making the use of GMAW in the construction industry rather limited. Furthermore, the use of a shielding gas makes GMAW an unpopular underwater welding process, but can be used in space since there is no oxygen to oxidize the weld.

2.2 MIG Welding Advantages

Because of continuously fed electrode, MIG welding process is much faster as compared to other welding process.

a) It can produce joints with deep penetration.
b) Thick and thin, both typed of work pieces can be welded.
c) Larger metal deposition rates are achieved.
d) The process can be easily mechanized.
e) Higher arc travel speeds associated with MIG welding reduce distortion considerably.
f) Because of continuously fed electrode, MIG welding process is much faster as compared to TIG or stick electrode welding.

2.3 MIG Welding Disadvantages

a) Welding equipments are more complex, more costly and less portable.
b) Since air drafts may disperse the shielding gas, MIG welding may not work well in outdoor welding applications.
c) Weld metal cooling rates are higher than with the processes that deposit slag over the weld metal.

2.4 MIG Welding Applications

a) The process can be used for the welding of carbon, silicon and low alloy steels, stainless steels, aluminum, magnesium, copper, nickel, and their alloys, titanium, etc.
b) For welding tool steels and dies.
c) For the manufacture of refrigerator parts.
d) MIG welding has been used successfully in industries like aircraft, automobile, pressure vessel, and ship building.

3. Literature Survey

The research on parameter optimization of different types of welding processes for obtaining various responses in input and output have been done by a number of researchers using a wide range of methods and materials. They make use of various types of methods, techniques and mathematical models for evaluating and obtaining results. A response surface model was developed by Ajit Hooda, et al. [6] to predict tensile strength of inert gas metal arc welded AISI 1040 medium carbon steel joints. The process parameters such as welding voltage, current, wire speed and gas flow rate was studied. The experiments were conducted based on a four-factor, three-level, and face centered composite design matrix.

G. Padmanaban, V. Balasubramanian [7] developed an empirical relationship to effectively predict the tensile strength of pulsed current gas tungsten arc welded AZ31B magnesium alloy joints at 95% confidence level. The significant process parameters such as peak current, base current, pulse frequency and pulse on time were studied. The experiments were conducted based on a four-factor, five-level, central composite design matrix.

H.-J. Lee et al. [8] had done a study on parameter optimization in the circumferential GTA welding of aluminium pipes using a semi-analytical finite-element method. When an aluminium pipe is welded circumferentially under constant welding conditions, the width and depth of the weld bead increase gradually along the welding direction. Therefore, the welding parameters should be optimized continuously to obtain a uniform weld bead along the entire circumference of the pipe. As the welding parameters to be optimized, the welding velocity, the effective radius of heat source and the heat input are considered. The sequences of welding parameters was optimized and compared with experimental results to verify the accuracy of the proposed model.

S.C. Juang and Y.S. Tarng [9] study Process parameter selection for optimizing the weld pool geometry in the tungsten inert gas welding of stainless steel. In their study, the selection of process parameters for obtaining an optimal weld pool geometry in the tungsten inert gas (TIG) welding of stainless steel is presented. Basically, the geometry of the weld pool has several quality characteristics, for example, the front height, front width, back height and back width of the weld pool. To consider these quality characteristics together in the selection of process parameters, the modified Taguchi method is adopted to analyze the effect of each welding process parameter on the weld pool geometry, and then to determine the process parameters with the optimal weld pool geometry.

Syarul Asraf Mohamat et al. [10] study the effect of flux core arc welding (FCAW) processes on different parameters. Flux Core Arc Welding (FCAW) is an arc welding process that using continuous flux-cored filler wire. The flux is used as a welding protection from the atmosphere environment. This project is study about the effect of FCAW process on different parameters by using robotic welding with the variables in welding current, speed and arc voltage. The effects are on welding penetration, micro structural and hardness measurement. Mild steel with 6 mm thickness is used in this study as a base metal.

V. Lazića et al. [11] study the Estimates of weld ability and selection of the optimal procedure and technology for welding of high strength steels. High strength steels belong into a group of high quality steels, with exceptional mechanical properties, especially in regards to tensile strength. At the same time, as their deficiency is emphasized the limited and difficult weld ability. In other words, some of those steels are weldable only with application of special measures related to controlled heat input. In that way, the favorable mechanical properties can be kept within the heat affected zone, with condition that the optimal welding technology is selected.

Edwin Raja Dhas et al. [12] review on optimization of welding process. In order to meet the global competition and the survival of products in the market a new way of thinking is necessary to change and improve the existing technology and to develop products at economical price. The process variable must be measured, controlled and optimized to get the desired and valuable outputs. The typical process parameters for a welding process which affect the desired output for a welding process are welding speed, arc voltage, welding current, welding electrode etc. Optimization of the welding process parameters depends upon the ability to measure and control the process variables involved in the welding process.

4. Objectives

1) To identify the significant process parameters for base material EN 31.
2) To study the hardness and microstructure of the base materials, heat affected zone (HAZ) and weldment.
3) To Study the tensile strength of the welded joint materials.
4) To study the effect of variable welding parameters on response.
5) Optimizing the process parameters for maximum response value.
6) Verification of result.

5. Methodology

A systematic scientific approach is necessary to design and carry out the experimentation properly.

For deriving clear and accurate conclusion/ inferences from the experimental observations, there is a need of properly planned experimentation. Response Surface Methodology (RSM) is considered to be a very useful strategy for accomplishing these tasks. In general, RSM establishes the methods for drawing inferences from observations when these are not exact but subject to variation. The RSM have already been used for study the effect of various factor and their interactions and the development of response surface models in weld surfacing and abrasive flow machining (AFM). Response Surface Methodology (RSM) was introduced by Box and Wilson in 1951 and later popularized by Montgomery.

In order to study the single and multi dimension effect (interaction between applied factors) of welding parameters on the tensile strength, hardness & strength of weld bead, the design of experiments and response surface methodology (RSM) technique were used in this study. The various steps for conducting the efficient experimentation have also been discussed in accordance with the response surface methodology. The various parameters which directly effects the welding are arc voltage, and welding current. The scheme of experimentation has also been discussed on the basis of target in this chapter. The experiments were conducted as per the selected scheme of experiments in order to develop a mathematical model for welding parameters.

5.1 Experimental Design

Design of experiment methodology was first proposed by Sir R. A. Fisher in 1920's to show the expediency of simultaneous variation of all the input parameters in contrast to the widespread 'single factor' experiment. Since then several experimental techniques such as response surface methodology [32-33], full factorial design [33-34], fractional factorial design [35] and Taguchi methods [36-37] have come into prominence. Box and Hunter [38] extended response surface methodology that fits the second order response surface accurately.

The advantages of Design of Experiments are [32-33]: -

1. Identification of important input variables influencing the response i.e. tensile strength, hardness of weld bead, penetration in the present case.
2. Reduced number of experimental trials.
3. Optimal setting of parameters.
4. Determination of experimental error.
5. Obtaining the inference regarding the effects of input parameters on the response/characteristics of the process.

In the present investigation Response Surface Methodology has been used to model tensile strength & hardness and to study the effect of applied factors and interactions between the applied factors.

6. Results and Conclusion

The plates of EN31 high carbon steel were welded by using the procedure as illustrated in above chapter. The test specimens for testing the tensile strength, and hardness were prepared. The samples were of rectangular bar type having 25 mm width, 7 mm thickness and 75 mm gauge length and the area was 175 mm. The quality of the weld depends upon various factors likewise arc voltage, welding current, welding speed and most importantly on the quality of the welder. These factors can affect the penetration of the weld, weld bead width and depth. So the welding of the specimens was carried out by a qualified welder.

Picture 2 Test specimens of base material before various testing

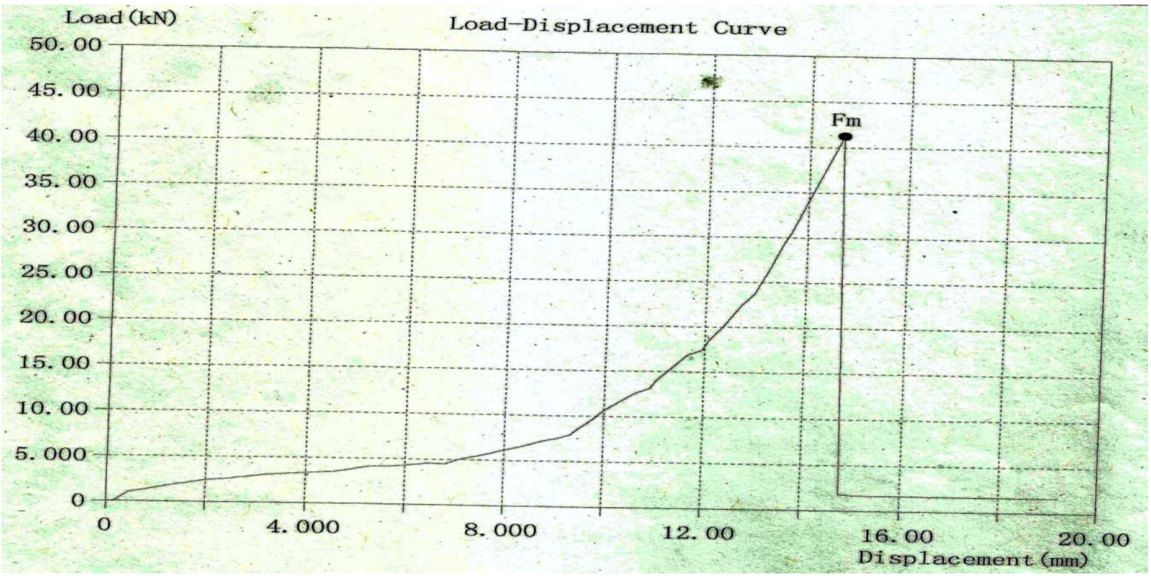
Picture 3 Test specimens of base material after testing

Various tests such as microstructure testing, tensile strength test, and hardness test were carried out on the prepared specimens.

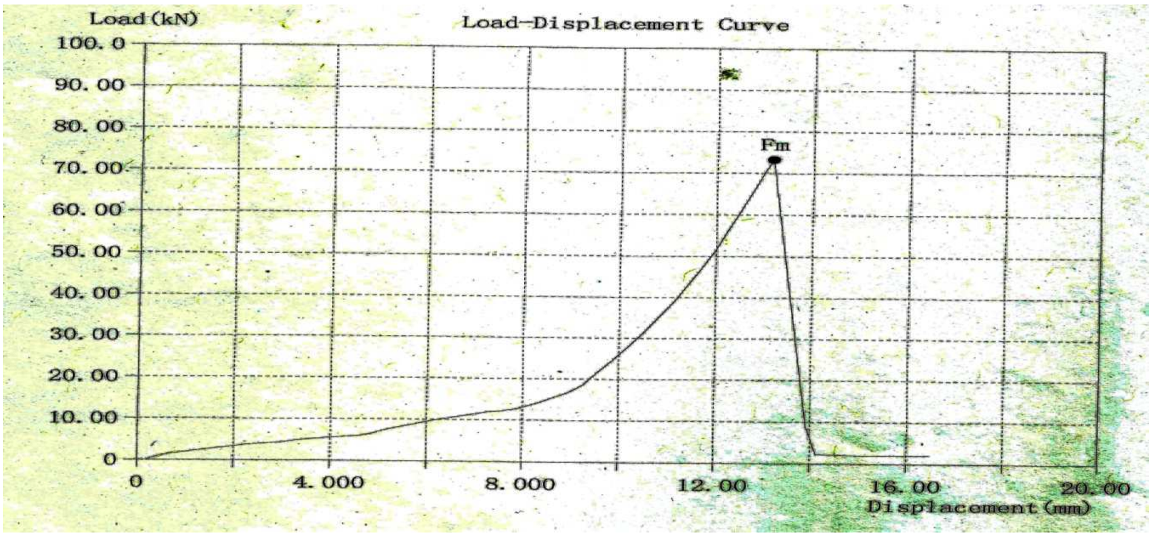
6.1 Tensile Strength

The tensile strength for all the 10 run was tested on UTM machine State-of-art Servo hydraulic machines.

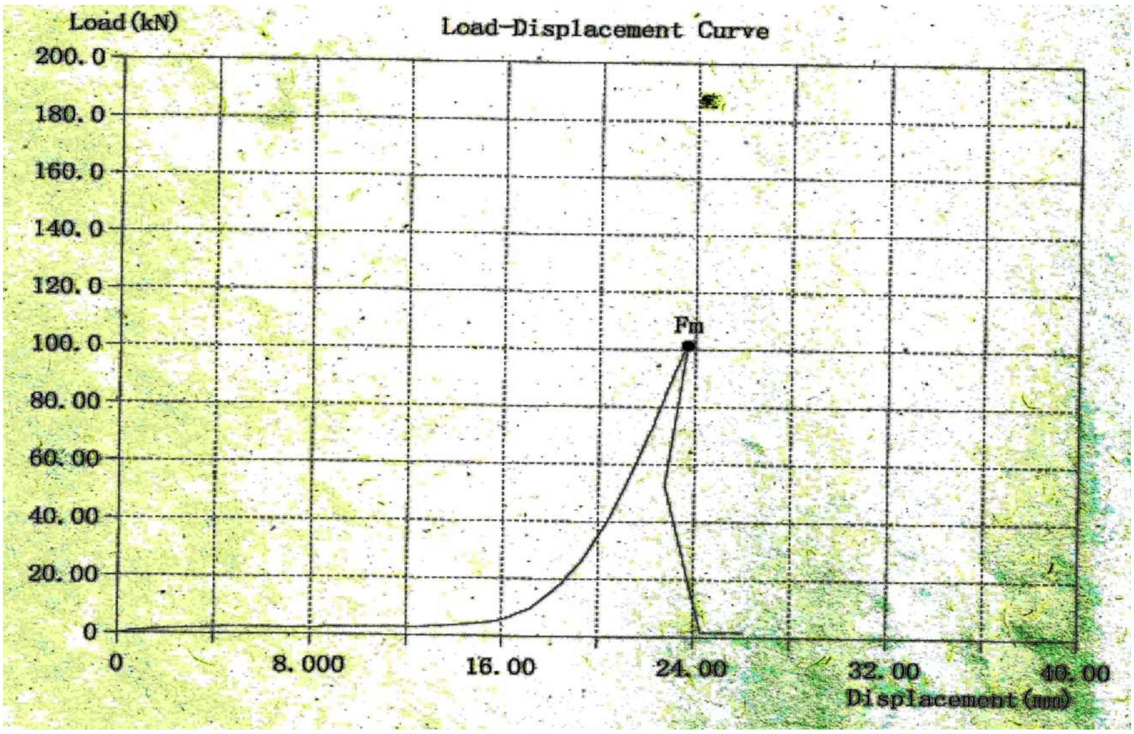
There were two input factors: arc voltage and welding current. And the tests were carried out on samples of specimens welded according to design matrix as shown in picture.



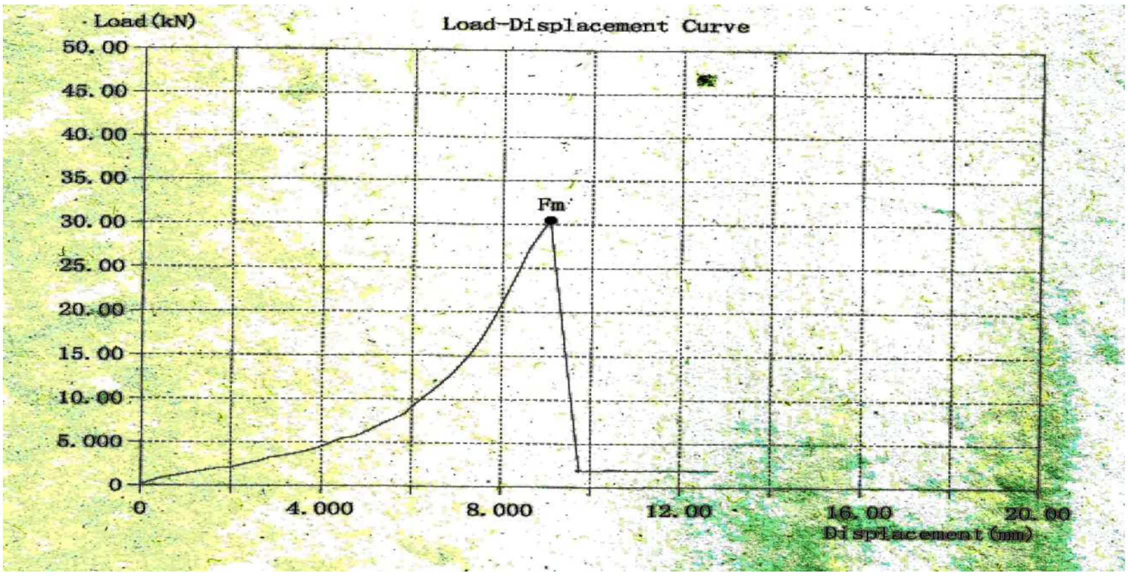
Graph 1 Loads – Displacement Curve for run no. 1



Graph 2 Loads – Displacement Curve for run no. 4



Graph 3 Loads – Displacement Curve for run no. 7



Graph 4 Loads – Displacement Curve for run no. 9

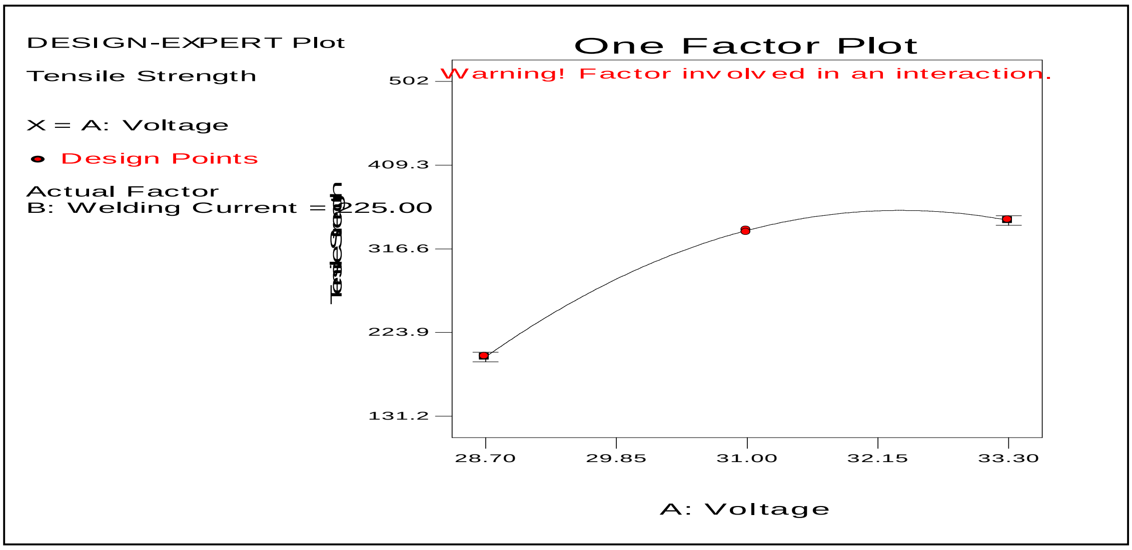
Table 1 Tensile Strength of Test Samples

Run No.	Factor 1	Factor 1	Response 1
	A Arc Voltage (V)	**B Welding Current (A)**	**Tensile Strength (Mpa)**
1	28.7	225	197.5
2	31.0	225	337.7
3	28.7	255	381.8
4	33.3	225	348.8
5	31.0	225	335.2
6	31.0	255	226.8
7	33.3	255	459.4
8	33.3	195	222.5
9	28.7	195	131.2
10	31.0	195	502.0

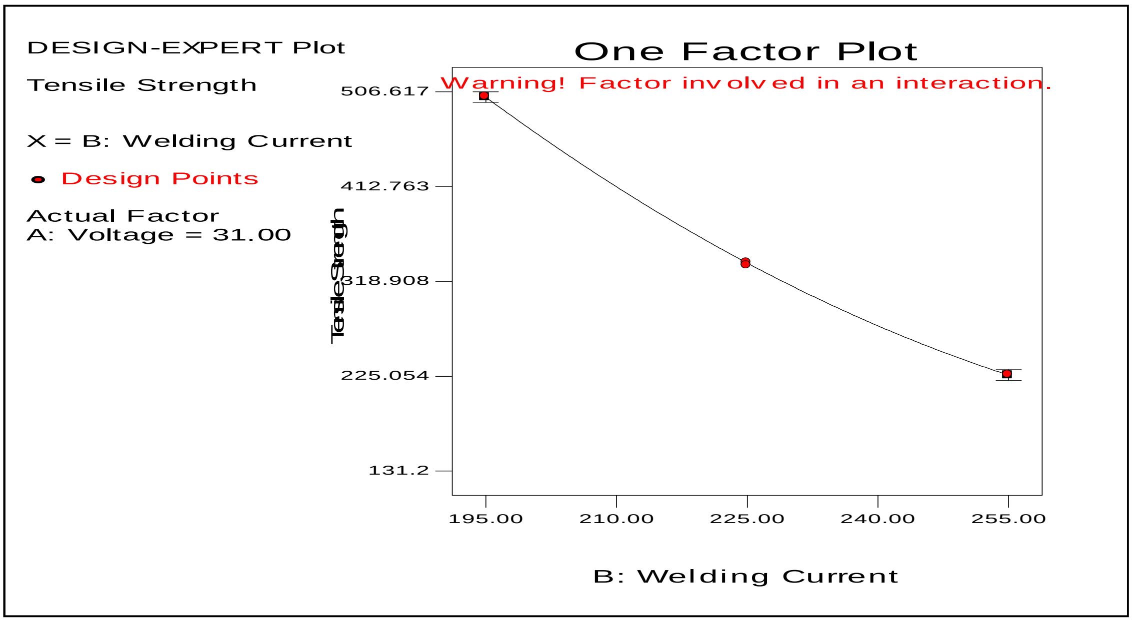
There are two directions in which tensile strength can be tested from the specimens which are shown below:

a) Longitudinal

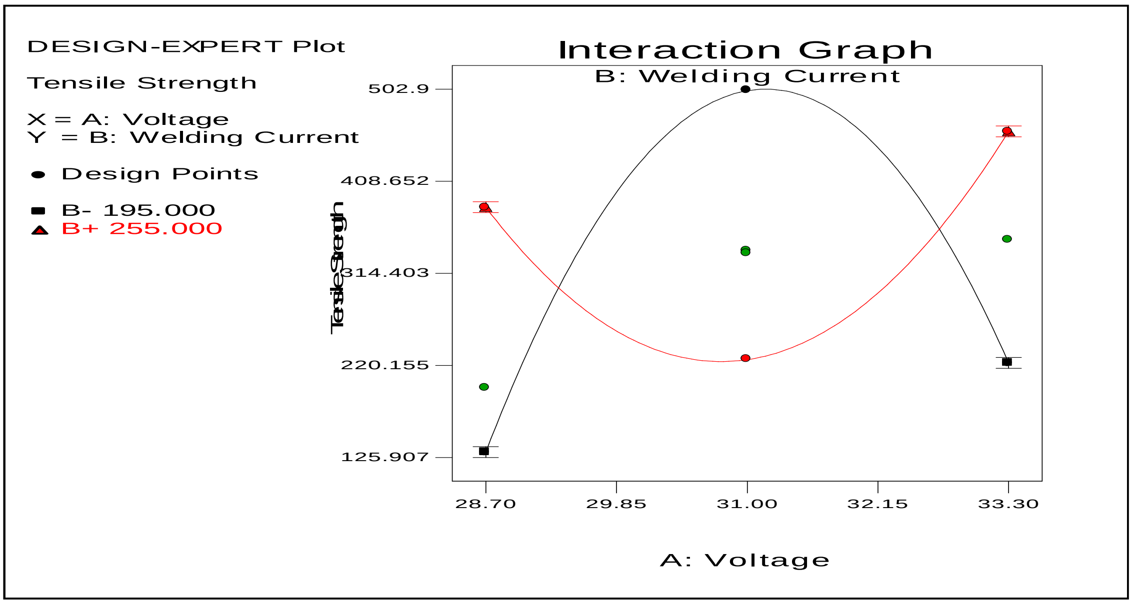
b) Transverse



Graph 5 One Factor Plot Voltage Vs Tensile Strength at Current 225A



Graph 6 One Factor Plot Welding Current Vs Tensile Strength at Voltage 31V



Graph 7 Interaction Graph

So, accordingly the test samples can be prepared in two ways for tensile strength testing. For longitudinal the test samples were cut from the specimen along the direction of welding and for transverse testing the test specimen was cut from the specimen at right angle to the direction of welding. This research work was associated with transverse direction only. So the table 1 shows values of transverse tensile strength.

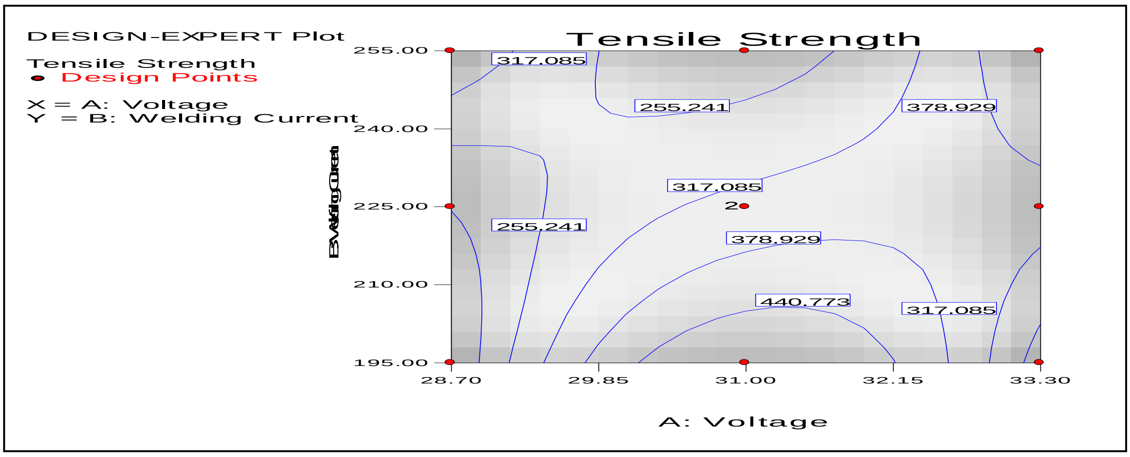
6.1.1 Sequential model

The results of tensile strength thus obtained were analyzed using Design of Experiment software called Design Expert. In fit summary the process order was selected according the values obtained shown in Table 2 and known as sequential model.

Table 2 Sequential Model Sum of Squares

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Mean	9.88E+05	1	9.88E+05			Suggested
Linear	24599.89	2	12299.94	0.85	0.4684	
2FI	46.92	1	46.92	2.77E-03	0.9597	
Quadratic	10345.88	2	5172.94	0.23	0.8067	
Cubic	91259.34	2	45629.67	12771.84	< 0.0001	Aliased
Residual	7.15	2	3.57			
Total	1.11E+06	10	1.11E+05			

From the model as shown above, select the highest order polynomial where additional terms were significant and the model was not aliased. So, we selected 2FI model as our model.



Graph 8 Tensile Strength

6.1.2 ANOVA

The analysis of Response Surface Model was done by using ANOVA. As our model was found linear as discussed in sequential model of sum squares, so the Response Surface Linear Model was analyzed by ANOVA.

a) Analysis of variance table

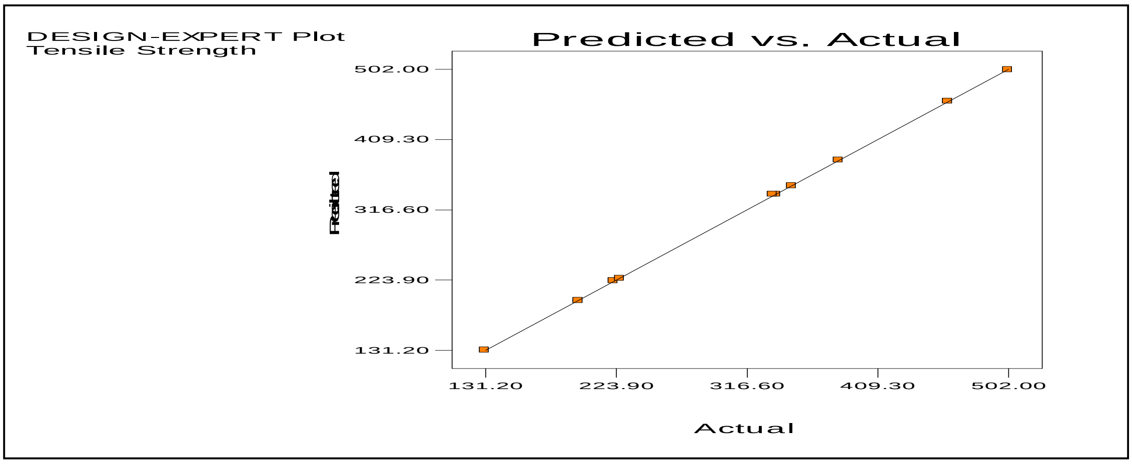
ANOVA for Response Surface Linear Model is shown in Table 3 below.

Table 3 ANOVA Table for Tensile Strength (Partial sum of squares)

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F	
Model	1.26E+05	7	18036.01	5048.31	0.0002	Significant
Arc Voltage A	1.14E+04	1	11445.84	3203.72	0.0003	
Welding Current B	37867.52	1	37867.52	10599.2	< 0.0001	
A2	9741.68	1	9741.68	2726.72	0.0004	
B2	1655.41	1	1655.41	463.35	0.0022	
AB	46.92	1	46.92	13.13	0.0684	
A2B	89769.7	1	89769.7	25126.72	< 0.0001	
AB2	1489.64	1	1489.64	416.95	0.0024	

Residual	7.15	2	3.57			
Lack of Fit	3.5	1	3.5	0.96	0.5064	Not Significant
Pure Error	3.64	1	3.64			
Cor Total	1.26E+05	9				

The Model F-value of 5048.31 implies the model was significant. There is only a 0.02% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms were significant. In this case A, B, A^2 B^2, A^2B, AB^2 was significant model terms. Values greater than 0.05000 indicate the model terms were not significant. If there were many insignificant model terms (not counting those required to support hierarchy), model reduction may improve model.



Graph 9 Predicted Vs Actual values of tensile strength

The "Lack of Fit F-value" of 0.96 implies that the Lack of Fit was not significant. There was a 50.64% chance that a "Lack of Fit F-value" this large could occur due to noise. Lack of fit was bad; we want the model to fit.

b) Final Equation in Terms of Coded Factors

$$\text{Tensile Strength} = +337.06+75.65 * \text{Voltage} - 137.60 * \text{Welding Current} - 64.61 * \text{Voltage}^2 + 26.64 * \text{Welding Current}^2 - 3.42 * \text{Voltage} * \text{Welding Current} + 259.47 * \text{Voltage}^2 * \text{Welding Current} - 33.43 * \text{Voltage} * \text{Welding Current}^2$$

c) Final Equation in Terms of Actual Factors

$$\text{Tensile Strength} = -3.38424E+005 + 22792.18858 * \text{Voltage} + 1329.61684 * \text{Welding Current} - 380.09013 * \text{Voltage}^2 + 0.53016 * \text{Welding Current}^2 - 94.15353 * \text{Voltage} * \text{Welding Current} + 1.63500 * \text{Voltage}^2 * \text{Welding Current} - 0.016147 * \text{Voltage} * \text{Welding Current}^2$$

6.1.3 Optimization

Now the results thus obtained and analyzed were optimized using RSP approach in D.O.E software. The constraints are shown in Table 4 below.

Table 4 Constraints

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
Arc Voltage	is in range	28.7	33.3	1	1	3
Welding Current	is in range	195	255	1	1	3
Tensile Strength	maximize	131.2	502	1	1	3

The input parameters and response may be assigned criteria accordingly. Here we had taken the input parameters: arc voltage and welding current 'is in range' criteria while response parameter: tensile strength was assigned 'maximize' criteria.

6.2 Result

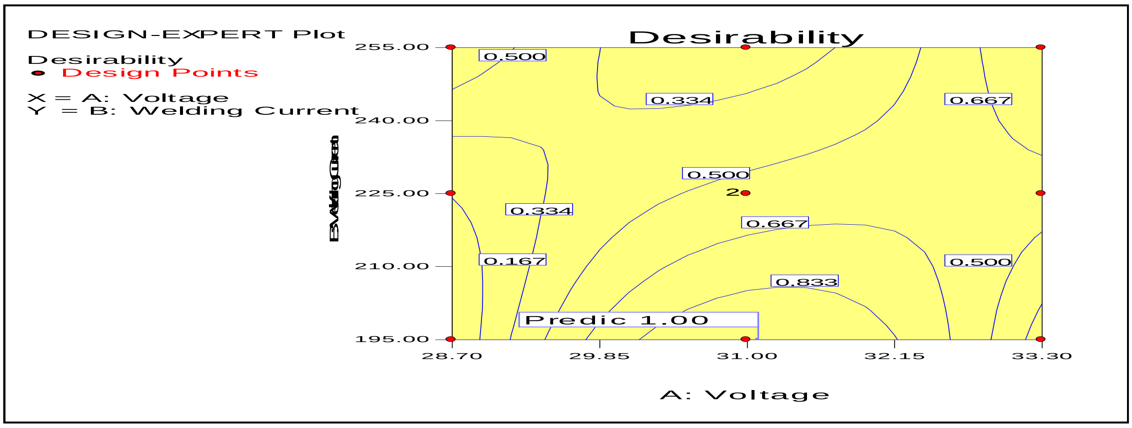
The optimization of above said input processing parameters provides eight solutions for maximized value of tensile strength.

Table 5 Solutions

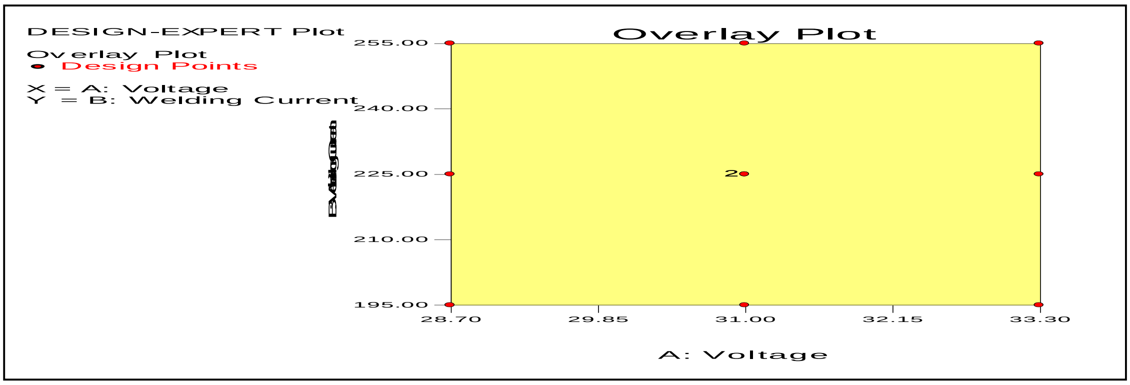
Number	Voltage	Welding Current	Tensile Strength	Desirability	Remarks

1	31.08	195.08	502.042	1	**Selected**
2	31.25	195.03	502.278	1	
3	31.20	195.00	502.778	1	
4	31.22	195.10	502.060	1	
5	31.13	195.09	502.253	1	
6	31.11	195.09	502.197	1	
7	31.16	195.13	502.107	1	
8	33.30	255.00	459.753	0.886065713	
8 Solutions found					

Table 5 shows the final result values of variable parameters and tensile strength of EN31 steel. The analysis shows that at an arc voltage of 31.08 to 31.30 volts and welding current of 195.00 to 195.11 ampere, the maximum tensile strength 502.042 to 502.778 for run no. 10.



Graph 10 Desirability Graph



Graph 11 Overlay Plot

7. Conclusion

The similar weld joint of EN31 material was developed effectively with MIG welding with selected range of input variable parameters. So, MIG welding procedure is effective welding procedure for obtaining maximum tensile strength in EN31 steel. Further it was found that out of selected variable process parameters: arc voltage and welding current, arc voltage was the parameter which affects the tensile strength of EN31 weld joints at most.

In future work, we can take remaining constant variable like wire feed rate, gas flow rate, electrode stick out welding position, welding speed etc. as process variable parameters and can study and evaluate their effect on tensile strength of the EN31.

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