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OPTIMIZATION OF PROCESS PARAMETERS AND STUDY OF HARDNESS DURING HARD FACING OF MILD STEEL USING TAGUCHI METHOD

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ABSTRACT

Hard facing is an important tool in tribology in which a layer of wear resistant material deposited over base metal or substrate to improve surface characteristics. There are numerous processes and consumables available in the market to improve the surface characteristics of components. This technique has potential to deposit hard-faced layer on substrate. The properties usually sought are greater resistance to wear from abrasion, impact, adhesion (metal-to-metal), heat, corrosion or any combination of these factors. Hard facing is applied only to specific areas of metal parts that are exposed to wear. There is often no need to protect the entire surface of a component from wear. Hard facing can be applied selectively and in different thickness to suit the exact requirements of a piece of equipment, thereby proving a most economical way of combating wear.

Shielded metal arc welding is most commonly used process for hard facing due to its easy availability and versatility of operation. Low carbon steel is selected for the present work as substrate material due to its low cost, easy availability and variety of applications. In the present work a detailed study was done to study the effect of current, types of hard facing electrode and number of layers on substrate on micro-hardness and wear behavior of low carbon mild steel 1020 deposit by SMAW.

KEYWORDS:.

INTRODUCTION

Welding plays an important role in the development of our society and mankind as a whole. One of the indexes used for measuring the prosperity of a country is the per capita steel consumption. Higher the production of steel, the greater is the role of welding. Welding is a process of permanent joining of two materials through localized coalescence resulting from a suitable combination of temperature, pressure and metallurgical conditions. Depending upon the combination of temperature and pressure from a high temperature with low pressure to a high pressure with low temperature, a wide range of welding processes has been developed [24]. While there are many methods for joining metals, welding is one of the most convenient and rapid methods available. It is a principal means of fabricating and repairing metal parts. The term welding refers to the process of joining metals by heating them to their melting temperature and causing the molten metal to flow together.

Welding, like any skilled trade, is broad in scope and one cannot become a welder simply by reading a book. One need practice and experience as well as patience, however much can be gained through study. Historically the welding was developed in the ancient times and can be traced during the Bronze Age when the lap joints were made by heating and hammering the two metal pieces. During excavation, parts and tools have been found, which were welded by pressure welding during the time as back as 1000 B.C [26].

The earliest known form of welding, called forge welding, dates back to the year 2000 B.C. Forge welding is the process of joining metals by heating and hammering until the metals are fused (mixed) together. Although forge welding still exists, it is mainly limited to the blacksmith trade. Some of the most recently welding technologies include: Friction welding, which uses rotational speed and upset pressure to provide friction heat, the pressure

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maintained until the two pieces get welded. Inertia welding, in which one of the work piece is connected to flywheel and other is restrained from rotating. It is a specialized process and has applications only where a sufficient volume of similar parts is to be welded because of the initial expense for equipment and tooling. Laser welding is one of the newest processes. The laser was originally developed at the Bell Telephone Laboratories as a communication device. Because of the tremendous concentration of energy in a small space, it proved to be a powerful heat source. Friction-stir welding is a solid-state joining process (meaning the metal is not melted during the process) and is used for applications where the original metal characteristics must remain unchanged as far as possible. It was invented and experimentally proven by Wayne Thomas and a team of his colleagues at the Welding Institute UK in December 1991 [26].

The four main components of welding include:

- The base metals
- A heat source
- Filler material
- Shielding gas or flux.

In the welding process the metal gets heated to its melting point, at the same time there is some sort of shielding from the atmosphere to protect it, and then a filler metal is added to the area that needs to be joined ultimately producing a single piece of metal. In order to obtain coalescence between two metals there must be a combination of proximity and activity between the molecules of the pieces being joined, sufficient to cause the motion of common metallic crystals. Proximity and activity can be increased by plastic deformation (solid-state-welding) or by melting the two surfaces so that fusion occurs (fusion welding).In solid-state-welding the surfaces to be joined are mechanically or chemically cleaned prior to welding while in fusion welding the contaminants are removed from the molten pool by the use of fluxes. In vacuum or outer space the removal of contaminant layer is quite easy and welds are formed under light pressure.

Applications of welding technology

- Welding finds its intensive applications in automobile industry, and in the construction of buildings, bridges, submarines, pressure vessels, offshore structures, storage tanks, pipelines and water turbines.
- In making extensions to the hospital building, where construction noise is required to be minimum.
- Rapid progress in exploring the space has been made possibly by new methods of welding and the knowledge of welding metallurgy.
- The aircraft industry cannot meet the enormous demands for airplanes, fighter and guided planes, space crafts, rockets and missiles without welding.
- The process is used in critical applications like the fabrication of fission chambers of nuclear power plants [22].

Hard Facing

Hard facing is a process of depositing a layer of material over base metal or substrate either to improve surface characteristics like corrosion resistance, wear resistance etc. or to get required size of dimension. If a hard wear resistant material is deposited over a soft, ductile material to improve the wear resistance then the process is called hard facing. When the layer of material deposited for corrosion resistance the process is known as cladding. Sometime worn out parts are built up to required size so that they can be put back into service. Hard facing is one of the most useful and economical ways to improve the performance of components submitted to severe wear condition. Hard facing is commonly employed method to improve surface properties of agriculture tools, components for mining operation; soil preparation equipment's and earth moving equipment [12]. An alloy is homogeneously deposited into the surface of a soft material (usually low or medium carbon steels) by welding with the purpose of increase hardness and wear resistance without significant loss in ductility and toughness of the substrate. A wide variety of hard facing alloys is commercially available for protection against wear. Deposits with a microstructure composed by disperse carbides in austenite matrix are extensively used for abrasion application and are typically classified according to the expected hardness [8]. Durability and longevity of any material is priceless for any nation especially developing countries like India. All types of industrial set ups irrespective of whether being in manufacturing or service sector had off late drawn their reputation from the durability and reliability of their products. Degradation of material by wear and corrosion cost a very high loss whether it is of reputation or economic loss to all the countries. Although considerable attention has already been paid by the researchers to develop modern techniques and methods to arrest and control the problems resulting from wear and corrosion, still there is a need for further research to reduce the losses incurred because of them. It is estimated that more that 30% of wear and corrosion related cost can be reduced by developing and using better techniques of controlling wear and corrosion. These wear and corrosion related problems can be minimized mainly by two methods:

1. By using high cost wear and corrosion and corrosion resistant alloys better than the existing low cost ones.
2. By improving the wear and corrosion resistance of the existing metals and alloys by applying certain modifications to the surface.

As the wear is a surface phenomenon and occurs mostly at outer mating surfaces, therefore it is more appropriate and economical to use the latter method of making surface modification than using the former one which will not only involve very high cost of the operation but also involve longer time as compared to the second technique. The hard facing technique has in the meantime, grown into a well-accepted industrial technology. Due to continuous rise in the cost of materials as well as increased material requirements, the hard facing has been into prominence in the last few decades. Developments in hard facing techniques as well as advances in hard facing electrode have given rise to surface coatings with excellent wear resistant properties under severe service conditions, thus enlarging the field of its application. In this presented thesis on wear study and hardness study, the Shielded Metal Arc Welding (SMAW) method of making surface modification to improve the wear and hardness properties of mild steel materials has been used. The mild steel is hard faced with two different grade hard facing electrode having hardness 250-300BHN and 500-600BHN respectively. The mild steel is frequently used material for hard facing due to its low cost, which at same time soft material with poor wear properties. To reduce this wear problem, the hard facing was done by hard face electrode using SMAW on the mild steel plate and were investigated with regard to their wear, hardness; effect of heat input, and bead geometry characteristics. Complex carbide electrodes are also used especially when abrasive wear is accompanied by other wear mechanisms [9]. Several welding techniques such as oxyacetylene welding(OAW), gas metal arc welding, shielded metal arc welding, and submerged arc welding can be used for hard facing. The most important difference among these techniques lies in the process capabilities of the welding process welding efficiency, the weld plate dilution and the manufacturing cost of welding consumable [20]. Studies show that any industrialized nation loses between 4-6% of GNP only due to wear and only abrasion wear counts 63% of total loss due to wear. Material loss due to wear in mining mineral processing industries, earth moving equipment's, agricultural implements, oil well drill bits, railway frogs and crossings, sugar mills, steel plants, power plants and several other industries is significantly high. Amongst the various commercially viable surface-coating techniques, thermal spraying, chemical vapor deposition and physical vapor deposition methods have frequently been considered in the recent time. The hard facing technique has in the meantime, grown into a well-accepted industrial technology. Due to continuous rise in the cost of materials as well as increased material requirements, the hard facing has been into prominence in the last few decades. Developments in hard facing techniques as well as advances in hard facing electrode have given rise to surface coatings with excellent wear resistant properties under severe service conditions thus enlarging the field of its application. The economics of weld surfacing is usually very favorable and this applies well to both the smallest and the largest weld repair jobs. Some weld repair jobs may take only few minutes and others may require weeks for proper preparation and welding. A wide variety of hard facing alloys is commercially available for protection against wear. Deposits with a microstructure composed by disperse carbides in austenite matrix are extensively used for abrasion application and are typically classified according to the expected hardness [21].

EXPERIMENTATION

This chapter is about the experimental procedure and other related aspects of the present study. The chapter deals with the methodology adopted to achieve the goals or objectives for the present work which includes the hard facing of mild steel using hard facing electrode and analysis of result with Taguchi methodology. After finalization of process parameters and levels, the complete set of eight trials has been prepared as per orthogonal array selected from the Minitab software. The input parameters and levels given below in the table 3.1

Table 3.1 Input parameters and Levels

Parameters	**coding**	**Level 1**	**Level 2**
Welding current	I	160	180
electrode	E	A	C
Number of layer (NOL)	L	1	3

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Base Plate & Electrode Used

According to the AISI standard the grade of Low carbon Mild steel 1020 is used having dimensions 150 x 30 x10 (mm^3).The chemical compositions are shown in table 3.2

Table 3.2 Chemical composition of base plate

C	***Si***	***Mn***	***P***	***S***	***Fe***
0.20	***0.19***	***0.52***	***0.03***	***0.033***	***Rest***

The electrode used for experimentation is DUROBUILD-A and DUROBUILD-C having harness 266-318HV and 528-633HV respectively. It is an all position electrode for structural work. Medium penetration for lower dilution levels with least spatter. Versatile electrode used for variety of application of welding. Almost all general purpose welding is done by shielded metal arc welding using coated electrode. The coating electrodes consist of core wire with a covering of coating material.

Table 3.3 Chemical composition of Electrode A

C	Si	Mn	cr	Fe
0.18	0.42	0.76	2.00	Rest

Table 3.4 Chemical composition of Electrode C

C	Si	Mn	cr	Mo	V	Fe
0.50	0.70	0.70	7.00	0.80	0.50	Rest

Conducting Trials Runs

Trail runs were conducted on the base plate according to different parameters selected randomly from the orthogonal array. It is also worth mentioning that the welding conditions such as electrode type, electrode size, electrode to work angle, baking and hence moisture content conditions, welding positions and welding speed etc. were kept constant to the maximum possibility. In the trial runs it was observed changing the electrode changes the hardness and dilution both. Also same variation was encountered with changing the number of welding layers. Number of specimens were prepared and examined visually and then selective specimens were selected for further investigations based upon the visual examination, hardness testing, dilution and wear test examinations were conducted over selected specimens.

Conducting Actual Runs

Beads on mild steel plates have been deposited as per orthogonal array using hard facing electrode with dimensions of $4mm \times 450mm$. and $5mm \times 450mm$. DCEN polarity was used to minimize the dilution which otherwise will decrease the hardness. Experiments were conducted according to orthogonal array with different combinations of selected parameters.

Base Metal Preparation

Low carbon mild steel was used as a base metal. The surfaces to be hard faced must be clean to obtain good fusion between the filler metal and the base metal. This means that they must be free of relatively thick oxide, moisture, greases, oils, paints or any other substance.

Testing

Following tests were conducted on the samples obtained after experiment.

Hardness Test

Hardness test was done at CITCO Chandigarh. The hardness test was carried out by polishing the cross-sectioned samples with Amri papers up to grade 2000. For micro-hardness testing the specimens were prepared using standard

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procedure like belt grinding, polishing using successively fine grades of emery up to 2000 grit size. This was helpful in removing coarse and fine oxide layer as well as scratches on the surface that were to be metal graphically analyzed. Micro-hardness tester was used to measure micro-hardness at various zones of interest in different weldment. A load of 500 grams and a dwell time of 20 seconds were used for these studies. The results obtained are given in next chapter. Different readings were taken along the edge length of welded specimen and average of all the readings was taken to get the final value.

Fig. 3.1 Micro-hardness tester

RESULTS AND DISCUSSION

Experimental Results

The results of this experimentation regarding over lays for hard facing of low carbon steel using hard facing electrode, discussed in this chapter. The table 4.1 shows the L8 orthogonal array for different levels and input parameters.

Table 4.1 L8 orthogonal array

Sample No.	Welding current (I)	Electrode (E)	No. of layers (L)
1	1	1	1
2	1	1	2
3	2	1	1
4	2	1	2
5	1	2	1
6	1	2	2
7	2	2	1
8	2	2	2

The mechanical testing of welded specimens are given in Table 4.2. The samples are categorized as 1 to 8 as per the welding conditions which are welding current, electrode and number of layer.

Table 4.2 Average micro hardness of sample at different welding conditions

Sample No.	Welding current (I)	Electrode (E)	No. of layers (L)	Average micro hardness (HV)
1	160	A	1	299
2	160	A	3	490

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3	180	A	1	273
4	180	A	3	450
5	160	C	1	610
6	160	C	3	780
7	180	C	1	587
8	180	C	3	750

Analysis of Micro-Hardness

Micro-hardness analysis done here is dependable variable on three factors:

1. Welding Current
2. Welding electrodes
3. No. of welding layers

Various graphs and tests have been constructed to determine which factors have a statistically significant effect on the micro-hardness. Analysis of variance for S/N ratios for micro hardness calculated from software as given in Table 4.3.The average micro hardness obtained from the micro hardness test conducted on 8 specimens. The Micro Hardness range from 273HV to 780HV as shown in table 4.2.

Larger the better

$$SN_L = -10 \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} 1/y_i^2\right)$$

Where y_i represents the experimentally observed value of the ith experiments, n is the repeated number of each experiment in each run. The S/N ratio from the observed values is calculated in decibel (dB). If F statistic > critical value, then we have significance at the 95% confidence level. P- value shows the significance of model as it must be less than 0.05.

The following entities for the analysis of variance (ANOVA) have been calculated.

1. Sum of square (SS) for the general, group effects and residual effects.
2. Associated degree of freedom (df) with [n (factors)-1].
3. Mean square (MS) (dividing SS by df).

Since the P-value in the table 4.3 is less than 0.05, there is a statistically significant relationship between the variables at the 95% confidence level. From the table 4.3 it is clear that electrode and no. of layer are significant factor. Also the electrode contribution is highest i.e. 72.07% with an residual error of 0.79%. The main effect of hard facing is to increase the hardness, so larger is better option is selected from Taguchi design and accordingly response for signal to noise ratio is generated. It was found that level-2 of electrode and level-2 of no. of layers gives the optimum values. Among all the welded specimens maximum micro hardness (780HV) is observed in specimen welded with parameters 160 A current with electrode C at 3 layer of welding and minimum with 180 A current and electrode A at 1 layer of welding, which is 273 HV.

Table 4.3 Analysis of variance for S/N ratios for micro hardness

Parameters	Degree of Freedom(df)	Sum of Squares(SS)	Mean Squares(MS)	F value	P value	Percentage contribution
Current (I)	1	0.6074	0.6074	0.98	0.378	0.77

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Electrode (E)	1	56.8052	56.8052	91.74	0.001	72.07
No of layer (L)	1	20.7859	20.7859	33.57	0.004	26.37
Residual error	4	2.4767	0.6192			0.79
Total	7	80.6752	-	-	-	-

Table 4.4 S/N Ratio of all micro hardness samples

Sample No.	Welding current (I)	Electrode (E)	No. of layers (L)	S/N Ratio
1	160	A	1	49.51
2	160	A	3	53.80
3	180	A	1	48.72
4	180	A	3	53.06
5	160	C	1	55.71
6	160	C	3	57.84
7	180	C	1	55.37
8	180	C	3	57.50

Electrode deposited on the base material has the most significant effect on micro hardness. It has been observed that from table 4.2 with the increase of welding current from 160A to 180A, micro hardness decreases with electrode A and single layer of welding due to reason that high current results in slower cooling rates resulting in softer matrix having lower hardness. The highest micro hardness has highest S/N ratio calculated using "MINITAB" software at parameter 160 welding current, electrode C and three number of layer. S/N ratio represents the magnitude of the mean of a process (response) compared to its variation. Depending upon the input parameters ANOVA is applied to authenticate the significant or non-significant factor with percentage contribution calculated as percentage contribution.

Table 4.5 Response Table for Hardness

Level	Welding Current (I)	Electrode (E)	No. of layers (L)
1	54.22	51.28	52.33
2	53.67	56.61	55.55
Delta	0.55	5.33	3.22
Rank	3	1	2

Main Effects Plot for S/N Ratios

The main effect plots for S/N ratios are shown in figure 4.1. This plot shows the variation of micro-hardness (HV) with change in three parameters: welding current, electrodes and no. of layers of welding. In plots, the x-axis indicates the value of each process parameter (at two levels for welding current, electrodes and no. of welding layers), y-axis the response value (micro-hardness). Horizontal line indicates the mean value of the response or micro-hardness. The main effect plots are used to determine the optimal design conditions to obtain the optimum micro-hardness (HV). Main effect plots for micro-hardness (HV) are plotted between:

1. Micro-hardness (HV) V/s electrodes
2. Micro-hardness (HV) V/s Welding Current

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3. Micro-hardness (HV) V/s no. of layers.

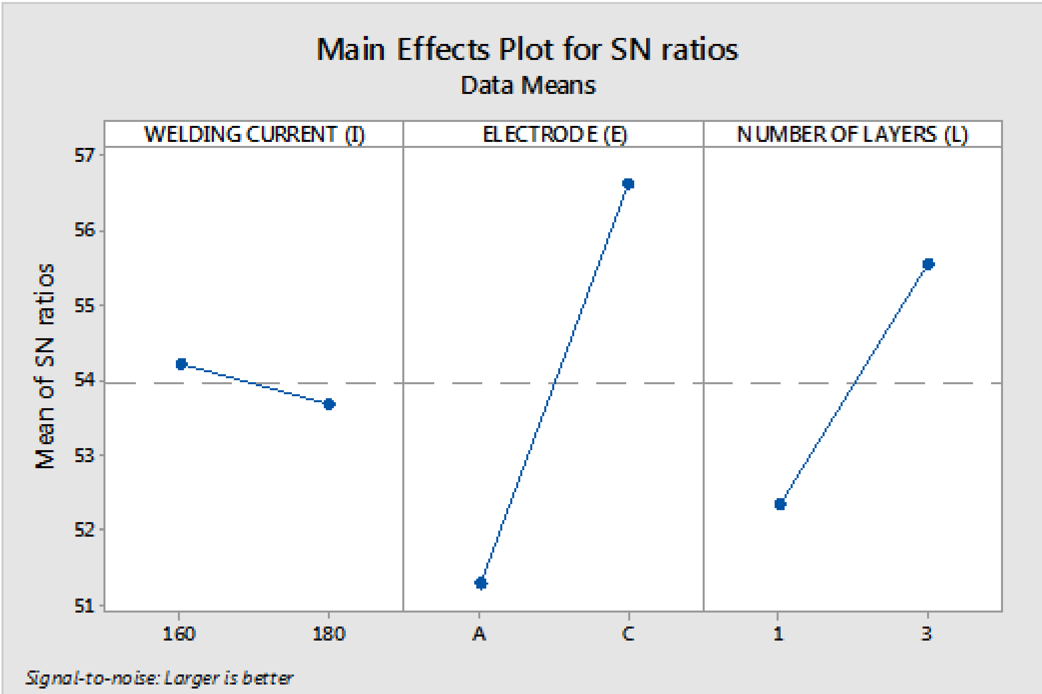

Fig. 4.1 Main effect plots for S/N ratios for micro-hardness

The effect of each parameter on the micro hardness is plotted on the graph in form of lines in figure 4.1. From the main effect plots for S/N ratios it is clear that the micro hardness decreases as the current is increased. Main effects plot for S/N ratios between electrodes, no. of layers of welding and micro hardness show that the micro hardness increases linearly from lower to higher value with increase in no. of layers of welding and electrodes from A to C. From this it is concluded that the electrodes and no. of layers have the most significant effect on the micro-hardness (HV).

Probability Plot for Micro Hardness

From the figure 4.2 probability plot of micro hardness (HV) shows that the data is approximately adjacent to straight line having a good co-relation between experimental results and predicted values. There is minimum variation between the observed values. A normal distribution with a mean of 529.9 and a standard deviation of 188.2 appears to fit the data fairly well:

- The plotted points form a reasonably straight line.
- The plotted points follow the fitted distribution line fairly closely.

Because the distribution fits the data, we can use the fitted line to estimate percentiles for the population.

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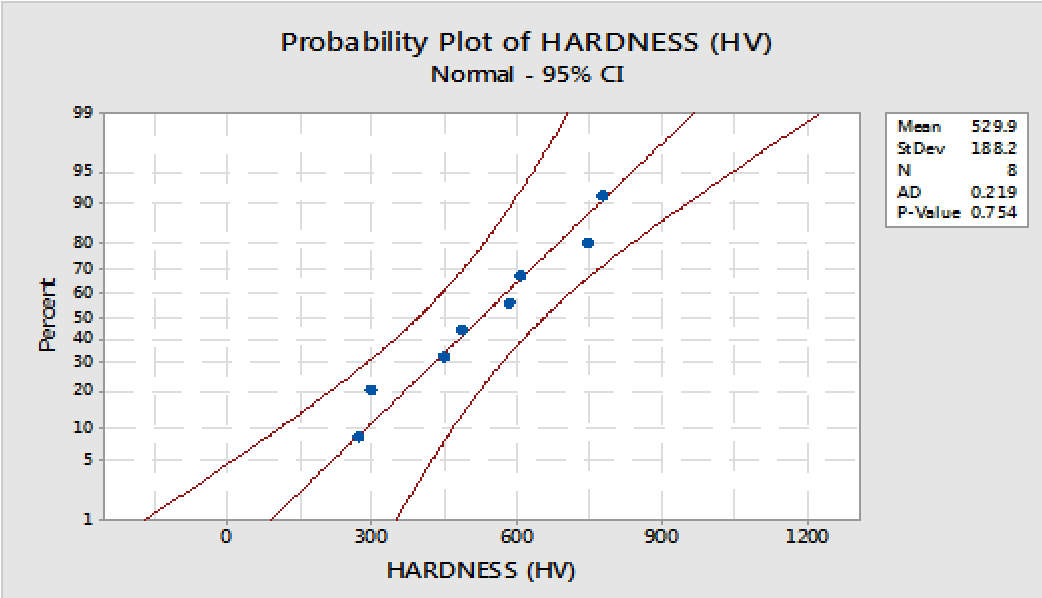

Fig. 4.2 Probability distribution for micro-hardness

Time Series Plot for Micro Hardness

In time series plot there is a sequence of measurements of some numerical quantity made at some regular interval. Figure 4.3 shows time series plot of mean micro hardness. This graph shows a plot of mean micro-hardness versus number of experimental runs. Time series plots consist of time scale (number of runs) on X- axis and Data scale (micro-hardness) on the Y- axis. From figure 4.3, it is clear that the two extreme points on periodic Fluctuation represent the minimum and maximum micro-hardness at 3rd and 6th run of experiment respectively

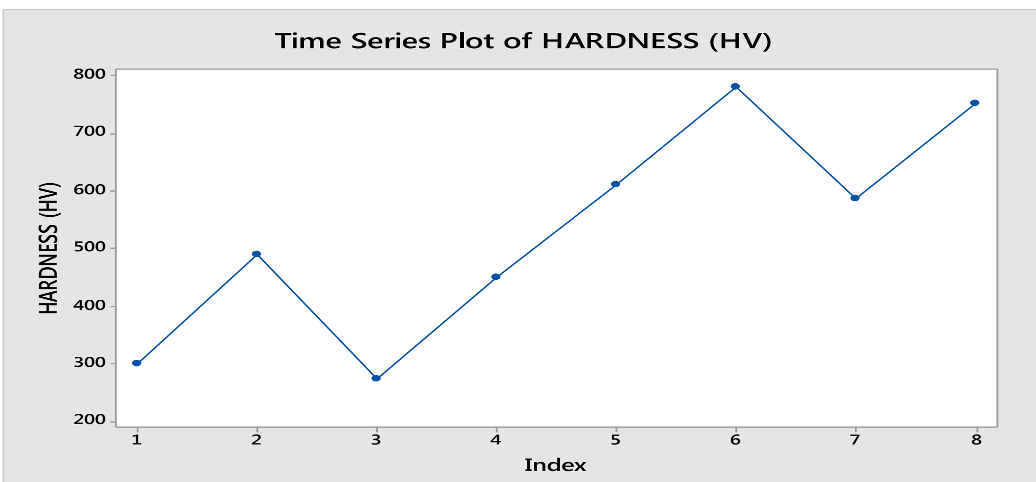

Fig. 4. 3 Time series plot for micro-hardness

Main Effect Plot for Micro hardness

Main effect of current on hardness can be revealed from figure 4.4. As the value of current is increased, the value of hardness is decreased due to dilution effect. An increase in the value of hardness with change in electrode and in welding layers as is increased from 1 to 3.

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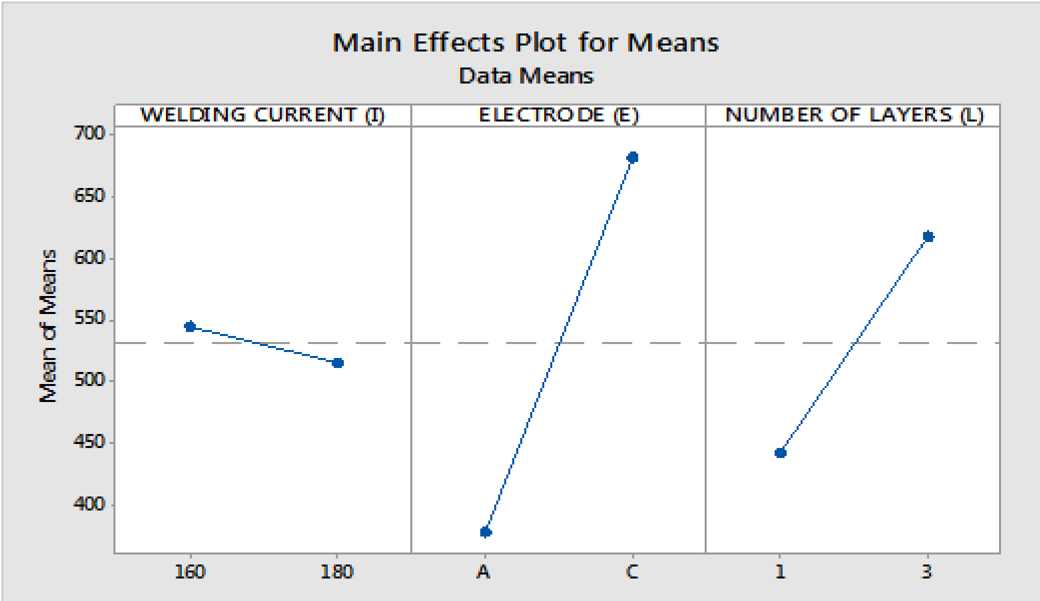

Fig. 4. 4 Main effect plot for micro hardness

Table 4.10 Confirmation Test result

Parameters	Optimal parameters	Predicted optimal value	Experimental value	Error percentage
Hardness (HV)	I1E2L2	784	776	1.02

CONCLUSIONS & FUTURE SCOPE

Conclusions

Following conclusions have been drawn from the dissertation work:

Effect on Hardness

Among all the welded specimens optimum micro hardness (780 HV) is observed in specimen welded with parameters 160 A current with electrode C at 3 layers of welding. From the selected parameters i.e electrode and number of layer significantly affect the hardness. The percentage contribution for electrode is 72.07 followed by number of layer (26.37).

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