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Study on Abrasive Wear Characteristics of Fe-Cr-C Hardfacing Alloy and Effect of Welding Parameters

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Abstract

Wear is a property of material to resist the component and replace for the functional usage. There are methods to prevent the wear by surface coating that is one, by heat treatment and another by hardfacing by welding. In heat treatment it is not possible to deposit the coatings on the base metal to maximum thickness. This is possible by hardfacing using welding process. The abrasive wear characteristics of different hardfacing electrodes deposited on Mild steel (M.S) plate was studied using the dry sand rubber wheel abrasion tester. The results illustrates that different hardfacing electrodes as well as the weld procedures variation using the variation of chromium, silicon, and carbon have large effects on the abrasion resistance are mainly attributed to the variation in deposit chemistry and microstructures. Carbon and chromium content is an important factor in determining microstructure of such hardfacing electrodes and therefore abrasive wear resistance. Hardfacing materials tend to be suited to specifications of wear. Further more the prime requirements of a metal part is that it has exceptionally good resistance to wear, corrosion or high temperatures. Rather than make the entire part from expensive wear resistance alloy, it is more economical to make it from ordinary steel and then cover the critical surfaces with a layer of weld metal capable of withstanding the service conditions. The application of a durable surface layer to a metal is called hardfacing and a simple way to apply hard surfacing materials is by arc welding. The present work was carried out to study the influence of variables such as current, travel speed, metallurgical variables such as deposit chemistry and subsequently on the abrasive behavior of chromium and carbon hardfacing deposites in statically designed experiments.

Keywords: Abrasion resistance, Chromium alloy, Chromium carbide, Hardness, Hardfacing, Wear mechanisms..

Introduction

The prime requirement of a metal part is that it has exceptionally good resistance to wear, corrosion and high temperatures. Instead of making the entire part from some expensive wear resistant, corrosion resistant and temperature resistant alloy, It is more economical to make it from an ordinary steel and then cover the critical surfaces with a layer of weld metal capable of withstanding the service conditions [5]. The application of a durable surfacing layer to a metal is called hard surfacing materials that can be weld for hard surfacing [4] and selecting the one best suited to a particular application involves balancing cost against performance, as in the selection of any engineering material. Two AWS specifications that perform to hard surfacing are surfacing rods and electrodes.

Fe-Cr-C alloys are used in severe conditions where there is extreme erosion and therefore abrasion resistance [1, 2] is necessary. Their exceptional abrasive and erosive wear resistance results primarily from their high volume fraction of hard carbides, though the toughness of the matrix also contributes to the wear resistance.

The investigations of Fe-Cr-C alloy microstructures have shown that these types of materials have hypoeutectic, eutectic, and hypereutectic [16] structures. M7C3 primary carbides [15] form in large amounts at higher carbon concentrations. These types of

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microstructures have good wear resistance properties.

Several welding techniques such as oxyacetylene gas welding (OAW), gas metal arc welding (GMAW), metal inert gas welding (MIGW), Tungsten inert gas welding (TIGW), shielded metal arc welding (SMAW) [3] can be used for hardfacing. The most important differences among these techniques lie in the welding efficiency, the weld plate dilution and the manufacturing cost of welding consumables. SMAW is commonly used due to the low cost of electrodes and easier applications. The present investigation aims to study two commercial electrodes in terms of their chemical composition, microstructure, hardness and abrasive wear resistance

Experimentation

A. Hardfacing Welding Processes

The most common welding processes for hardfacing are shielded metal arc welding (covered electrode), flux cored arc welding and submerged arc welding. Although other processes such as oxy fuel and gas tungsten arc can be used, their low deposition rates are limited in some applications. The welding processes named shielded metal arc welding (SMAW) was selected for this study.

B. Test Speciman Preparation

Base Metal

The selection of base metal is very essential in deciding what alloy to use for hardfacing deposit. Since welding procedure differs according to the base metal. The base metal selected for this study is Mild steel which composes the main elements of carbon, silicon, manganese, sulphur, and phosphorous and ferrous. The chemical composition is shown in Table 1.

Table 1 Chemical composition of base metal (In weight percentages)

C	Si	Mn	S	p	Fe
0.18	0.32	1.47	0.013	0.029	Bal

C. Hardfacing alloy

Two different commercial hardfacing alloys were used for overlaying. These alloys were selected due to its low cost and easy availability in the local market and suitability for the service condition (low stress abrasion). They are basically iron – based alloys [6, 17] having varying amount of chromium, carbon, silicon and other alloying elements as they are more suitable for shielded metal arc welding process. Chemical compositions of two electrodes are presented in Table 2.

Table 2 Chemical composition of hardfacing alloy (In weight percentages)

Electrode	C	Si	Mn	S	p	Cr	Mo	Ni	V	Fe
Hardfacing 1	0.33	0.28	1.15	0.014	0.025	2.22	-	-	-	Bal
Hardfacing 2	0.1	0.38	1.51	0.024	0.03	2.15	0.745	1.09	0.103	Bal

D. Welding Conditions

The standard size test specimens of 16 nos. with the dimensions of 250×100×12 mm were selected for the experiment. The following precautions are taken before hardfacing.

- The electrodes are perfectly dried in the furnace and baked at 250o C one hour before the use
- Area of the weld is properly cleaned
- Preheated the hardfacing area to a minimum of 200o C

E. Machine Specifications

Name: TORNADO MIG 630 Arc welding machine
Current: 100-630 A
Input Voltage: 415 V ± 10% / 50-60 Hz / 3 Phase
Machine Capacity: 50 KVA

Methodology

The experiment was carried out in three stages to investigate the effect of current, travel speed and voltage on hardfacing electrodes, and the corresponding hardness was determined.

i. In first stage, voltage (V) and travel speed (S) were kept constant and current (A) was increased.
ii. In second stage, voltage (V) and current (A) were kept constant and travel speed (S) was increased.
iii. In third stage, current (A) and travel speed (S) were kept constant and voltage (V) was increased.

Stages of Experiment

Table 3 Varying current

Electrode	Current (A)	Voltage (V)	Travel Speed (cm/min)	Hardness (HV 0.5)
Hardfacing 1	200	25	23.1	380
	250	25	23.1	318
	300	25	23.1	317
Hardfacing 2	180	25	23.1	370
	200	25	23.1	416
	250	25	23.1	330

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Table 4 Varying travel speed

Electrode	Travel speed (cm/min)	Voltage (V)	Current (A)	Hardness (HV 0.5)
Hardfacing 1	15.0	25	200	417
	21.4	25	200	418
	50.0	25	200	356
Hardfacing 2	16.67	25	200	377
	25.0	25	200	388
	50.0	25	200	406

Table 5 Varying voltage

Electrode	Voltage (V)	Current (A)	Travel Speed (cm/min)	Hardness (HV 0.5)
Hardfacing 1	15	215	37.5	537
	25	215	37.5	390
Hardfacing 2	15	215	37.5	401
	25	215	37.5	357

The selected standard size of the test specimen is shown in figure 1.The results of hardfacing obtained by varying current, travel speed and voltage along with their hardness and the corresponding relationship between them are shown in figures 2, 3 and 4 respectively. From graphs, it is concluded that as current, travel speed and voltage increases the hardness of surface and the layer next to the surface decreases. Figure 2 shows that, as current increases the hardness of the bead and HAZ decreases. Figure 3 shows that, as travel speed increases the hardness of the bead and HAZ decreases. Figure 4 shows that, as voltage increases the hardness of the bead and HAZ decreases.

Figure 1. Standard test specimen of size 75mmX 26mmX6mm

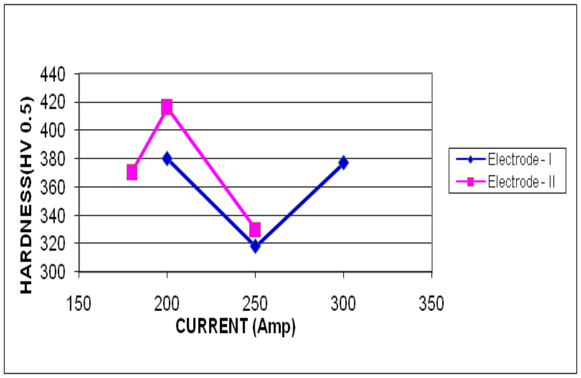

Figure 2. Hardness v/s current keeping voltage (25volts) and Travel speed (23.1 cm/min) constant

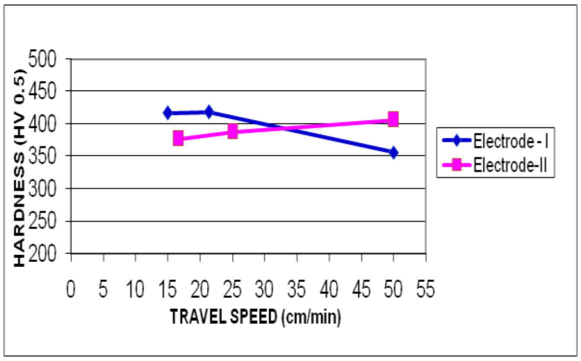

Figure 3. Hardness v/s. travel speed keeping current (200Amp) and (25 volts) constant

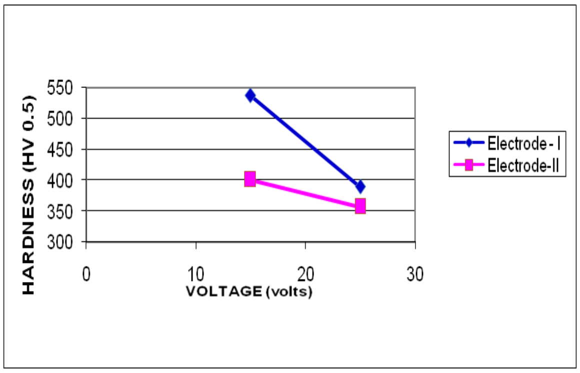

Figure 4. Hardness v/s voltage keeping current (215Amp) and travel speed (37.5 cm/min) constant

Results and Discussion

Hardness Test

The specimens were cut to a size of 100x30x12mm for hardness testing and were polished using standard metallographic procedure. Micro hardness surveys were made on these specimens using Vickers hardness tester along the direction of thickness from the top surface towards

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the base metal after every 0.5mm. These surface values are plotted in the form of a graph shown in figure 5. The hardness survey of heat affected zone (HAZ) samples for every 0.5mm depth was made. The results indicate that the hardness values are more on the welded surface and decrease towards the base metal and remain constant on the base metal.

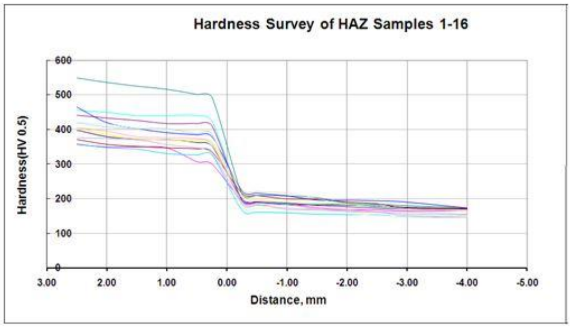

Figure 5 Hardness Survey of HAZ.

Dry Sand Abrasive Wear Test

In the present study, sample of 75x26x6 mm size were used for testing as shown in figure 1 as per ASTMG65 standards. Specimens were ground using surface grinder to make the surface flat. Before the abrasive wear test all the specimens were cleaned with acetone and then weighed on an electronic balance with an accuracy of ± 0.1 mg. The three-body abrasive wear tests were conducted using a dry sand/rubber wheel abrasion tester as per ASTM G65-04 (2010) shown in figure 6a. The sand particles of AFS 60 grade (figure 6b) were used as abrasives and they were angular in shape with sharp edges. The sand particles were sieved (size200–250 µm), cleaned and dried in an oven for 6 hr at 40 0C. In this test, samples were held against a rotating rubber wheel under the constant flow of abrasives in between the sample and the rubber wheel under predetermined load. The actual photograph of the testing machine is shown in figure7.

Test Conditions

Speed: 200 ± 5 rpm
Sample test duration: 15 and 30 min.
Abrasive: loose silica sand having particle size 200 - 250µm.

Load is kept constant at 130.5 N for all the samples. After each test, the samples were cleaned with acetone and then weighed on the electronic balance. The wear loss was calculated as weight losses in gms. Sample of 26x75x6 mm size were used for analysis. Specimens were ground using surface grinder to make the surface flat. Dry sand abrasive wear test was carried out as per ASTM G65 standards. In this test, samples were held against a rotating rubber wheel under the constant flow of abrasives in between the sample and the rubber wheel under predetermined load. The wear testing machine is shown in figure 7 and the test conditions are given here under:

Speed: 200±5rpm
Sample run duration: 30 minutes
Abrasive: loose silica sand having particle size 200 to 250 µm

Silica sand of size between 200 to 250µm was used as abrasive. Load is kept constant at 130.5N for all the specimens. The wear rate was calculated as weight loss in gms. Results indicate that as hardness increases, the loss of wear decreases. Electrode-I has less wear as compared to electrode-II as the percentage of chromium, carbon and silicon is more in electrode-I. However the composition of chromium, carbon & silicon in the weld deposit made with type-I electrode is higher than that of weld deposit made with type-II electrode. Higher amount of chromium, carbon, silicon and finer structure resulted in higher hardness where as lower hardness values were recorded in weld deposit with less amount of Cr, C & Si & coarser structure. From wear testing data under various conditions of the parameters, it can be stated that weld deposits made with type I electrode are more wear resistant than the weld deposits made with type II electrode

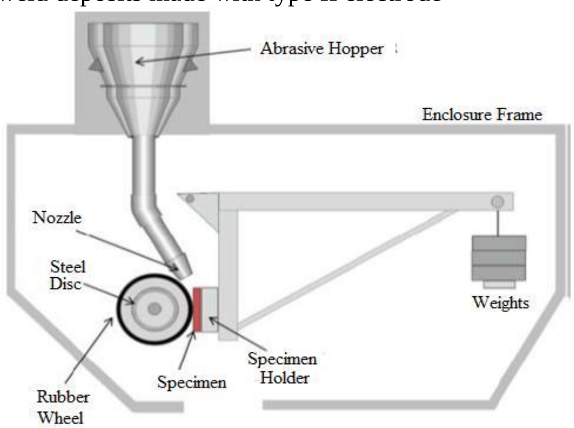

Figure 6(a): Dry Sand/Rubber Wheel Abrasion Tester

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Figure 6(b): SEM Picture of Silica Sand (200-250 µm)

Figure 7: Dry sand abrasive wear testing machine

In three-body abrasion, the sand particles behaved in one of the following ways. From free fall, the sand particles gained energy from the rubber wheel (figure 8a) and then struck the sample surface, which would result in the formation of pits. Secondly, the abrasive particles were embedded in the rubber wheel, transforming the three-body abrasion into multi-pass two-body abrasion (figure 8b). Thirdly, the particles roll at the interface causing plastic deformation to the hardfaced alloy (figure 8c). These stages are illustrated in figure 8a-8c respectively.

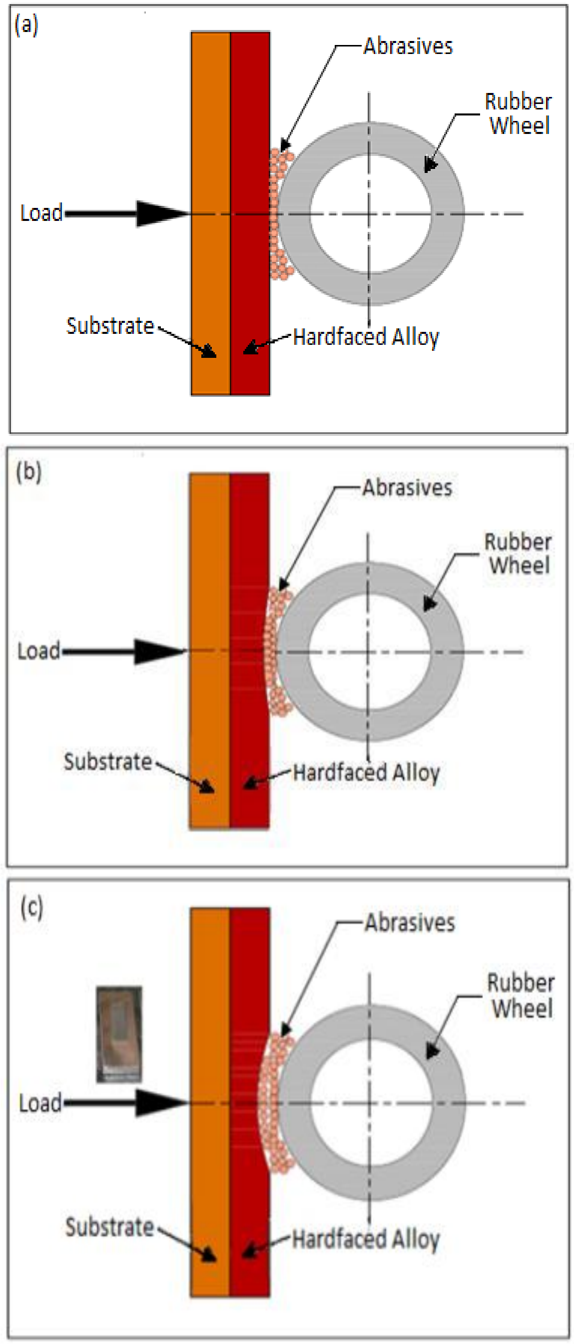

Figure 8: Stages of Abrasion: a) Initial, b) Middle and c) End of Tests

Wear is generally a complex process, which is influenced by the many system variables, such as materials properties, environment and mode of loading. In this study, two Fe-Cr-C hardfaced alloys of different composition and microstructure were investigated under three-body abrasion.

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Various researchers have been demonstrated that the application of hardfaced alloy on cast iron/mild steel significantly increases the surface hardness and results in increased resistance to abrasive wear [6-8], it has been shown in this work that the hardness of two hardfaced alloys were very different, their wear loss were dissimilar under the same test conditions. This indicates that the importance of microstructural parameters, such as the amount and size of the carbides, weld parameters, toughness and type of phases in determining the wear resistance [9-12].

The development of Fe-Cr-C hardfacings has been based around the understanding that good wear resistance is obtained with materials that have a high volume fraction of hard phases that are supported in a tough matrix. Both hardfacing 1 (type 1 electrode) and hardfacing 2 (type 2 electrode) are composed of similar phases; however, hardfacing 1 has a significantly larger amount of carbide phases than hardfacing 2.

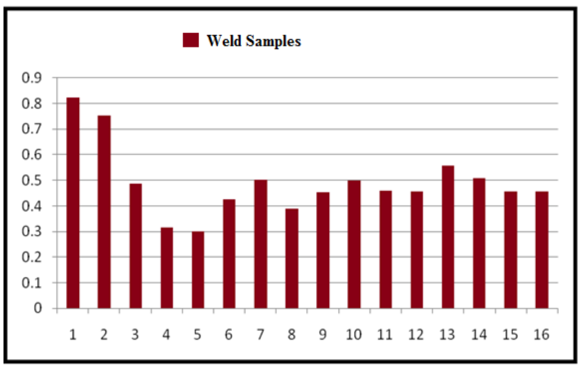

Figure 9: Wear Loss of Weld Sample 15 min

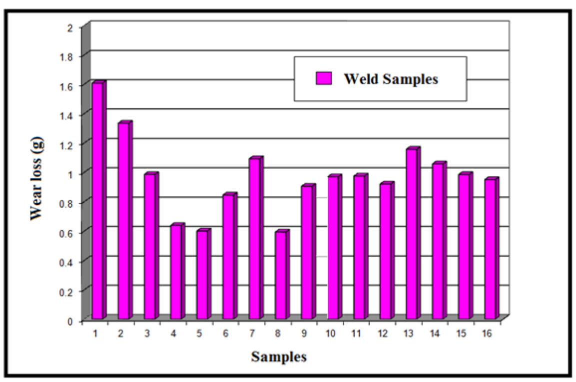

Figure 10: Wear Loss of Weld Samples 30 min

The results indicate that as hardness increases, the loss of wear decreases (figures 9 and 10). Electrode-I has less wear as compared to electrode- II as the percentage of chromium, carbon and silicon are more in electrode-I. However the composition of chromium, carbon and silicon in the weld deposit made with type-1 electrode is higher than that of weld deposit made with type-2 electrode. Higher amount of chromium [18] , carbon, silicon and finer structure resulted in higher hardness whereas lower hardness values were recorded in weld deposit with less amount of Cr, C and Si and coarser structure.

The wear resistance increases with increase in chromium, carbon and silicon present in the hardfaced alloy 1. The experimental results are in agreement with those reported [9- 11] on hardfacing alloys tested under low stress against a rubber wheel. Meanwhile, decrease in the wear resistance with decreasing chromium, carbon and silicon were observed in type 2 electrode and is in consistent with other published works. The reduction of the wear resistance with type 2 electrode could be due to the fact that the surface hardness was greatly reduced as compared to type 1 electrode. Higher hardness of samples increasing the apparent contact area allows a large number of sand particles to encounter the interface and share the stress. This, in turn, leads to a steady state or reduction in the wear rate.

The wear test results of the type 1 electrode deposited hardfaced alloy indicate that a better wear performance. In type 2 electrode deposited hardfaced alloy, the wear resistance is poor compared to those obtained for type 1 hardfacing alloys. In type 2 electrode deposited hardfaced alloys, the abrasion was simultaneously initiated on the hard and soft phases of the weld material. In this situation, soft surface was continuously exposed to the interface throughout the entire test. It can be clearly seen from figures 9 and 10 that the presence of lower chromium and silicon in the interface increases the wear rate. On the other hand, in the case of the rich chromium, and silicon, the abrasion started through contact with the hard phase.

Mechanical properties influence the abrasive wear performance of a material. When considering the properties individually, it has been found that the hardness played a main role in controlling the abrasive wear [13]. The compression strength could have a stronger influence on the abrasive wear property than the tensile strength thereby the load is applied in the form of compression thereby pressing the specimen towards the sand particles at the interface [14]. This attracted the attention to explore the possibility of a correlation between the selected

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mechanical properties and the wear loss of the hardfaced alloys.

Table 6 and 7 shows the wear loss as well as the hardness of all the samples [Electrode I and Electrode II]. From the table it can be seen that when considering the hardness alone, the wear resistance of all the hardfaced alloys tested, a better correlation was obtained in the present work. The higher the hardness, the lower was the wear loss [15]. From wear testing data under various conditions of the parameters, it can be stated that type 1 electrode deposited hardfaced alloys are more wear resistant than the type 2 electrode deposited hardfaced alloys.

The work summarizes that type 1 electrode deposited by considering optimum weld parameters i.e., current 200 Amps, travel speed of 21.3 cm/min and potential difference of 15 volts of hardfaced alloys has beneficial effect on the three- body wear as well as on the hardness, thus re-emphasizing the fact that the introduction of rich Cr, C and Si in type 1 electrode has got the advantage of enhancing the properties.

Table 6: The Relation between Hardness and Abrasion Resistance for Hardfacing 1(Electrode 1)

Sample number	Load (N)	Weight loss (g)	Hardness (HV 0.5)
1	130.5	1.6075	377
2	130.5	1.3345	318
3	130.5	0.9861	380
4	130.5	0.638	417
5	130.5	0.6007	418
6	130.5	0.8454	356
7	130.5	1.0923	537
8	130.5	0.5934	390

Table 7: The Relation between Hardness and Abrasion Resistance for Hardfacing 2(Electrode 2)

Sample number	Load (N)	Weight loss (g)	Hardness (HV 0.5)
9	130.5	0.9051	330
10	130.5	0.9698	416
11	130.5	0.9746	370
12	130.5	0.9205	406
13	130.5	1.1571	388
14	130.5	1.0576	377
15	130.5	0.9852	357
16	130.5	0.9506	401

Conclusions

Experimental investigation revealed that, weld metal chemistry & hardness have significant influence on wear property. Wear resistance increases with increase in percentage of chromium & carbon content in weld deposits and the hardness mainly depends on process parameters such as welding current, arc voltage & speed of arc travel. The analysis carried out on hardness survey of HAZ samples for every 0.5mm depth indicates that the hardness values are more on the weld surface & decrease towards the base metal & remains constant on the base metal.

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