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Effect of Co-Cr based Electrodes Coating on Hardness using Currents and using Metal Arc Welding

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Abstract: In the present study, mild steel was hardfaced using Co and Cr based electrodes at two different currents and using metal arc welding. The effect of sliding speed was studied on sliding wear. One of the mechanical property i.e. impact strength was also studied. It is observed that Hardness increases as the percentage of chromium & carbon content in weld deposits is increased and Cr hardfacing electrode having higher percentage of chromium, carbon and nickel. Overall chromium based hardfaced metal gives best results in terms of wear rate which is most accountable for degradation and erosion of metals.
Keywords: hardfaced, Co, Cr, sliding wear

I. INTRODUCTION

A lot of mechanical equipment such as the dredges service in aggressive working environment for a long time can easily cause abrasion and erosion damage and greatly shorten their service life [1]. Core components such as crushers are exposed to heavy impact and sliding wear and require efficient surface protection measures to avoid costly downtimes and to reduce costs for expensive spare parts [2]. Wear resistance against abrasion and impact are often required to extend the lifetime of machinery equipment efficiently. Wear is the degradation of metal surface, showing a continuous loss of material, due to relative motion between that main metal surface and another materials or substances whichever come in the contact with the original one. Many types of wear have been recognized such as abrasive, erosive, adhesive, corrosion, oxidation and surface fatigue wear etc. Materials contact to each other through their surfaces. Therefore, the surface and subsurface regions are affected by the interactions between two or more bodies causing wear [3]. Wear is the damage to a solid surface, generally, involving progressive loss of material due to relative motion between that surface and a contacting surface. Core components such as crushers are exposed to heavy impact wear and require efficient surface protection measures to avoid costly downtimes and to reduce costs for expensive spare parts. Wear resistance against abrasion and impact are often required to extend the lifetime of machinery equipment efficiently [4]. Various methods used for preventing the any type of wear are hardfacing and coating. Hardfacing is used to improve the wear and corrosion resistance of components exposed to severe service conditions. Thus to extend their service life, this method offers the ability to apply thick protective coatings metallurgical bonded to the substrate material. Spray Coating is more expensive than hardfacing [5]. On the other hand, hardfacing is effective and economical procedure which enhances the properties of base material to combat the abrasion wear. Several studies have been conducted for investigation of wear mechanisms and suitable material combinations for impact wear conditions typical to crushers, mixing and milling equipment. But the development in the area of hardfacing application by arc welding using different electrodes is hindered by different reasons like the lack of agreement of results obtained by different researchers [6]. Mild Steel is one of the most commonly used materials in industrial applications due to its low cost, high strength and durability but bare mild steel has higher wear rate during working in severe conditions. So, in the present work it is planned to investigate the effect of abrasion wear behaviour of hardfaced mild steel at different welding current and sliding speed.

A. Experiment

In this study, Pin-on-Disc testing method was used for characterization the wear rate for different types of hardfaced alloys. In this study, firstly the specimens were made by depositing the layers of Co and Cr based electrodes on the mild steel plate. After the deposition of the hardfaced layer on the mild steel plates, the samples are cut in equal dimensions. Before experiment, specimen pins of 10X10 mm cross section were rubbed against a hardened steel disc of surface roughness of 0.5–0.6 mm, to prepare the specimen for an even contact. The load for rubbing was same at which the experiment was conducted. Later on this rough disc was exchanged with a steel disc of En 31 hardened to 60 HRC and having Ra values in between 0.2–0.3 mm. Then pin surface is made flat such that it will support the load over its entire cross-section area of sliding end. Sliding/impact wear test is performed in the next stage in dry conditions. Before starting the experiment, pins were initially weighed after cleaning with acetone and drying. It was rubbed over the steel disc at three different speeds of 2m/s, 4m/s and 8 m/s. Later on the pin was again cleaned by same method, dried and weighed with the help of a balance with a least count of 0.01mg. The 20 N load applied in normal direction was

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constant for each experiment. All experiments were conducted two times in exactly the same manner and the precise value of weight loss was taken for calculating the specific wear rate. Some of the parameters such as increase in coefficient of friction increase in disc temperature and mark of abrasion on disc, as light colour change in disc surface and noise generation occurred during the experiment. Experimental data is given in the Table 1.

Table 1: Welding parameters for Experimentation

Electrode material	Chromium and cobalt
Welding current (amp)	150 and 180
Disc Speed (m/sec)	2,4 and 8
Disc speed (RPM)	477, 955 and 1911
Hardfacing thickness	5mm
Cross section	10x10
Load (N)	20

II. TESTING

A. *Specific Wear Rate*

There are several parameters for quantifying the wear performances of materials. Two of the widely used parameters to compare the wear performance of the materials are wear coefficient and specific wear rate. Coefficient of wear is rather irrelevant in tool wear studies since it includes a variable work piece hardness parameter. Thus, specific wear rate is more preferred. Wear rate was evaluated in terms of weight loss per unit load and per unit sliding distance. The formula to calculate specific wear rate is as follow:

$$k = \frac{\Delta m}{\rho l D}$$

Where k = specific wear rate (mm^3/ Nm)
Δm= wear volume
ρ= Density of material
l = normal load
D = Distance covered

B. *Rockwell Hardness*

Hardness is the measure of how resistant solid matter is to various kinds of permanent shape change when a compressive force is applied. Hard materials resist scratches or being worn out by friction with another body. The wear resistance of materials is directly proportional to the hardness. So it is necessary to measure the hardness values of selected steels. The Rockwell hardness tester is used to measure the hardness. The test consists in forcing an indenter of standard cone or ball into the surface of a work piece in two operations and measuring the permanent increase of depth of indentation of this indenter under specified conditions. From it Rockwell hardness is deduced. The ball is used for soft materials and cone is used for hard ones. Rockwell hardness is denoted by HRC. The hardness was measured in HRC at four different points on each specimen and the average value of hardness was taken under 100 kgf load. Fig. 1 shows the Rockwell hardness tester.

Fig. 1: Rockwell hardness testing machine

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C. Impact Testing

Impact testing is an ASTM standard method of determining the impact resistance of materials. Generally, there are two types of impact tests i.e. Izod impact test and Charpy impact test. The Izod impact test differs from the Charpy impact test in the size of the specimen and the way in which specimen are mounted. Izod test specimen has a cross sectional areas of 10 mm X 10 mm and a length of 75 mm with a 2 mm deep 45^0 notch. The notch is not provided at the centre. Specimen with a circular cross section may also be used but these are not common as square cross section. The work piece or specimen in case of Izod test is mounted vertically. The work piece acts as a cantilever beam. The Izod Impact test is carried out to determine the energy absorbed by the specimen and to calculate the toughness. This test is carried out to observe the energy absorbed by bare and Co and Cr- based welded specimen and a comparison is made to find the strength. As the toughness is inversely proportional to the hardness, so to make a relationship between toughness and hardness and to check this mechanical property of Co and Cr based welding, the test has been conducted. In this testing, a pivoting arm is raised to a specific height and then released. The arm swings down hitting the sample, breaking the workpiece. The energy absorbed by the sample is calculated from the height the arm swings to after hitting the sample.

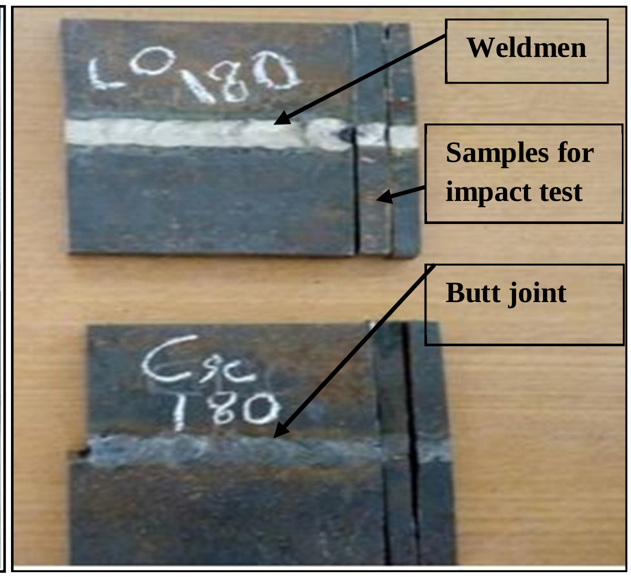

Fig. 2: (a) Impact testing machine (b) Samples for Impact test

Fig. 3: Impact test samples after test

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III. RESULTS AND DISCUSSIONS

Comparison of Mild Steel, Co and Cr based hardfaced specimens on the basis of specific wear rate at three different speeds in dry sliding conditions. Twelve experimental tests were carried out for analysis at different conditions. The influence of each parameter was carried out with the help of various plots. Optimization has been carried out by studying various plots.

A. Hardness

The hardness is plotted as a function of hardfacing at different welding current (MS- without hardfacing). For the mild steel specimen, minimum hardness number is obtained, as expected for a ductile metal. Higher hardness number is obtained for chromium based hardfacing which was coated at 180 ampere of welding current followed by cobalt based hardfacing. The hardness of the material plays an important role to resist the erosion rates of material. Increasing the hardness by adding carbon on the material is highly desired. Although, carbon will raise the brittleness, on the one hand, carbon can form carbide with a high hardness with another alloy to prevent abrasive and sliding erosion.

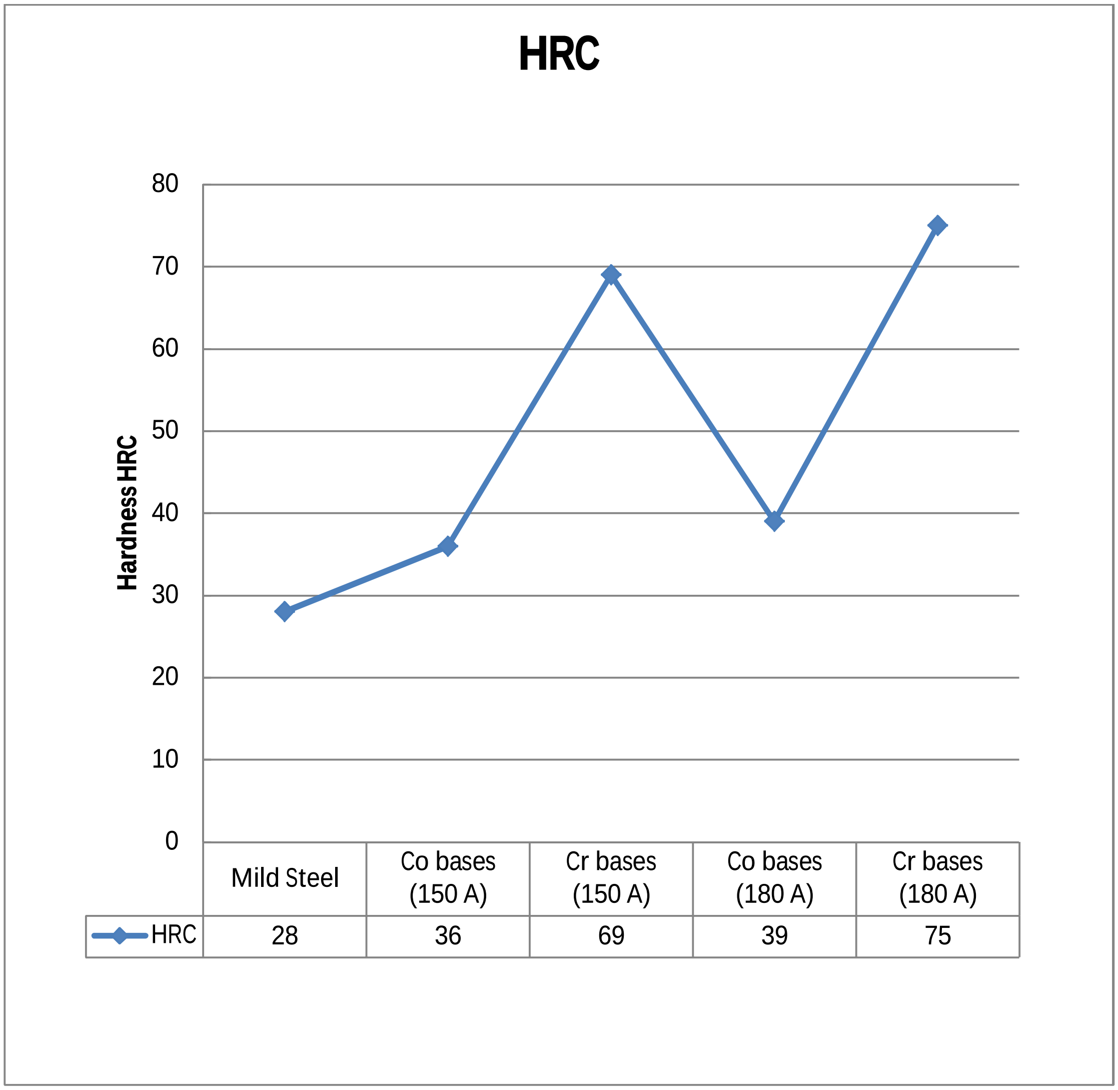

Figure 4 Hardness of base metal and hard metals

B. Weight Loss

The samples of all work pieces were cleaned thoroughly with acetone. Each sample was weighed before and after experiments using a digital balance having an accuracy of ±0.01 mg. The pins were mounted one by one for each experiment on the pin holder of the tribo-meter used for wear test. For all experiments, the sliding speeds were kept as 2 m/s, 4 m/s and 8 m/s. The weight loss of different hardfaced samples at different speeds is shown in Fig 5 and 6.

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Table 2: Weight loss of samples at different sliding speeds

Material	Speed	Initial weight (In gms)	Weight after wear (In gms)	Average weight loss (In gms)
MS	477RPM @2m/sec	36.48	36.43	0.05
	955 RPM@4m/sec.	36.3	36.22	0.08
	1911RPM @8m/sec.	37.01	36.88	0.13
Co (180amp)	477RPM @2m/sec	34.2806	34.2740	.0066
	955 RPM@4m/sec.	43.3794	43.3532	.0262
	1911RPM @8m/sec.	43.4032	43.3794	.0238
C0 (150amp)	477 RPM@2m/sec	37.4657	37.4607	.0050
	955RPM @4 m/sec	33.7753	33.7370	.0383
	1911RPM@8 m/sec	33.7370	33.7070	.0511
Cr (180amp)	477RPM@2m/sec.	34.1795	34.1762	.0033
	955RPM@4m/sec.	36.4903	36.4810	.0093
	1911RPM@8m/sec.	36.4991	36.4903	.0088
Cr (150amp)	477RPM@2m/sec.	38.0875	38.0841	.0034
	955RPM@4m/sec.	37.8667	37.8524	.0143
	1911RPM@8m/sec.	37.8999	37.8803	.0196

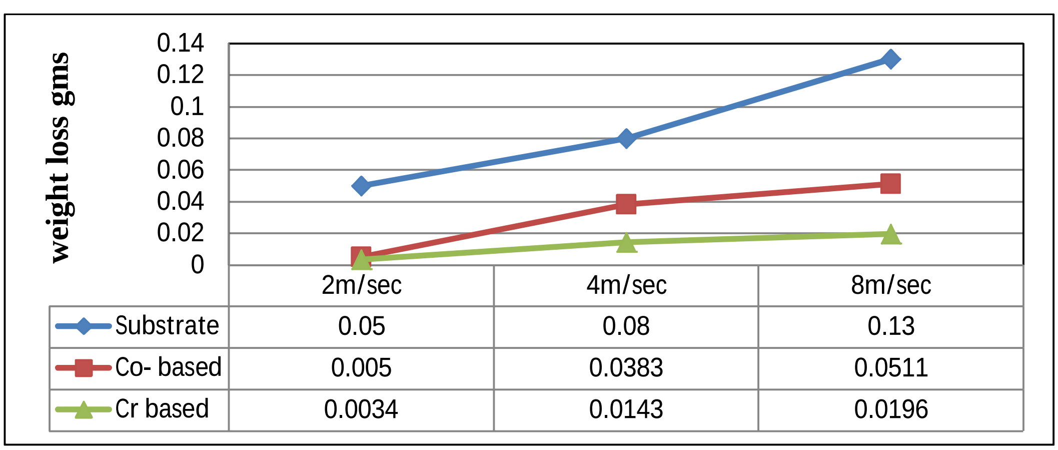

Fig. 5: Weight loss of samples hardfaced at 150-amp current at different sliding speeds

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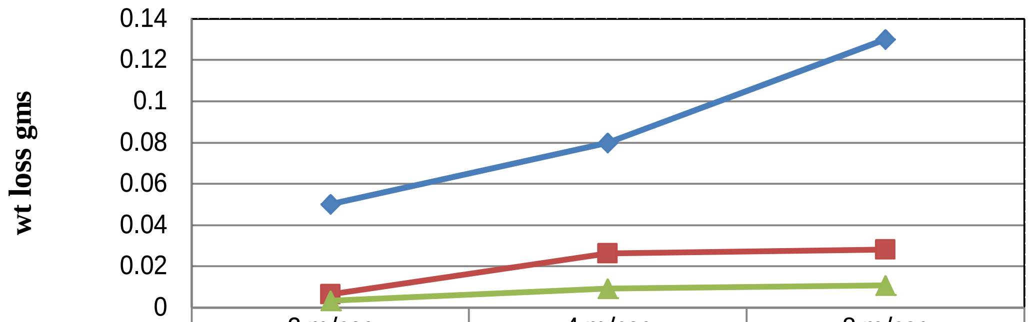
The above Fig. 5 shows the average weight loss of the specimens after the experiments at different sliding speeds. As shown in Fig 5, bare material (MS) has higher weight loss at all sliding speeds as comparison with Co-based and Cr- based hardfaced metal. In hardfacing material, the sliding wear decreases significantly or says that weight loss is decreasing as the chromium addition is increasing as compared to matrix metal. It can be attributed to the increase in hardness of the material due to the presence of hard carbide particles. Material removal in a ductile material such as mild steel is due to the indentation and ploughing/sliding action of the sliding disc which is made from hard steel material (EN31 steel disc). Such ploughing action of hard steel counterpart and improves the wear resistance. Comparing the wear properties of Co with Cr, it is observed that despite their higher hardness, Cr show improved wear resistance as compared to Co composites.



	2 m/sec	4 m/sec	8 m/sec
Substrate	0.05	0.08	0.13
Co- based	0.0066	0.0262	0.0283
Cr based	0.0033	0.0093	0.0109

Fig: 7: Weight loss of samples hardfaced at 180-amp current at different sliding speeds

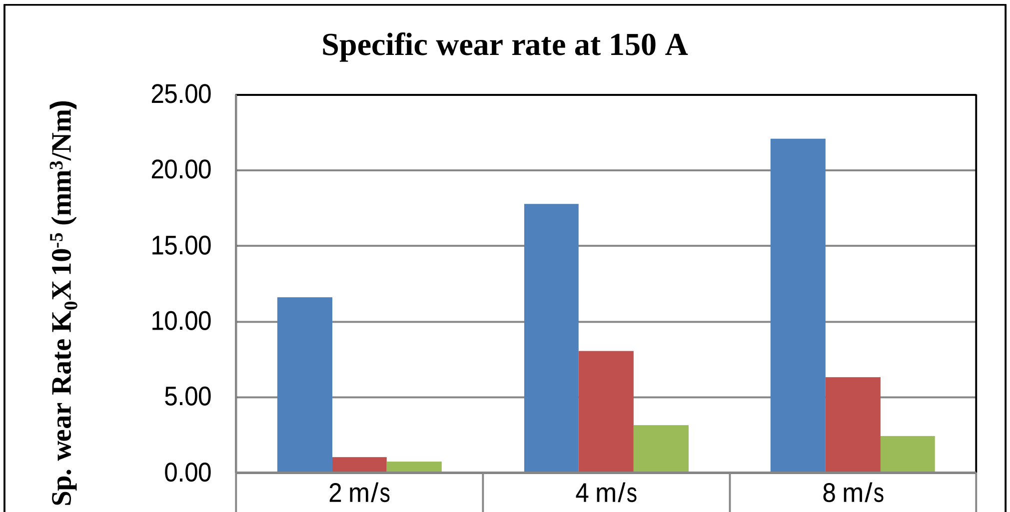
The above Fig. 7 shows the average weight loss of the specimens (which were hardfaced at 180 ampere of welding current) after the experiments at different sliding speeds. As shown in Fig. 7, bare material (MS) has higher weight loss at all sliding speeds as comparison with Co-based and Cr- based hardfaced metal.

C. Effect of Sliding Speed

As observed from Fig. 6 and Fig. 7, the weight loss increases as the speed increases in all the cases. This is due to the fact that increase in sliding speed increases the frictional forces as well as temperature of the surface, due to which the layers at the upper surface gets soften and results in increased weight loss. The time available for the heat dissipation is short and the surface temperature at the interference is significantly higher. Also, weight loss increases due to the increased sliding distance. As the speed increases, the sliding distance also increases. This increased sliding distance directly affects the weight loss. So, to reduce the weight loss the optimal speed should be used. It is due to the fact which leads to increase in wear.

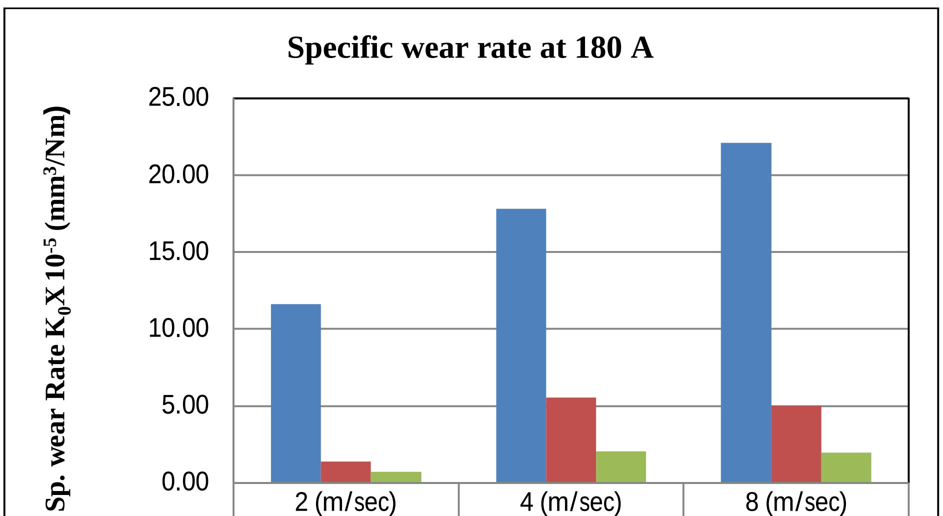
D. Wear Rate

To evaluate the sliding wear behaviour of the different hardfacing metals, it is important to regard the hardness. The hardness which is determined by both, the hardness of the matrix and the hard phases respectively, is a general measure for the wear resistance. The influence of different hardfacing electrodes (for welding current-150 amp) on the wear rate is shown in Fig. 8. The higher wear rate is observed for mild steel (base metal) as expected because of lower hardness and higher ductility. The lowest wear rate and weight loss revels for chromium electrodes hardfacing followed by cobalt base electrodes. It is found that the hardfaced specimens have positive effect in terms of wear rate at different sliding speeds. As the hardness of specimens increased after hardfacing, the wear rate decreased. It is due to hardness value for hardfacing performance is the best as a wear resistant material [1]. Metallurgical variables such as hardness, toughness, microstructure and chemical composition, are an important influence on abrasion and sliding wear as suggested by [2]. Though, the hardness of cobalt electrode is low as compared to chromium electrodes, the rate of wear is not high as expected. Not only hardness has an effect on wear but also parameters such as hardness, toughness, microstructure and chemical composition. Cr base electrode has a higher composition of carbon and nickel than other Cobalt base electrode and MS steel. As the carbon content increased, wear rate decreased. Similarly Wear rate has decreased by increasing the Carbon (C) and the Nickel (Ni) proportion in the chemical composition of the hardfacing.



	2 m/s	4 m/s	8 m/s
Mild steel	11.60	17.80	22.10
Co Hardmetal	1.05	8.08	6.33
Cr hardmetal	0.75	3.16	2.43

Fig. 8: The influence of different hardfacing electrodes on the wear rate (hardfacing at 150 A)



	2 (m/sec)	4 (m/sec)	8 (m/sec)
Mild steel	11.60	17.80	22.10
Co hardmetal	1.39	5.53	5.02
Cr hardmetal	0.73	2.06	1.95

Fig. 9: The influence of different hardfacing electrodes on the wear rate (hardfacing at 180 A)

As shown in Fig 9, the welding current for hardfacing is increased from 150 to 180 ampere. It is found that there is a significant difference in the wear of the hardfaced metals and the base metal. The lowest wear is found for the Cr electrode and the highest for the base metal (MS Steel) at all sliding speeds. These results attributed that there is no significant difference in wear ate and weight loss after changing the welding parameter i.e. welding current for hardfacing. It can also be seen that there is overall relationship between wear rate and hard metal hardness at all sliding speeds. To sum up wear rate is strongly related to hardness characteristics of the hardfaced metal but as the sliding speed is increasing wear rate is also increased for all specimens expect their hardness number. Overall chromium based hard metal gives best results in terms of wear rate which is most accountable for degradation and erosion of metals.

E. Impact Strength

The Izod impact test was done on both Co based and Cr based electrode welded mild steel specimens. The results show the effect of hardness on the impact strength of specimens. The mild steel was butt welded using two values of current. At the current of 150 ampere, the measured hardness was less than the value measured for 180 ampere. The results show that as the hardness increases, the impact strength decreases. This is due to the fact that as the hardness increases, the metals become more brittle and a brittle material has less impact strength. The maximum energy is stored by Cobalt welded specimen at 150 ampere current. This also implies that as the welding current increases, the hardness also increases.

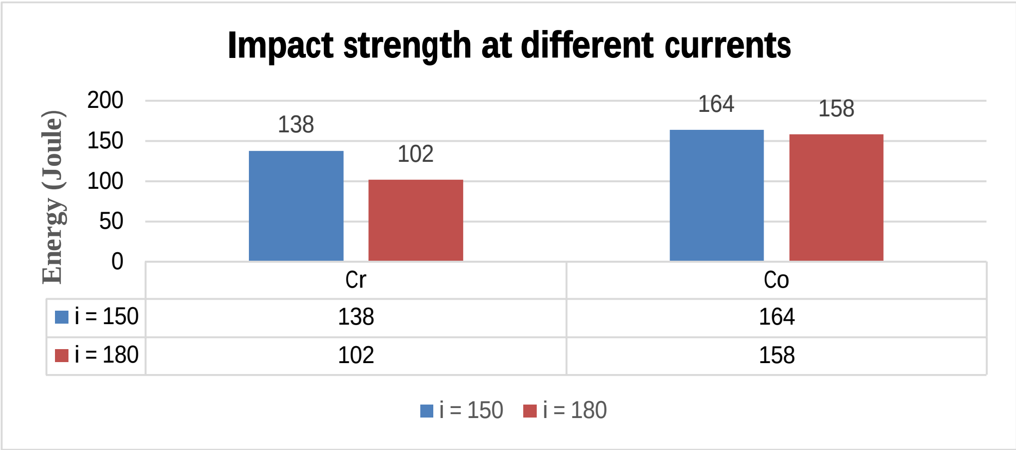


Fig. 10: Impact strength at different currents

IV. CONCLUSION

It is observed that weld metal hardness has significant influence on wear property. As expected due to lower hardness and higher ductility MS in bare condition gives worst results. Hardness increases as the percentage of chromium & carbon content in weld deposits is increased. Hardness also depends upon type of hardfacing material used and the process parameters adapted to hardfaced the material, such as welding current. Wear is low in the Chromium based hardfaced metal followed by Cobalt base hardfaced metal. This is due to the Cr hardfacing electrode having higher percentage of chromium, carbon and nickel. It is seen that at higher speed higher friction and higher heat occur in dry condition, which leads to soften the contact area of metal and leads to higher wear rate. Overall chromium based hardfaced metal gives best results in terms of wear rate which is most accountable for degradation and erosion of metals.

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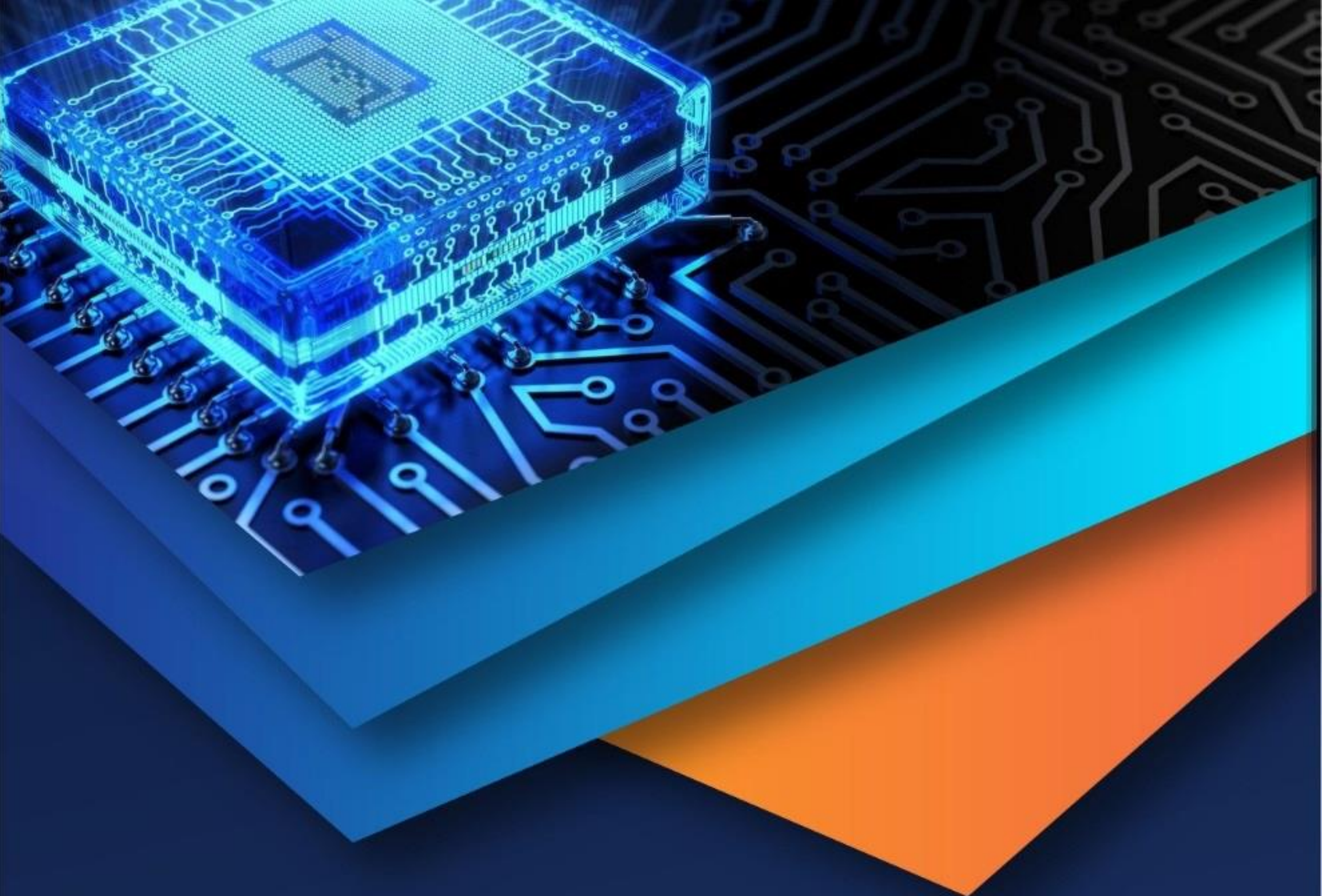

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