An experimental investigation on wear characteristics of C-45 grade steel overlay with stellite

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Abstract. Abrasive wear is of particular importance in various ground-engaging applications and the necessity of tools with high wear resistant materials has increased exponentially to extend the life span as well as to reduce the cost involved in manufacturing. This work is mainly focusing on the development of wear resistance for the aforementioned ground-engaging applications. An overlaying alloy (stellite 6) in the form of electrode form was used to coat the mild steel of grade C-45, which was used as the substrate material. The wear behaviour was characterized using a Pin-on-Disk test setup in a dry condition. A correlation between the size of overlaid material and the size of the C-45 material was observed by an optical microscope and observed that the presence of the CoCr alloy matrix significantly improves the wear resistance. The presence of the CoCr alloy matrix is found to enhance the wear resistance by reducing the rate of wear of the material. The results show that the increasing coating thickness increases the hardness of the material and the significant improvement in the wear resistance with coating.

1. Introduction
In the ground-engaging applications, the wear resistance property is of paramount importance in order for improved lifespan and low-cost manufacturing. Generally, to achieve the high wear resistance property, a variety of methods are being utilized, and the selection of one particular choice is based on the cost and the ease of manufacturing. Besides, the suitable coating material is mainly depended on the nature of the substrate, such as physical and chemical properties [1,2]. The high-cost cobalt, which is a crucial ingredient for many high wear resistance alloys, has consistently motivated the researchers to develop an alloy of similar characteristics that use comparatively low-cost materials, such as Fe or Ni. But still, Co-based alloys are commonly found in high wear resistance applications. A group of typical Co-based alloy, known as stellite, is used in places where high hardness, high corrosion resistance at elevated temperatures and high wear resistance under high pressure, are required. It has been shown that the characteristic properties of these alloys are influenced by the chemistry, microstructure and process history [3].

Among various stellite alloys, stellite 6 (Co–28, Cr–4, W–1.1C (wt.%)) is commonly used in industrial applications. It was developed in the early 1930s as one of the wear resistant CoCr alloys. It finds a lot of application potential in the field of the medical sector and manufacturing industries. Moreover, this is considered as the first-ever heat-resistant alloy that has been trailed for use in jet engines [4,5]. It has outstanding metal-to-metal sliding, galling, and cavitation wear resistance. However, it is not used in
applications where severe hard particle abrasion takes place. The surface of the alloy undergoes considerable strain hardening during the event of wear or even during machining by work hardening mechanism, and the use of appropriate machining tools and conditions is crucial to obtain the optimal outcomes. It has better resistance to thermal and mechanical shock and the optimal creep strength is obtained by a suitable thermomechanical treatment [6].

Various stellite alloys, surface-treated alloy steels, and cemented carbides have been evaluated for erosion resistance. It was found that the erosion behaviour depends primarily on the cemented carbides binder phase in the Co-rich solid solution that controls the erosion [7]. The Ni-based WC (tungsten carbides) are more resistant to erosion than the cobalt-based alloys [8–10]. The CoCr alloy matrix contains hard dispersed carbides, which strengthen and increase the hardness of the alloy. However, these carbides decrease the ductility of the alloy. The chemistry, distribution, and morphology of the carbide particles are affected by the process history, such as fabrication route, thermomechanical treatment, and thereby the mechanical characteristics of the alloy. The presence of a low-volume fraction of carbide particles in the Co-based alloy increases the corrosion and wear properties. The microstructure was known for the improved wear resistance and hardness of the coating. Further investigations demonstrate delamination wear is the dominant mechanism material removal in the coated and uncoated alloys.

The hard-facing alloy in the powder form is typically deposited using a wire using automatic gas tungsten arc welding or gas tungsten arc welding. It was attempted to correlate the wear behaviour to factors, such as chemistry, deposited hardness, and microstructure. One of the earliest wear characterizations on NOREM alloys was conducted on weld consumables in the form of powder, and castings were deposited using the plasma transfer arc welding (PTAW) method; the wire was deposited using gas tungsten arc welding (GTAW). Generally, galling wear is evaluated using a pin-on-disc geometry of the specimen. Pins and discs were hard-faced with the same alloy, typically the very common test condition [11]. Using pin-on-disc wear testing on TJR biomaterials, namely, UHMWPE articulating against cobalt-chrome (CoCr), and it was found that the geometry of the pin, number of cycles, and the applied stress level are vital factors that affect the wear behaviour of the material.

The wear behaviour of super alloy-coated stainless steel, ductile iron surface, and Ti-based alloys and other substrate materials can be found in the literature [12–14]. However, the performance of stellite coated tools steels for machining applications still lacks in the literature. In the present work, therefore, the wear behaviour of medium carbon steel (C-45) overlaid by stellite 6 using tungsten inert gas (TIG) surface processing was studied.

2. Experimental details

Stellite 6, with chemical composition adhering as shown in table 1, was coated on the substrate, mild steel of grade C-45, using the tungsten inert gas (TIG) welding technique using a MAGIC WAVE 2600 apparatus. The TIG process deposition conditions used in the present study are shown in Table 2. The substrate (30 mm length and 10mm diameter) and stellite 6 electrode (3.15mm diameter) was used as overlay material [14] in the present study. Prior to the experiment, the top surface was flattened, and contaminants were removed using acetone. The hardness of the alloy after coating was measured using a Rockwell hardness testing machine using a diamond cone indenter with a load of 150 kgf. The wear test was carried out on a set of four samples, one without coating (S0) and the other three coated samples with varying coating thickness ranging from 1 to 2 mm (S1, S1.5, S2), utilizing a pin-on-disc test setup using the ASTM G 99-95a standard 1. The measured ground surface finish of the samples was found to be 8 microns. Test parameters for the present work are as follows; speed (m/s), load (N), distance, (m), temperature (K), and ambient condition. Microstructural analysis was done on the work-out samples using an optical microscope. The software used to determine wear result is Winducom 2010. The specifications of the pin on the disk apparatus for calculating wear characteristics are shown in table 3.
Table 1. Alloy composition of stellite 6 electrode

| Elements | Co   | Cr | W  | Fe  | Si  | C   | Ni  | Mo | Others |
|----------|------|----|----|-----|-----|-----|-----|----|--------|
| (wt. %)  | Rest | 29 | 4  | 3   | <2  | 1.2 | 2   | <1 | <1     |

Table 2. Conditions of TIG overlay welding

| Experimental variable               | Value |
|-------------------------------------|-------|
| Electrode diameter (mm)             | 3.15  |
| Voltage (V)                         | 14-17 |
| Current (A)                         | 120   |
| Heat input (kJ/cm)                  | 30    |
| Travel speed (cm/min)               | 5     |
| Protective gas rate of flow (mm/min)| 15    |

Table 3. General specifications

| Parameter                | Specification                        |
|--------------------------|--------------------------------------|
| Pin Diameter             | 5 to 12 mm                            |
| Vertical Loads           | up to 10 N                            |
| Contact Stress           | up to 2 GPa (depending on materials) |
| Disk diameter            | 100 mm                                |
| Speed                    | 180 rpm to 1500 rpm                   |
| Vertical weights         | 1 to 2000 grams                       |
| Voltage                  | 120 V / 220 V                         |
| Current                  | 2 amps                                |
| Frequency                | 50 or 60 cycles                       |

3. Results and discussion

3.1. Hardness vs. coating thickness

Generally, the wear rate is directly affected by the hardness of a material. Hence, higher hardness is one of the primary criteria for an improved wear property of any material. In the present study, the Rockwell hardness test was conducted to determine the wear characteristics of a material at a load of 150 kgf using a diamond cone indenter. It can be observed that the hardness of the coated samples is higher than that of the uncoated sample, as shown in Table 4. A maximum hardness of 41.5±2.3 HRC was observed in both 1.5 mm and 2 mm thick coated samples. Whereas the uncoated samples exhibit the hardness of the substrate material, which is C-45.

Table 4. Hardness of the coated and uncoated samples

| Material condition | $S_0$ | $S_1$ | $S_{1.5}$ | $S_2$ |
|--------------------|-------|-------|-----------|-------|
| Hardness (HRC)     | $21\pm1.41$ | $36.5\pm1.2$ | $40.5\pm2.3$ | $40.5\pm2.65$ |
From Figure 1, it can be seen that the hardness of the sample increases with increasing the coating thickness exponentially to 1.5 mm and later saturates. This can be attributed to the coated material as it is harder than the matrix and thereby increasing the hardness of the sample. Since hardness is a surface property, and the indenter indent on the surface, the thickness of the coating plays a vital role in enhancing the hardness of the material. Once a critical thickness is attained during coating, the further increment in the thickness does not significantly affect the hardness as it is a surface and a subsurface property, as mentioned above.

![Plot showing the Rockwell hardness of the coated and uncoated samples at different coating thicknesses.](image)

**Figure 1.** Plot showing the Rockwell hardness of the coated and uncoated samples at different coating thicknesses.

### 3.2. Wear behaviour of coated and uncoated material

The wear resistance behaviour of coated and uncoated samples was characterized using a pin-on-disc test setup, and the weight (mass) loss after wear test was measured using a weighing machine. In the pin-on-disk wear test, the graph is plotted between time (X-axis) and wear (Y-axis). Time is calculated in terms of seconds, and wear is calculated in terms of microns. A comparison graph is obtained between the C-45 and stellite overlaid samples. It can be seen from Figures 2, 3, 4; the wear rate is varying between C-45 and overlaid samples. The wear rate with less value has greater resistance to wear. From Figures 2, 3, 4, the lower specific wear rates indicate better wear resistance. So, it can be said that samples overlaid with stellite have greater resistance to wear.
Figure 2. Comparisons of wear characteristics between C-45 and Stellite material

Figure 3. Comparisons of wear characteristics between Stellite (1mm) and Stellite (1.5mm) material
In Figure 2, the wear rate of stellite overlaid material has a low wear rate, which indicates that it has better wear resistance than C-45 material. In Figure 3, both materials are of stellite overlaid material. The wear rate of the stellite overlaid material of 1.5 mm has a low wear rate, which indicates that it has better wear resistance than stellite (1mm) material. In Figure 4, both materials are of stellite overlaid material. The wear rate of stellite overlaid material of 2 mm has a low wear rate, which indicates that it has better wear resistance than stellite (1.5mm) material. The mass of the sample before and after the wear test was measure using a precision weighing balance in order to obtain the mass loss after the test.

**Table 5.** Weights of each sample

| Material condition | Mass (g) Before test | Mass (g) After test | Mass loss (g) |
|--------------------|----------------------|---------------------|---------------|
| S0                 | 21.0321              | 21.021              | 0.0111        |
| S1                 | 21.0265              | 21.0215             | 0.005         |
| S1.5               | 21.0267              | 21.0214             | 0.0053        |
| S2                 | 21.0269              | 21.0215             | 0.0054        |
Figure 5. Mass of the sample before and after the test

![Figure 5](image)

The weight of the sample before and after the test is listed in Table 5. A maximum weight (mass) loss of 0.0111 g was observed in the uncoated sample, whereas the minimum mass loss of 0.005 g in the sample having the thickness of coating 1 mm, as shown in Figure 5. From figure 6, it can be seen that the mass loss decreases rapidly with the thickness and saturates for all the coated samples. However, all the coated samples exhibit more or less similar wear characteristics irrespective of the coating thickness. This result suggests that the critical coating thickness for the sample is less than 1 mm because the wear characteristics remain the same for all the samples that are coated above 1 mm thick.

Figure 6. Plot showing the variation in mass loss after the wear test

![Figure 6](image)
3.3. Microstructural analysis
Microstructural analysis was done using an optical microscope after wear test in order to find the alterations in the microstructure at the surface. Figure 7 (a) reveals the severe alteration of the microstructure at the surface. As the wear rate is higher for the uncoated material, the damages such as surface cracks and other bulk defects can be seen. Whereas, the coated samples, as shown in figure 7 (b, c, d), show better surface features due to the less wear at the surface.

![Optical micrographs](image)

**Figure 7.** Optical micrographs of samples (a) S0 (uncoated sample C-45) (b) S1 (coated overlaid sample with thickness 1 mm), (c) S1.5 (coated overlaid sample with thickness 1.5 mm), and (d) S2 (coated overlaid sample with thickness 2 mm)

4. Conclusions
In the present study, the wear characteristics of a medium carbon steel (C-45) was overlaid with stellite 6 with various thickness using the TIG process was studied. The hardness, wear resistance, and the microstructure of the surface layer was investigated. From the results, the following conclusions are made:

- Surface modification of C-45 steel can be done using the overlaying of stellite by the TIG surfacing process for wear resistance applications.
- The hardness of the material increases with an increase in coating thickness, and maximum hardness of 40 HRC was observed in the material with 2 mm coating.
Improved wear resistance was observed with coating, and the coating thickness beyond 1 mm does not have a significant influence on the wear behaviour.

The microstructure of the samples reveals the severe damage to the uncoated sample, whereas the coated samples show apparent features due to the high wear resistance.

5. References

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