

“Investigation of Organic Based Pack Carburizing for Mild Steel Surface Hardening”

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ABSTRACT :

Case-hardening steels are well known for their superior mechanical properties and their application. This research investigates the hardness and wear behavior of mild steel for treatments with organic compositions with agro waste additive at 950 °C. The steel specimens were packed with the mixtures, heated for 120 min, and water quenched as follows: (Case 1) sugarcane Waste bagasse, and eggshells; (Case 2) wood charcoal, and eggshells; and (case 3) Chromium-Tanned Leather waste and eggshells. The Rockwell hardness of treated samples was measured, and the wear tests were carried out using pin-on-disc and abrasive methods. It was found that the charcoal–eggshell and leather, eggshells treatments led to higher hardness and superior wear resistance due to the formation of carburization phases.

Key words: *Chromium Tanned Leather, Organic Based pack carburizing, eggshells, surface Hardness*

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I. INTRODUCTION

Mild steel finds near-universal use in manufacturing and fabrication industries because of its affordability, simple easy processing, welding, and moderately opposing mechanical properties when considered for various applications [1]. Due to its limiting bearing upon hardness and wear resistance, it would suffer poor performance in the cases of high friction, abrasion, or contact fatigue [1,2]. Therefore, surface-hardening treatments, including carburizing, carbonitriding, nitriding, and induction hardening, are exercised Designed to improve the surface qualities of mild steel while permitting a tough and ductile core [1,2]. This task has been primarily carried out by using a gaseous or liquid medium with some toxic cyanide salts, and hence, the issue of urgently searching for an environment-friendly alternative was raised [3]. Thus, the possibility of finding a safer, cheaper, and eco-friendly alternative arose. Organic Additionally, agricultural waste substances are included subjected to investigations as alternative carbonaceous substances used for Case hardening of materials.[4] used powders from eggshells and palm kernel shells for carburizing, while [5,7] considered Sugarcane Bagasse and coconut shell charcoal for mild steel carburizing. Researchers have also found that using charcoal and urea together improves nitrogen diffusion and surface hardness in mild steel during carbonitriding (Puspitasari et al., 2017) Although every one of these investigations evidently indicated some promising increases in hardness, most of them contribute to carbon enrichment (carburizing) organic waste mixtures. The research gap that arises here is that there is no systematic study of the powder-based carburizing process with both carbon-rich with eggshell(calcium carbonate) powder organic wastes under controlled conditions. Moreover, very little is known about how the different organic compositions, especially those involving , eggshell, Sugarcane Bagasse, and charcoal, Chromium-Tanned Leather waste, affect the hardness of mild steel compared to the usual, harmful process. processing times such as that encountered in stainless steel. This study is undertaken to bridge the gap by experimenting on Case hardening of mild steel in three different organic powder compositions prepared from locally available organic-waste materials. The powders were packed around the specimens in a sealed container and heated in a Muffle furnace at 950 °C for 120 minutes. In single and twin-medium summary, in so far as the project focuses, eco-friendly and low-cost interventions could enhance the mechanical behavior of mild steel. This research, therefore, stands as a fair contribution to sustainable material engineering while offering a sound response to industrial problems where the leverage of cost and resource efficiencies are of paramount importance.

1.1 Need of present work :

Agriculture is the economic base pertains to the majority of developing nations with 60% of people dependent on the sector for livelihood in India. Though mechanization lessens human drudgery and enhances productivity, the mechanization level within these nations remains low. One reason There is a shortage of cheap, durable, and quality implements, with poor awareness and demonstration of modern mechanization-related technologies. Mechanization may include not only power-operated machines or equipment but also simple implements which use animal and human power. The farm tools that are used most frequently include are ploughs, furrow openers, khurpy, and kudali. Indian agro-industries and local artisans usually manufacture such implements using easily available and cheaper materials such as are categorized as mild and low carbon steels so as to keep the price within reach of both small and big farmers.

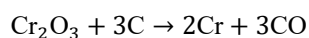
During operations in both dry and wet soil, a very small farm implement undergoes severe abrasion by stone & sand particles. Such a scratching action is a primary causes that lead to its premature wear and failure. To extend the lifespan of these tools, it's crucial to minimize wear. Unfortunately, many agro-industries struggle with this owing to restricted resources and a lack of affordable surface engineering technologies, which has hindered their ability to significantly enhance the resilience to wear and overall these steels' mechanical characteristics. While numerous researchers have tried aimed at enhancing the wear resistance of steel materials for greater durability, farm-implement steels under real soil conditions have received surprisingly little attention. This highlights a pressing need for the development of low-cost, practical methods to boost the performance of mild steels in agricultural settings. This work tackles that challenge by exploring Case hardening of mild steel through eco-friendly carburizing treatments using organic waste. The method involves heating mild steel samples packed with various agro-industrial powders—like sugarcane bagasse, Chromium-Tanned Leather waste , eggshells, charcoal, —at 950 °C 120 minutes in a sealed container. The process helps carbon seep into the surface, creating tough carbides that significantly boost hardness and wear resistance. This study not only supports improving farm tools but also has broader applications in areas that need better surface properties, like gears, springs, automotive parts, and various engineering components. Plus, using organic-waste materials makes this method sustainable, cost-effective, and perfect for both rural and industrial.

The main aim of this research is to find out those key process parameters that will make organic waste-based carburizing of mild steel, using the selected organic waste materials as alternative carbon sources, a more effective method. More specifically, this study will look into the effects of processing temperature, holding time, and the composition of the carburizing medium on surface hardness. Recent research provides evidence that organic and agricultural wastes, for instance, palm kernel shell, sugarcane bagasse, coconut shell, eggshell powders, and cassava leaves can be used as renewable carbon and nitrogen sources for the improvement of surface hardness and case depth. this study goes further than the previous one by adding the combination of wood charcoal, chromium-tanned leather waste, sugarcane bagasse, and eggshell powder in different proportions, to the concept of sustainability. Moreover, the natural energizer role of the calcium carbonate-rich eggshell powder will be scrutinized in terms of its effect on carbon diffusion kinetics and surface layer development. The overall goal is to create an eco-friendly, cost-effective, and technically viable surface-hardening route that enhances the mechanical performance of mild steel without the use of toxic or conventional carburizing agents.

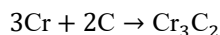
1.2 Decomposition of chromium tanned leather:

At a controlled temperature of around 950 °C along with very slow ventilation, the chromium tanned leather in a stainless steel container undergoes a series of pyrolysis and carbothermic reduction reactions. The process begins at 200–500 °C where the leather's organic parts, mainly collagen fibers and tanning additives, are thermally decomposed. This produces volatile gases such as CO₂, CO, CH₄, and NH₃ . . . and at the same time, leaves behind a char of carbon. During this process, the chromium that was originally present as tanning compounds begins to oxidize and change into chromium(III) oxide (Cr₂O₃) through a combination of dehydroxylation and oxidation. The green-colored Cr₂O₃ is very stable at high temperatures and thus becomes the main solid phase embedded in the carbonaceous matrix.

When the temperature equals 500 °C and higher, the remaining carbon (or char) acts as a reducer in low oxygen (slow-ventilation) conditions, thus facilitating the carbothermic reduction of Cr₂O₃ according to the following reaction:

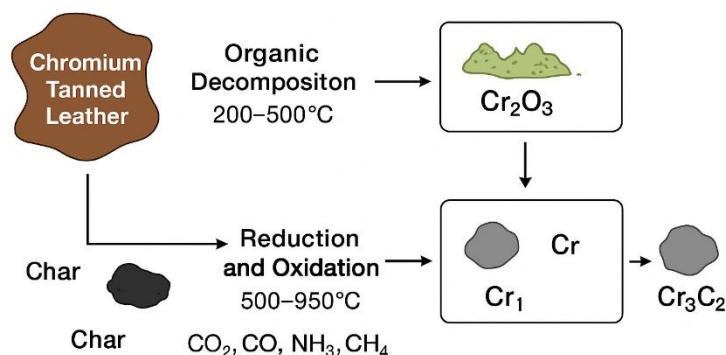


The process of reduction usually starts near 740–800 °C and gradually increases with the system reaching 950 °C, cutting down to half mainly under the influence of reducing gases like CO, CH₄, and H₂ that are produced during pyrolysis [16,17]. At this high-temperature and carbon-rich condition, the metallic chromium (Cr) produced from the reduction of Cr₂O₃ may continue to react with carbon and produce short-chained chromium carbides mainly Cr₃C₂ through solid-state reactions like:



Chromium-Tanned Leather

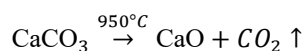
Heated in Stainless Steel at 950°C with Slow Ventilation



[17,18] Under strict control of the temperature, which is approximately 950 °C, and with extremely slow air circulation, the chromium leather tanning process in a stainless steel container was subjected to a series of reactions involving pyrolysis and carbothermic reduction. The thermal treatment starts at 200–500 °C, where the organic components of the leather mostly composed of collagen fibers and tanning agents are subjected to thermal degradation. This results in the formation of volatile gases like CO_2 , CO , CH_4 , and NH_3 . . . and, concurrently, carbon remains in the form of a char. The chromium originally present in the form of tanning compounds is gradually oxidized and converted to chromium(III) oxide (Cr_2O_3) through the combined processes of dehydroxylation and oxidation. The greenish-colored Cr_2O_3 is very high-temperature stable and thus ends up as the main solid phase that is intertwined with the carbon-bearing matrix.

1.3 Decompose of Eggshells Powder:

When heating eggshells in a slow-ventilated stainless steel container at a temperature of 950 °C, calcium carbonate (CaCO_3) which is the main element to, continues the process of thermal decomposition to produce calcium oxide (CaO) with the release of carbon dioxide (CO_2) gas:



The slow ventilation provides a controlled release of CO_2 which prevents the rapid oxidation of the eggshell particles as well as their spattering. The produced calcium oxide has a high reactivity and can either be used as a flux or energizer in surface hardening treatments, hence better diffusion of carbon when applied in organic-based carburizing processes.

II. MATERIAL AND METHODS

Mild steel specimens were procured locally and machined into blocks of 40 mm × 40 mm × 10 mm to ensure uniformity for both wear and hardness evaluations. The chemical composition of the steel is listed in Table 1

Table: 1 chemical composition of mild steel

C	Si	Mn	P	Cr	Ni	Cu	Al	Mo	S	Fe	Element
0.13%	0.03%	0.5%	0.03%	0.2%	0.2%	0.09%	0.02%	0.02%	0.02%	Balance	%

The selected dimensions allowed for consistent penetration during Rockwell hardness test measurements and reliable contact during the abrasive wear testing.

Organic materials such as wood charcoal, sugarcane bagasse, chromium-tanned leather waste, and eggshell powder were used to modify the surface as a source of carbon. Charcoal was crushed and sieved to –52 mesh, while the other organic materials were dried, finely milled and homogenized to distribute the material thoroughly

and facilitate effective diffusion of carbon during thermal treatment.

Surface hardening process was done through pack carburizing with three different compositions: Case 1 (sugarcane bagasse 80% + eggshell 20%), Case 2 (charcoal 70% + eggshell 30%), and Case 3 (chromium-tanned leather waste 70% + eggshell 30%). Each mixture was prepared together with the mild steel specimens placed in stainless steel containers with small ventilation openings. The containers were heated in a muffle furnace at 950 °C for 120 min to achieve uniform heat distribution and controlled thermal exposure. After the heat treatment, the specimens were cooled in water immediately to maintain the surface microstructure developed during the process.

The performance of the wear was determined using a Pin-on-Disc device for applying loads between 14.7 to 19.6 N while keeping the disc speed at 300 rpm for a total sliding of 300s. The wear volume, sliding distance, wear rate, and wear resistance were determined as per the weight loss of the specimens, considering the density of mild steel as 7.85 g/cm³. Hardness determinations were made with a Rockwell Hardness Testing Machine on the HRC scale according to ASTM E18, using a Brale diamond indenter of 120° applied under a 10 kg minor load followed by a 150 kg major load, and the hardness values were recorded after the load was removed.

Microstructural characterization was performed by means of optical microscopy. The specimens were sectioned and then ground, in a sequence, with the use of emery papers of 320–1200 grit, polished with the 1 µm and 0.5 µm alumina suspensions and finally etched in 2% Nital solution for 5–10 s. The micrographs were taken for evaluating carbides and martensitic structures, and for comparing the surface chromium carbide and treated versus untreated specimens.

III. RESULT AND DISCUSSION

“The results indicate that using organic-based pack carburizing significantly boosts the surface hardness and wear resistance of mild steel when compared to untreated samples. Among the different mixtures tested, the combination of charcoal and eggshell, as well as leather and eggshell, showed higher hardness values than the sugarcane bagasse and eggshell mix, all within the same treatment time. These findings align with previous research that utilized chemical energizers like barium carbonate, but they also highlight that eco-friendly waste materials can achieve similar results without any toxic effects. The broader implications of these findings will be explored in the next section, which will lead to conclusions and recommendations for future research”

Different types of specimen of mild steels were carburized under carbonaceous at 950 degree celsius; they were then subjected to various kinds of test, such as abrasive wear test, hardness test, and microstructure examination. The outcomes of the abrasive wear test of the samples as received for different loads (i.e. 14.7N, 19.6 N) are recorded in Tables 2 and 3, as well as the findings from the Rockwell hardness test at 150-kg load in Table 4; the microstructures are examined using an optical microscope and are displayed in Figure 5 and 6. All these are composition without toxic chemical. The application impact shows that this treatment enables mild steel to resist wear when used as a moving part in machines [8,9] The carbon potential of charcoal, Chromium-Tanned Leather& Sugarcane Bagasse which supplied carbon to create the case appears favorable since carburization occurred. Multiple researchers have investigated this phenomenon [9,10]. The energizers achieve this by elevating the carbon potential within the carburizing composition. Multiple researchers together with authors have proposed this mechanism of energizers during carburizing processing [6,8,11].

3.1 Results of abrasive wear test:

The abrasive wear of mild steels, carburized at a fixed temperature of 950 °C is shown in Tables 2-3. Weight loss with respect to hardness for these steels has been represented in Fig 2 Generally speaking, abrasive Loss of weight for everyone treated steels decreases as hardness increases and depends upon the surface treatment method employed.

Table: 2 Wear Test results at 14.7 N (Load)

Case	Weight loss (g)	Wear Volume (cm ³ ×10 ⁻²)	Wear Rate (cm ² ×10 ⁻⁷)	Wear Resistance (cm ⁻² ×10 ⁷)
Untreated	0.208	2.65	3.87	2.58
Case 1	0.206	2.62	3.83	2.61
Case 2	0.107	1.36	1.99	5.03
Case 3	0.180	2.29	3.35	2.99

Table: 3 Wear Test Results at 19.4 N (Load)

Case	Weight loss (g)	Wear volume ($\text{cm}^3 \times 10^{-2}$)	Wear rate ($\text{cm}^2 \times 10^{-7}$)	Wear resistance ($\text{cm}^{-2} \times 10^6$)
Untreated	0.220	2.80	4.09	2.44
Case 1	0.219	2.79	4.08	2.45
Case 2	0.112	1.43	2.09	4.78
Case 3	0.197	2.51	3.67	2.72

Thus, the following may be drawn from the abrasive wear test results:

1. Incipient weight loss during abrasion is most in untreated steel, whereas minimum for carburizing steel at 950 °C.
2. By comparison among the treated steels (carburized), abrasive weight loss is highest in Case 1 (sugarcane bagasse + eggshell), whereas Cases 2 and 3 (wood charcoal + eggshell, Chromium-Tanned Leather + Eggshell) exhibit much less weight loss due to higher hardness obtained during carburizing.
3. The abrasion test was performed at two different loads, i.e., 14.7 N and 19.6 N. It is observed that, as shown in Fig. 2, the weight loss due to abrasion increases with the increase in applied load and is maximum at 19.6 N and minimum at 14.7 N.
4. The wear rate is at a maximum for the uncarburized mild steel and decreases as the hardness increases for the treated steels. Cases Two and three shows the least wear rates due to The high degree of hardness of the surface layer.
5. Wear rate is load-dependent and gets up as load increases; the peak wear was recorded at 19.6 N while the least occurred at 14.7 N (see Fig 3).
6. The highest wear resistance is attributed to the carburizing mild steel at 950 °C and the lowest wear resistance to that against uncarburized mild steel. Again between different treated steels, Cases 2 and 3 have relatively high wear resistance, whereas Case 1 fares lower in resistance levels (Fig. 4).
7. Taken together, the results indicate that carburizing at 950 °C produces the greatest enhancement in resistance to wear, with Cases 2 and 3 attaining the highest hardness and lowest weight loss, and wear rates. Though treated, Case 1 still loses more weight due to its low hardness.

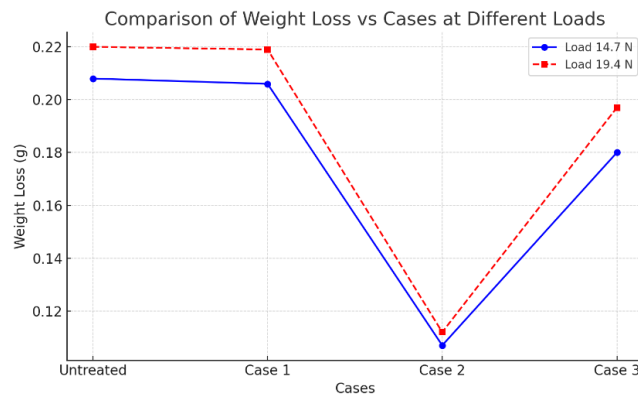


Figure: 2 Comparison between Weight loss VS cases for the two different loads of 14.7 N, 19.4 N

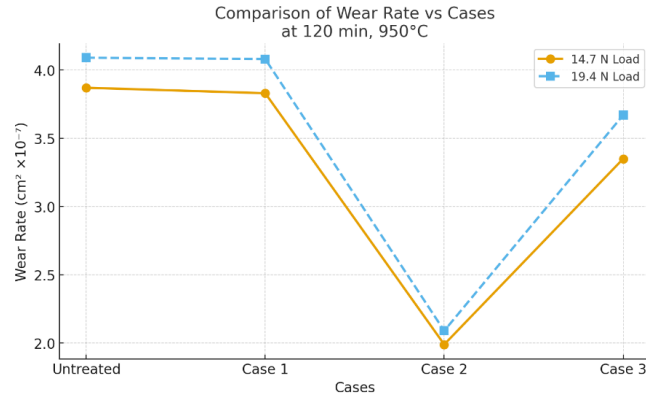


Figure:3 Comparison between wear rate VS cases for the two different loads of 14.7 N, 19.4 N

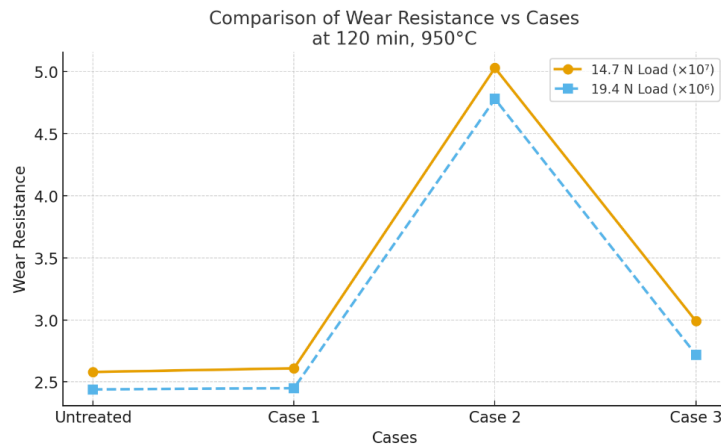


Figure: 4 Comparison between wear resistances VS cases for the two different loads of 14.7 N, 19.4 N

3.2 Results of Hardness test:

1. The tests were conducted at 950 °C for all three scenarios, 120 minutes with different organic mixtures.
2. Our carbonizing agents came from organic-waste materials (sugarcane bagasse, eggshell, charcoal, Chromium-Tanned Leather waste), making the process eco-friendly and sustainable as against the conventional chemical toxic carburizers.

The results in Table: 4 clearly reveal that:

Table: 4 Results of Hardness Tests on Various Mixtures

Case	Mixture	Hardness Reading 1 (HRC)	Hardness Reading 2 (HRC)	Hardness Reading 3 (HRC)	Average Hardness (HRC)
0	untreted	10.0	12.0	11.5	11.2
1	Sugarcane Bagasse + Eggshell	17.5	18.0	18.5	18.0
2	Charcoal + Eggshell	49.8	50.1	50.4	50.1
3	Leather + Eggshell	32.8	33.0	33.2	33.0

1. Case 1 (Sugarcane Bagasse + Eggshell) had a much lower hardness of 18 HRC, indicating weak carbon release at the given temperature and holding time. Slightly bigger than wood charcoal particles, sugarcane bagasse holds less carbon, thereby causing a severe drop in hardness.
2. Case 2 (Wood Charcoal + Eggshell), by contrast, achieved the highest hardness of 50.1 HRC under similar conditions of treatment (950 °C for 120 minutes). This highest hardness value was attributed to the fine particle size (–52 mesh) of wood charcoal, permitting rapid release of carbon.

In contrast, Case 3 (Chromium Tanned Leather + Eggshell) yielded an intermediate hardness of 33.0 HRC in the same conditions by virtue of the fact that raw leather decomposes slower and releases carbon less efficiently and minor trace of chromium oxide and chromium carbide than charcoal. and 3 (Leather Charcoal + Eggshell) achieved much higher hardness values (~33 HRC) within the same duration.

Hence, this indicates that mixtures of Cases 2 and 3 are more reactive, thereby ensuring rapid carbon diffusion in the mild steel surface.

3. However, the hardness measured in Case 3 (Chromium Tanned Leather + Eggshell) was around 33 HRC, which is below the typical hardening range prescribed for industrial applications such as gears, shafts, or any other components subjected to wear (50-60 HRC). On the other hand, Case 2 (Wood Charcoal + Eggshell) recorded an HRC value of 50.1, the recommended range for industry, and demonstrating its better efficiency as a carburizing medium.
4. For Case 3 (Chromium Tanned Leather + eggshell), practical application hardness and case depth would be acquired after a long holding time. More chromium carbide atoms could diffuse into the surface with longer exposure time, increasing hardness and consequently improving wear resistance from the present ~33 HRC.
5. In Case 1 (Sugarcane Bagasse + Eggshell), which yielded only 18 HRC, the material source is considered weak in its carbonating action. This material would probably need to be altered or blended with sources of high fixed carbon such as wood charcoal or subjected to extended heat treatment to improve its performance in carbon release and surface hardening.
6. Therefore, while The current study yields encouraging findings. using eco-friendly organic based carburizing agents, it also highlights that the process is time-consuming compared to conventional industrial methods.
7. In conclusion, this approach is environmentally sustainable and can replace harmful chemicals, but requires longer treatment durations to achieve application-level hardness.

3.3 Result of microstructure of mild steel:

The microstructure analysis of treated sample reveals hard carbide formations which emerged during the 950°C thermal cycle as presented in Figure 5 and Figure 6. The untreated sample maintains its original ferrite pearlite microstructure without any modifications thereby proving that the hardness changes are caused by the applied treatment.

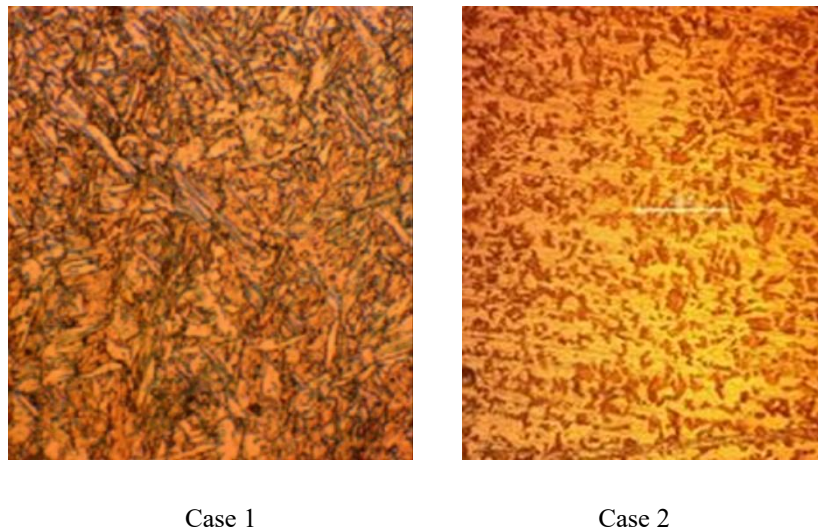


Figure 5: Microstructure of carburizing mild steel Case2 and 3 with dark phase of martensite and varying degree of carbide indicating increases carbon content at the surfaces (2% nital etched solution)100X

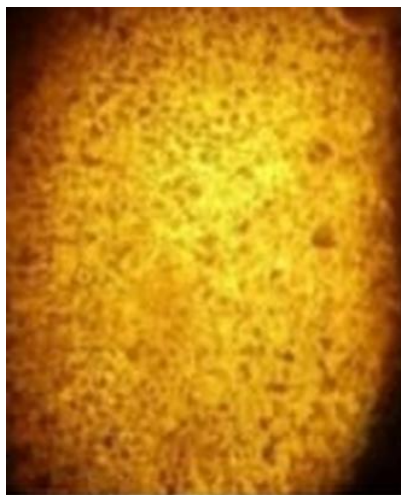


Figure 6 : Microstructure of untreated mild steel showing no dark phase of martensite indicating the ferrite and pearlite microstructure content at the surface (etched with 2% nital solution)100X

3.4 Weight Loss Effect of Different Carburizing on Mild Steel at 950°C

Variations observed in the weight loss due to abrasion under the same carburization temperature of 950 °C but with three different organic with agro-waste additive mixtures are tabulated in Tables 2-3 and shown graphically in Figs. 2 & 3. It was observed that, in general, abrasion weight loss is lowest for specimens carburized using Case 2 (Charcoal + Eggshell) and Case 3 (Leather waste + Eggshell), while Case 1 (Sugarcane Bagasse + Eggshell) and untreated specimens showed relatively higher weight loss.

The weight loss decrease in Cases 2 and 3 observed could be due to the higher hardness these mixtures imparted within the holding time of 120 minutes, thereby increasing wear resistance. Cases 1 needed a longer treatment for attaining similar hardness and diffusion depth, since sugarcane bagasse was less reactive and decomposed slower than the charcoal or leather-based carbon.

Hence even at a fixed carburizing temperature of 950 °C, the kind of organic mixture plays a vital role in figuring out the hardness and wear resistance characteristics of the carburized mild steel. Cases 2 and 3

3.5 Force applied and weight loss of the carburized mild steels:

The abrasive-wear test is run for two different normal forces, 14.7 and 19.4 N, for carburized mild steels, and the results are listed in the Table 2 - 3. It is perceived that the weight loss due to abrasion clearly in figuring out the rises with the rise in the applied load, being maximum at the applied load of 19.4 N and minimum at the applied load of 14.7 N. The observations indicate that weight loss due to abrasion increased with the applied load. This is because, as the normal force increases, the transition friction increases, which causes a resultant weight loss. A comparative graph showing the weight loss due to abrasion with two Additionally, various loads have been shown in Fig 2 which indicates that the weight loss due to abrasion is highest for the load curve of 19.4 N and lies above the other curve.

3.6 Effect of Hardness on Weight Loss Carburized Mild Steels

In **Case 1 (Sugarcane Bagasse + Eggshell)**, the average surface hardness obtained was approximately **18 HRC**, representing the lowest value among the three conditions. The corresponding weight loss was comparatively high, primarily due to the low fixed-carbon content in sugarcane bagasse. This resulted in a limited carbon diffusion depth and a weaker hardened case. The organic precursor required prolonged heat treatment to develop significant hardness, making it less suitable for industrial carburizing applications where shorter cycle times are preferred.

In **Case 2 (Charcoal + Eggshell)**, the surface hardness improved substantially to **50.1 HRC**, nearly twice that of Case 1. This considerable increase in hardness led to a marked reduction in weight loss during abrasion testing, indicating enhanced wear resistance. The presence of stable carbon from charcoal provided a consistent carbon potential, facilitating effective carburization and case formation. Thus, this mixture demonstrated the most efficient hardening behavior among the three organic formulations.

In **Case 3 (Chromium-Tanned Leather + Eggshell)**, the measured hardness was **33 HRC**, which, although higher than that of Case 1, remained lower than Case 2. The partial improvement is attributed to the formation of chromium carbides during the decomposition of chromium-tanned leather. However, due to the relatively short treatment duration of **120 minutes** and limited carbon monoxide generation under slow-ventilation conditions,

the carburizing reaction was incomplete. Consequently, the hardness was moderate, and the wear resistance was inferior compared to the charcoal-based case. Prolonged exposure or optimized ventilation may enhance chromium carbide formation and improve hardening efficiency in future studies.

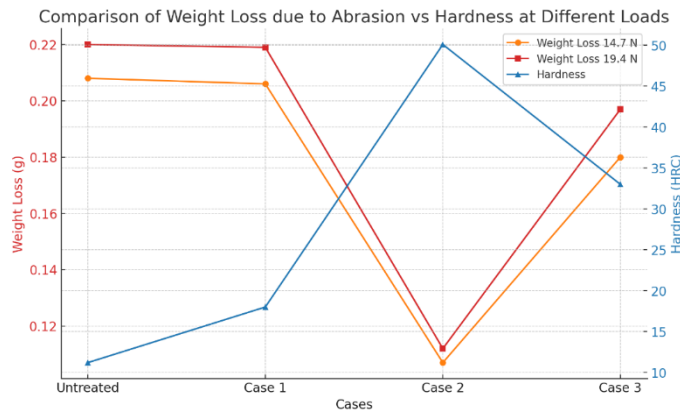


Figure: 7 comparison of weight loss due to abrasion VS hardness for the two different loads of 14.7 N, 19.4 N

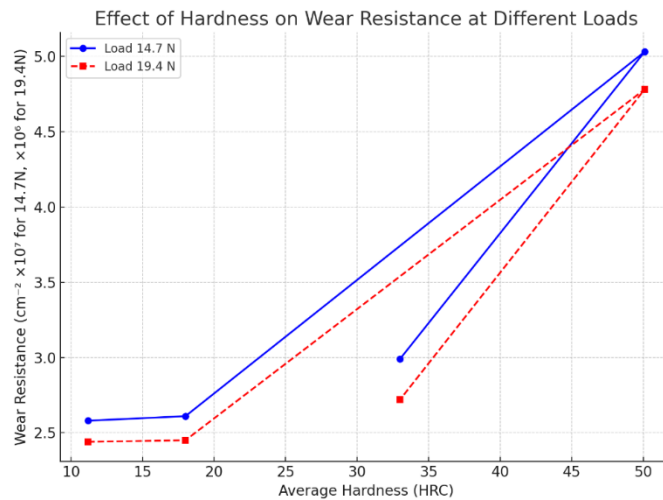


Figure: 8 Effect of Hardness VS Wear resistance for the two different loads of 14.7 N, 19.4 N

Conclusion

The present study on the “INVESTIGATION OF ORGANIC BASED PACK CARBURIZING FOR MILD STEEL SURFACE HARDENING ” has led to the following observations:

1. The type of organic and agro-waste additive mixture employed in the carburizing treatment at a fixed temperature of 950 °C was found to strongly affect the hardness and wear properties of mild steel.
2. In comparison to untreated steel, carburizing, and water quenching treatments raised the surface hardness and wear resistance of mild steel appreciably.
3. An increase in load induces an increase in weight loss, wear volume, and wear rate, thereby proving that abrasive wear is load-dependent.
4. Whereas Cases 2 impart hardness values as high as 50.1 HRC and hence lower weight loss, Case 1 imparts lower hardness values of around 18 HRC and higher weight loss.
5. This poor performance of Case 1 is because of the low content of fixed carbon in sugarcane bagasse that requires longer treatment times and hence is not appropriate for industrial use.
6. In contrast, Cases 2 and 3 provided excellent hardness and wear resistance in the first 120 minutes and, therefore, proved to be ecofriendly, sustainable, and industrially acceptable alternatives in Case hardening of mild steel.

7. The results validate that with increasing hardness, such as in Cases 2 and 3, the wear resistance increases, conversely weight loss, wear rate, and wear volume decrease.
8. Finally, it can be stated that organic and agro-waste additive, mainly charcoal and the mixtures based on leather, can be efficiently used as alternatives to conventional carburizing agents in enhancing the mechanical and wear properties of mild steel at 950 °C.

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