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A Review on Wear Performance and Economic Evaluation of Hardfaced Ploughshare Blades

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Abstract **- Wear and tear of machinery is a common challenge across all industrial sectors. Still, agricultural and earth-engaging equipment often requires more frequent replacements and increased operating costs due to significant wear. Conventionally, farmers replace worn-out cultivator blades with new ones. The worn-out blades are discarded as scrap, which recovers only limited economic value. Although various factors—including operational practices, soil types, and substrate materials—affect the wear rate of these blades, the hardness of the substrate material is particularly crucial in reducing wear. It is widely reported that hardfacing is an effective surface modification method to enhance the wear resistance and service life of agricultural tools. The present paper focuses on a review of wear resistance analysis of iron-based hardfacings. In addition, an economic evaluation based on cost per functional life is discussed using the typical cost of a bare blade and the hardfaced blade. The study concluded that hardfacing is a cost-effective approach and a sustainable alternative to blade replacement for agricultural equipment.**

Keywords - Hardfacing, Ploughshare blade, Abrasive wear, Economic evaluation, Iron-based hardfacing, Sustainable engineering.

INTRODUCTION

Agricultural tillage operation is an important practice to improve the soil qualities and increase crop productivity. Ploughshare blades are among the most critical components in the tillage operations. During tillage operations, the ploughshare blades are subjected to severe abrasive wear from continuous contact with hard soil particles, stones, and other hard inclusions. This leads to a significant loss of material from the surface and changes the working edge geometry of the ploughshare blades [1–6]. As a result, the efficiency of the ploughshare blades gets reduced and needs to be replaced frequently with new ones [7–9]. This increases the production cost and leads to downtime [10,11]. Generally, low or medium-alloy steel is used to manufacture tillage blades, but these grades of material do not have a sustainable life in soil conditions [12,13]. The farmers prefer to replace the worn-out ploughshare blades with new blades and sell the discarded blades as scrap, which increases the cost of tillage operations and reduces the life cycle of the blades. However, this approach results in high operating costs for low and medium-scale farmers. Moreover, the scrap blade recovers only the base metal value of the blade, while the manufacturing cost, which includes manufacturing energy, forming, casting, and heat treatment are lost. The National Agricultural Statistics Service of the USA reported that the annual replacement cost of agricultural equipment due to wear and corrosion is approximately $15 billion per year [14]. Although various approaches are used to mitigate the ploughshare blades' wear-related issues, hardfacing is widely adopted as a surface engineering technique to improve the surface properties subjected to abrasive wear. In agricultural applications, hardfacing has shown promising results in extending the service life of the tillage blades by depositing the hard wear-resistant alloys on the critical wear parts of the blades. However, various hardfacing alloys are employed on the blade surface, but iron-based hardfacings are easily available and economical. The novelty of this review lies in combining the reported wear performance of iron-based hardfaced ploughshare blades with a practical economic comparison relevant to Indian agricultural conditions. Although many studies focus on wear behaviour, this paper highlights cost per service life (Rs/ha) as a key decision parameter for determining whether blade replacement or hardfaced blades are economically preferable. The economic comparison presented in this review is based on typical cost and service life values reported in literature and field practice [10,15,16]. Actual performance may vary depending on soil conditions, operating parameters, and hardfacing procedure. Therefore, the results should be interpreted as indicative trends rather than absolute values.

2. METHODOLOGY

Over the past two decades (approximately 2005–2026), relevant literature was systematically surveyed from peer-reviewed sources. Most of the published studies have primarily focused on improving wear resistance by depositing hard alloys on the substrate material to extend blade life. However, comparatively limited attention has been given to the economic feasibility of hardfacing in agricultural applications. In this context, the present study not only reviews the metallurgical and performance aspects of hardfacing but also evaluates whether the process is economically justified for tillage blades. Relevant research articles and experimental studies were critically analysed to extract data on service life improvement, alloy composition, and microstructural characteristics. For the economic analysis, data were collected from published literature and local market surveys to estimate the cost of new blades, hardfacing materials, and labour charges. These cost values were compared with the increase in service life reported in earlier studies. A simple cost per hectare service life comparison was

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used to evaluate the economic benefit of hardfaced blades over conventional blades. Based on this analysis, the review examines whether hardfacing is technically useful and also cost-effective for tillage applications.

The following key aspects are covered in this review:

1. Hardfacing processes
2. Hardfacing techniques
3. Hardfacing alloys
4. Role of microstructure and carbide fraction in wear resistance
5. Performance evaluation under laboratory and field conditions
6. Economic evaluation of new and hardfaced ploughshare blades

3.1 Hardfacing Process

As reported [17] hardfacing involves the deposition of a superior wear-resistant alloy layer onto the surface of the component, as schematically illustrated in Figure 1. The major objective of hardfacing is to reduce the replacement cost and extend the service life of the equipment [18,19]. Previous studies have reported that surface properties such as hardness, wear, and corrosion resistance can be improved by the hardfacing method [20,21]. Furthermore, the worn-out parts can be rebuilt using the hardfacing technique, extending the equipment's life by two or three times [22]. Another study reported that hardfacing is a versatile and economical method to control the wear problem [11].

3.2 Hardfacing Depositing Techniques

Hardfacing can be deposited by different techniques, namely welding, spraying, and cladding [23]. Hardfacing can be overlaid on the surface by both conventional and non-conventional methods. But the researcher considered gas metal arc welding (GMAW), tungsten inert gas welding (TIG), laser beam welding (LBW), plasma transferred arc welding (PTAW), flux core arc welding (FCAW), and shielded metal arc welding (SMAW) as suitable hardfacing techniques to overlay the substrate [11,22,24]. Shielded Metal Arc Welding (SMAW) is the most commonly used process for hardfacing ploughshare blades. This process is simple, cost-effective, and suitable for both workshop and field repairs [25] . Other processes, such as Flux-Cored Arc Welding (FCAW) and Gas Metal Arc Welding (GMAW), have also been reported in literature, but their use is limited in rural agricultural settings due to higher equipment costs. The hardfacing technique is critical for increasing wear resistance. A comparative investigation of hardfacing processes using Shielded Metal Arc Welding (SMAW) **and** Flux-Cored Arc Welding (FCAW**)** reported that SMAW is a more economical and operationally reliable technique than FCAW under similar working conditions [26].

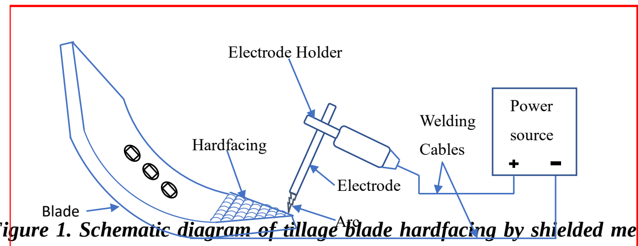

Figure 1. Schematic diagram of tillage blade hardfacing by shielded metal arc welding.

3.3 Iron-based hardfacing alloys and the effect of chromium content

The wear performance of various ferrous and non-ferrous alloys was investigated by the researchers. However, due to their affordability and adaptability, ferrous alloys have received significant attention to increase wear resistance [27]. Iron-based hardfacing alloys have been extensively employed for improving the wear resistance of agricultural tillage components due to their low cost, ease of deposition, and good metallurgical compatibility with carbon steel substrates [28,29]. Among various alloying elements, chromium has been identified as the most influential element governing the abrasive wear performance of iron-based hardfacings [30].
life of tillage tools, provided that chromium content, carbide morphology, and deposition parameters are carefully optimised. Several studies have reported that an increase in chromium content significantly enhances wear resistance through the formation of hard chromium carbides within the metal matrix [31–33]. Investigations on cast iron and low-carbon steel substrates revealed that wear resistance is strongly dependent on deposition technique, electrode carbon content, and resulting microstructure rather than hardness alone [34]. In particular, the volumetric fraction and distribution of carbides were found to play a more important role in wear performance than bulk hardness values [35,36]. As presented in Table 1, comparative studies on iron-based hardfacings containing chromium contents ranging from 3 to 29% consistently showed a reduction in wear rate with increasing chromium concentration [37]. Hardfacings containing higher chromium levels (≥12% Cr) exhibited superior abrasive wear resistance due to the presence of complex carbides such as Cr_7C_3 and $Cr_{23}C_6$ which effectively resist micro-cutting and ploughing actions caused by soil particles [38]. A study reported that, under laboratory conditions, specimens with 20% chromium exhibited higher wear resistance than other low-chromium hardfacings, which was attributed to the presence of complex carbides in the microstructure [39]. Another study reported that the field performance validated laboratory findings, showing significantly lower weight loss for chromium-rich hardfaced tillage blades compared to untreated components [40]. However, it was also observed that laboratory wear rates do not always directly correlate with actual field wear, highlighting the influence of complex soil–tool interactions [41]. Overall, iron-based chromium hardfacings represent a significant and economical solution for extending the service

Table 1. The wear performance of chromium content in iron-based hardfacing alloys

Alloy System / Composition	***Deposition Process***	***Wear Test Method***	***Key Findings***
Fe–Cr (3–10% Cr)	SMAW	Pin-on-disc (ASTM G99)	Moderate wear resistance; limited carbide formation
Fe–Cr (12–20% Cr)	MMAW / GTAW	Taber abrasion	Significant reduction in wear due to complex carbides
Fe–Cr (18–29% Cr)	SMAW	Field + Lab tests	Highest wear resistance; carbide-rich martensitic matrix

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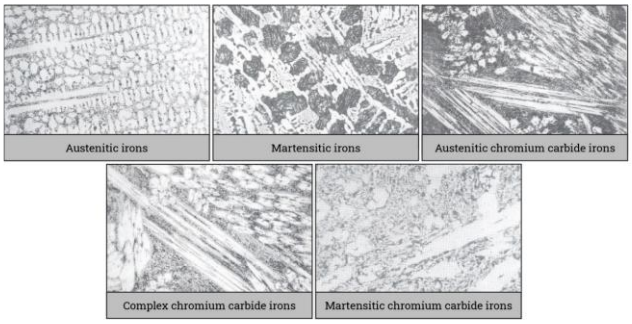
3.4 Role of Microstructure and Carbide Fraction in Wear Resistance

The abrasive wear resistance of hardfaced surfaces is predominantly influenced by their microstructural characteristics and the volume fraction of carbides present within the matrix. Microstructural features such as phase constitution, carbide morphology, size, and distribution directly influence key mechanical properties, including hardness, toughness, and load-bearing capacity. A carbide-rich and well-distributed microstructure enhances resistance against micro-cutting and ploughing mechanisms, while the surrounding matrix provides necessary toughness to prevent premature fracture or spalling during service. A literature survey revealed that wear resistance is significantly influenced by variations in the hardfacing deposition method, the electrode carbon content, and the microstructure. Further, it was revealed that hardness did not correlate directly with wear rate [42]. However, the volumetric percentage of carbides in the metal matrix improved wear resistance [43]. It has also been reported that the formation of complex carbides within the matrix significantly enhances resistance to abrasive wear [44]. In agricultural applications, studies comparing untreated and hardfaced tillage blades revealed that conventional blades experience higher material loss due to the presence of ferrite and pearlite in their microstructure, which are relatively soft compared to abrasive soil particles [31,45]. In contrast, hardfaced blades exhibit superior wear performance due to carbide reinforcement. Furthermore, an increase in chromium content in hardfacing alloys has been consistently associated with improved wear resistance, attributed to the formation of a higher volume of hard chromium-rich carbides that enhance surface hardness [46]. The addition of chromium-based alloying elements promotes the formation of lath martensite along with ferritic phases, leading to a marked increase in hardness and improved wear performance [45]. Figure 2 shows the microstructural characteristics of the iron–chromium-based hardfacing deposit, highlighting the carbide morphology, distribution, and matrix structure. Overall, these findings indicate that abrasive wear behaviour is primarily controlled by a combined effect of hardness, microstructure, and chemical composition rather than any single parameter alone.

3.5 Wear Performance of Hardfaced Ploughshare Blades

A literature review reported that hardfaced ploughshare blades exhibit lower wear rates than untreated blades and better retain their cutting geometry after field trials, as shown in Figure 3, [46–48]. The hardfacing process improves the surface properties of the substrate by depositing a harder alloy layer on the substrate. This increases the surface hardness or improves the microstructural properties, which play a major role in improving wear resistance. In most cases, hardfaced blades show extended service life ranging from 1.5 to 4 times that of conventional blades, as shown in Table 2, depending on operating conditions and alloy composition. Wear performance improvements are influenced by factors such as the number of hardfacing layers, welding parameters, and dilution with the base metal [49]. Although excessive hardness may lead to cracking, properly selected iron-based hardfacing alloys provide a good balance between wear resistance and toughness [51], [52].

Figure 2 Iron-chromium-based hardfacings with different microstructural



characteristics [18]

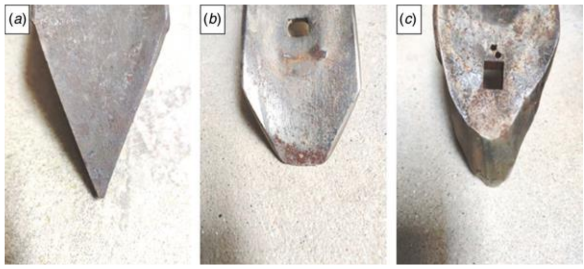


***Figure 3**. Comparison of (a) new blade, (b) bare blade after field trials showing severe edge loss, and (c) hardfaced blade after field trials exhibiting reduced edge wear. The hardfaced blade retains its cutting profile better than the uncoated blade [47].*

4. ECONOMIC EVALUATION

Although previous studies have reported that hardfacing enhances the service life of tillage blades, limited attention has been given to its economic viability. In practice, many farmers prefer replacing worn blades with new ones, assuming that direct replacement is more economical than applying hardfacing. Therefore, the present review incorporates a comparative cost analysis of untreated and hardfaced blades to evaluate their relative economic performance. A market survey indicated that the combined cost of hardfacing materials and labour is approximately 1.5 times the purchase cost of a new bare blade. However, findings from the literature show that hardfacing increases service life by approximately 1.5 to 4 times compared with untreated blades [6,8,10,38,44,53–55]. To assess economic feasibility, a cost per hectare approach was adopted, in which blade cost is normalised by its effective service life (₹/ha). Hardfacing is considered economically advantageous when the cost per unit area tilled is lower than that of a new untreated blade. This analytical framework provides a straightforward and practical basis for decision-making under variable agricultural operating conditions. As summarised in Table 3, the cost per hectare of hardfaced blades is lower (4.1 - 6.25) than that of bare blades (7.5) due to their extended service life. These findings indicate that improving durability through hardfacing can offer a more cost-effective solution than repeated

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replacement of untreated blades. Although the initial cost of the hardfaced blade is relatively high compared to the unhardfaced blade but operational cost of the hardfaced blade is less than that of the bare blade. It should be noted that the economic outcome may vary depending on soil conditions, operating parameters, and local cost fluctuations.

Table 2. WRI of Iron-based hardfacing materials reported in the literature.

Bare material	Typical Hardfacing elements	WRI	Reference
Medium carbon steel	Fe-C-Cr-Mn	1.3	[10]
EN-14B	Fe-C-Cr	2.5	[38]
EN-42	Fe-C-Cr	1.8	[53]
AISI	Fe-C-Cr	2.8	[6]
Low alloy steel	Fe-C-Cr-Nb	2.0	[8]
EN42	Fe-C-Cr-B	1.5	[44]
Low-carbon steel	Fe-C-Cr	4.2	[54]
Hardox 500	Fe-C-Cr	3.0	[55]

The results indicate that, despite a 70% increase in initial cost, the hardfaced blade reduces operational cost by approximately 17–45%, depending on the achieved service life. This confirms that durability enhancement through hardfacing can provide measurable economic benefit under typical agricultural working conditions.

5. CONCLUSIONS

- Abrasive wear is the primary cause of ploughshare blade failure due to the hard particles present in the soil
- Iron-based hardfacing significantly improves wear resistance, and it is attributed to the microstructural and mechanical properties of the surface

Table 3. Economic comparison of new and hardfaced ploughshare blades

Parameter	Unhardfaced blade	Hardfaced blade
Average Cost of blade (Rs)	150	250
Price Ratio	1	1.6
Average Service life (ha)	20	40-60
Average Cost per hectare (Rs/ha)	7.5	4.1-6.25

- Hardfacing provides a lower cost per functional life than replacement
- Iron-based hardfacing is a practical and sustainable solution for Indian agriculture

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