Research Article

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Investigation of the reduction of mouldboard ploughshare wear through hot stamping and hardfacing processes

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Abstract: The effects of the hot stamping process and different hardfacing techniques, such as shielded metal arc welding (SMAW) and gas metal arc welding (GMAW), on the abrasive wear of ploughshares were investigated under field operational conditions. The abrasive wear losses were determined by measuring the weight and dimension changes before and after tillage. The wear losses of hot-stamped and hardfaced ploughshares were less significant than those of the conventionally heat-treated ploughshare specimens used under field conditions. Conventional heat treatment and hardfacing by the SMAW process decreased the wear weight losses by 46.31% and the dimensional losses by 86.77% in comparison to the performance of the conventionally heat-treated ploughshares. These values were 36.90% and 88.17%, respectively, for conventional heat treatment and hardfacing by the GMAW process. There were no statistically significant differences between the SMAW and GMAW hardfacing processes in terms of wear losses. Hot stamping and heat treatment applications on the ploughshare also decreased wear losses by 19.03% and dimension losses by 13.82% in comparison to the conventional heat treatment process. According to the results of the overall study, hot stamping and hardfacing by SMAW and GMAW processes can be recommended as efficient solutions for decreasing the wear losses of ploughshares.

Key words: Abrasive wear, hardfacing, stamping, tillage tool

Sıcak presleme ve yüzey sertleştirme işlemleri ile kulaklı pulluk uç demirinin aşınmasının azaltılması üzerinde incelemeler

Özet: Bu çalışmada, pulluk uç demirinin abrazive aşınması üzerine sıcak presleme işleminin ve örtülü elektrotla metal ark kaynağı (SMAW) ve gaz altı metal ark kaynağı (GMAW) gibi farklı yüzey serteştirme tekniklerinin etkisi tarla koşullarında incelenmiştir. Aşınma kayıpları toprak işleme öncesi ve sonrasında ağırlık ve boyut değişimlerinin ölçülmesi ve değerlendirilmesi suretiyle belirlenmiştir. Aşınma kayıplarının sıcak presleme ve dolgu kaynağı yöntemiyle yüzey sertleştirme yapılmış pulluk uç demirlerinde, geleneksel ısıl işlem yapılmış numunelere göre tarla koşullarında önemli düzeyde daha az olduğu saptanmıştır. Geleneksel ısıl işlem + örtülü elektrotla metal ark kaynağı yüzey sertleştirme işlemi geleneksel ısıl işlem görmüş numunelere göre ağırlık aşınma kayıplarını % 46.31, boyut kayıplarını ise % 86.77 oranında azaltmıştır. Bu değerler geleneksel ısıl işlem + gaz altı metal ark kaynağı yüzey sertleştirme işlemi için sırasıyla % 36.90 ve % 88.17 olarak gerçekleşmiştir. Aşınma kayıpları bakımından örtülü elektrotla metal ark kaynağı ve gaz altı metal ark kaynağı işlemleri arasındaki farklar istatistiki olarak önemsiz bulunmuştur. Sıcak presleme + ısıl işlem görmüş pulluk uç demirleri geleneksel ısıl işlem görmüş numunelere göre ağırlık aşınma kayıplarını % 19.03, boyut kayıplarını ise % 13.82 oranında azaltmıştır. Tüm sonuçlar dikkate alındığında, pulluk uç demirlerinde meydana gelen aşınma kayıplarının azaltılması bakımından sıcak presleme, örtülü elektrotla metal ark kaynağı ve gaz altı metal ark kaynağı yöntemleri ile yüzey sertleştirme işlemleri etkili bir çözüm olarak önerilebilir.

Anahtar sözcükler: Abrazive aşınma, yüzey sertleştirme, presleme, toprak işleme aleti

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Introduction

The ploughshare and the mouldboard are the main soil engaging parts of the mouldboard plough that face higher wear rates (Weise and Bourarach 1999). The wear resistance of a specimen is mainly associated with its surface hardness. Although the wear resistance depends mainly on the hardness of the material, any important increase in hardness usually leads to an increased brittleness of the material and thus interferes with the wear behaviour. The ploughshare, which faces higher wear, needs to be tough and resistant to wear. An appropriate solution needs to be found at a point somewhere between the surface properties and the strength of this element.

The ploughshare's wear affects its operational life. It also changes its initial shape, which is one of the most important factors influencing the quality of the ploughing (Fielke 1996). The wear of ploughshares also leads to frequent interruptions in work for replacement purposes; contributes to high costs of labour, downtime, and parts; and results in the increase of direct costs through the considerable effects of higher fuel consumption and lower rates of work (Natsis et al. 1999; Bobobee et al. 2007). A major portion of wear losses can be attributed to the friction between the soil and the tool surface (Kushwaha et al. 1990; Kato 2000). In the soil tillage process, abrasion from the hard soil particles is the dominant influence on the wear of the tillage tool (Heffer 1994; Zum Gahr 1998). The abrasive wear depends highly on the mechanical and microstructural properties of the material, on the soil texture, and also on working conditions such as the cultivation depth and the soil water content (Owsiak 1997; Natsis et al. 1999). For that reason, several methods have been developed to increase the abrasive wear resistance of tillage tools. Most of the different hardfacing techniques, including carbonitriding, carburising, nitrocarburising, welding, and wear-resistant materials, have been studied by researchers (Foley et al. 1984; Jankauskas et al. 2008; Fares et al. 2009).

The hot stamping process is an innovative technique for producing ultra-high-strength steel components. In this process, the steel sheet is heated to a temperature in the austenite range, higher than the Ac3 temperature. The structure transforms fine-grained austenite completely at a temperature above the Ac3 line. The austenitised steel sheet is then transferred to a pressing machine. The material is compressed to make it denser. Thus, the spaces within the material can also be removed or reduced. The main advantages of the hot stamping process are the excellent shape accuracy of the components and also the possibility of producing ultra-high-strength parts without any springback (Naderi 2007). Research on the wear loss of hot-stamped ploughshares has received little consideration and this topic was investigated for the first time in this study.

Shielded metal arc welding (SMAW) is commonly used for hardfacing due to the low cost of the electrodes and the ease of application (Horvat et al. 2008). According to Bayhan (2006), the hardfacing process using electrodes was effective in reducing the wear on the tillage tool, chisel shares. Horvat et al. (2008) reported that the weight losses were also lower for the hardfaced ploughshares through the application of SMAW and high frequency induction welding (HFIW) than those for regular ploughshares, but the differences was not significant.

Gas metal arc welding (GMAW) is the most common industrial welding process, which is preferred for its versatility, speed, and the relative ease of adapting the process to robotic automation. GMAW is referred to by its subtypes, metal inert gas (MIG) and metal active gas (MAG) welding. In the MIG/MAG welding systems, a continuous and consumable wire electrode and a type of shielding gas are fed through a welding gun. A shielding gas that flows through the gas nozzle protects the arc and the pool of molten material. The gas plays an important role and determines several process characteristics as well as the performance of the process (Tülbentçi 1990). In this study, the effect of the GMAW process on the abrasive wear losses of ploughshares was investigated. To the best of the author's knowledge, this topic was studied here for the first time in the literature.

The aims of this experimental study were to evaluate the abrasive wear losses of ploughshares that were processed with different treatments, such as hot stamping and heat treatment, conventional heat treatment and the hardfacing of the edge of the ploughshare by shielded metal arc welding (SMAW), and conventional heat treatment and the hardfacing of the edge of the ploughshare by gas metal arc welding (GMAW) under field conditions of operation.

Materials and methods

Materials

As test materials, 30MnB5 and SAE 1040 steel were used in this study. The spectral analyses of the 30MnB5 and SAE 1040 steel are given in Table 1.

The alloying elements in steel have the effect of making steel possess the properties of ductility and strength. Carbon has a major effect on the properties of steel and is the primary hardening element in steel. Increasing the carbon content decreases the ductility and the weldability. Manganese also has a significant effect on the hardenability of steel and contributes to its strength and hardness, but less than carbon does. Phosphorus increases the strength and the hardness. Phosphorus and sulphur decrease the ductility and the notch impact toughness of steel. By reducing the carbon content, the ductility will improve but the strength will be decreased. The appropriate solution needs to be found by considering the trade-off between these 2 properties. One good solution is to use very low carbon content and add chromium and boron as the hardenability enhancers (Vandeputte et al. 2001; Naderi 2007). The conventional and the hot-stamped ploughshare sets were made by the company Ünlü Ziraat Aletleri, Turkey. The hot-stamped ploughshare sets were made of SAE 1040 steel due to its higher carbon content. The hot stamping process was composed of different steps such as the austenisation treatment, the transfer of the blank, the hot pressing and cutting, and the piercing and quenching steps. The shape of the ploughshare was formed by the stamping of the profile material. The conventionally heat-treated and the hardfaced ploughshare sets were made of 30MnB5 steel. The edge surfaces of the ploughshares were covered via 2 different hardfacing processes to increase their hardness. The chemical compositions of the hardfacing materials (producer's data) are presented in Table 2.

The reason for these electrodes being chosen was that they provide high resistance to wear. The structural and the mechanical properties of the material are much more severely affected by carbon than by all of the other alloying elements, and carbon increases the strength of the weld metal. Manganese also increases the strength properties of the weld metal and provides deoxidation in the weld bath. Chromium is the alloying element participating in the composition of a variety of weld metals to improve the mechanical properties and to increase the corrosion resistance (Tülbentçi 1990). By using HF-1 and the HF-2 electrodes with the same content, the effect of SMAW and GMAW welding processes on the wear were investigated.

The schematic representation of the mouldboard plough and the ploughshare that were used are given in Figure 1. Some physical properties of the soil in which the research was conducted are given in Table 3.

Table 1. The spectral analyses of 30MnB5 and SAE 1040 steel (%).

Material	C	Si	Mn	P	S	B
30MnB5	0.287	0.277	1.418	0.011	0.005	0.0011
SAE 1040	0.401	0.243	0.850	0.020	0.013	-

Table 2. The chemical composition of the weld metal of the hardfacing electrode (%).

Hard-Facing (HF) Electrode	Cr	C	Mn	Fe
HF-1 (covered electrode) and HF-2 (welding wire)	35	5	0.5	Balance

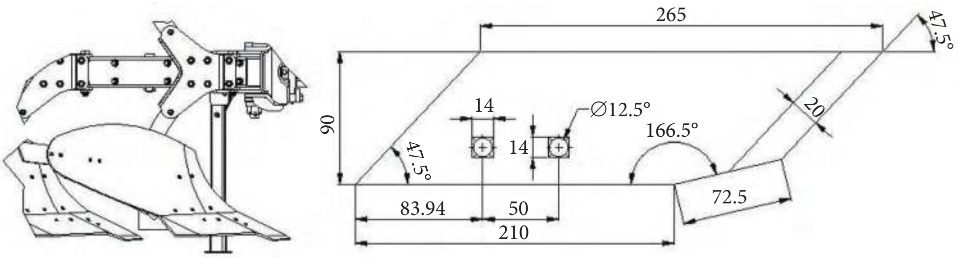

Figure 1. The schematic representation of the mouldboard plough and the ploughshare.

Table 3. Some physical properties of the study soil.

Parcel	Soil Depth (cm)	Texture (%)			Texture	Volume Weight (g cm^{-3})	Moisture Content (%) (Degraded Sample)
		Sand	Clay	Silt		(Pristine Sample)	
1	0-30	45.81	15.89	38.30	Loam	1.546	6.70
2	0-30	41.19	16.06	42.75	Loam	1.505	2.01

Method

The spectral analysis of the steel used for tested shares was determined with an ARL 4460 optic emission analyser. The hardness values of the specimens were investigated at a load of 10 N by using a Wolpert Wilson Micro-Vickers 401 MVA hardness tester according to the Vickers method (Machado 2006; Horvat et al. 2008).

The experimental treatment parameters are presented in Table 4. The parameters of the welding processes are given in Table 5. The used gas was a mixture of 97.5% argon and 2.5% CO_2 for the GMAW process.

The experimental field was located in Menemen, İzmir, in the Aegean region of Turkey. The field experiment was conducted on a 3-block parcel. Each parcel block was considered as a single repetition of the test. The experiment was carried out using a 4-furrow plough with a working width of 140 cm. Because the position of the furrow is important

Table 4. The experimental parameters for the treatments.

Treatments and Materials	Quenching Conditions
Conventional Heat Treatment (CHT) Material: 30MnB5	CHT; austenisation temperature: 900 °C for 35 min, quenched in 20 °C water; tempering temperature: 400 °C for 55 min
CHT + HF-1 Material: 30MnB5	CHT + HF-1 (edge of the ploughshare was processed by the SMAW technique with HF-1 and one layer was made)
CHT + HF-2 Material: 30MnB5	CHT + HF-2 (edge of the ploughshare was processed by the GMAW technique with HF-2 and one layer was made)
Hot Stamping (S) + Heat Treatment (HT) Material: SAE 1040	Stamping temperature: 1080 °C, stamping force: 500 N mm^{-2} + heat treatment (austenisation temperature: 850 °C for 35 min, quenched in 20 °C water; tempering temperature: 280 °C for 45 min)

Table 5. Welding process parameters.

Hardfacing Material and Welding Process	Average Voltage (V)	Average Current (A)	Travel Speed (mm s^{-1})	Current Type
HF-1/SMAW	29	106	1.67	DC (+)
HF-2/GMAW	32	150	2.33	MIG DC (+)

for the wear loss, one ploughshare was placed on the first position on the mouldboard plough, on the second, on the third, and finally on the fourth furrow, respectively, during the experiment. Thus, a ploughshare was used in each location for 0.875 ha, and with each ploughshare a total of 3.5 ha (working width of furrow: 0.35 m × 100,000 m) was tilled. The average speed of the tractor during the experiment was 6.5 km h^{-1} and the average ploughing depth was 28 cm. The land was flat with a uniformly dispersed soil type and with crop residues of wheat stubble. For determining the weight loss of the ploughshare materials, the shares were separately weighed on a precision electronic balance with an accuracy of 0.01 g before and after the tillage. The measurement of the changes in dimension was carried out using a digital planimeter, OTTOPLAN 700/710, before and after the tillage. The wear per unit rate was dependent on the weight and the dimension loss per hectare. Analysis of variance (ANOVA) in accordance with the experimental design (randomised block) was applied to the data recorded in this field experiment. While ANOVA indicated significant differences, the LSD range test was used to compare the mean results. The differences were considered significant with a threshold of 99% ($P < 0.01$). The soil classification was done according to the textural triangle with the sand, the silt, and the clay content (Kaçar 2009).

Results

The average hardness of the conventionally heat-treated ploughshares was 540 HV, whereas that of the ploughshare treated by stamping and heat treatment was 567 HV. The average hardness of the welding zone was 850 HV for HF-1 and 830 HV for HF-2.

From the field testing conditions, the weight and dimension losses associated with the ploughshares are given in Table 6, and the appearance and surface morphologies of several samples as examined by optical microscope are given in Figures 2 and 3. The statistical analysis of the average weight and the dimension losses showed significant differences between the conventionally heat-treated, the stamped and heat-treated, and the CHT and hardfaced ploughshares. The

Table 6. The ploughshare weight and dimension losses.

Heat Treatments	Average Losses for the Ploughshare	
	Weight Losses (g ha^{-1})	Dimension Losses (mm^2 ha^{-1})
CHT	46.24 a**	406.67 a**
CHT + HF-1	24.82 c	53.81 c
CHT + HF-2	29.18 c	48.10 c
S + HT	37.44 b	350.48 b

**: Means having the same letters are not significantly different at the probability of 1% for LSD.

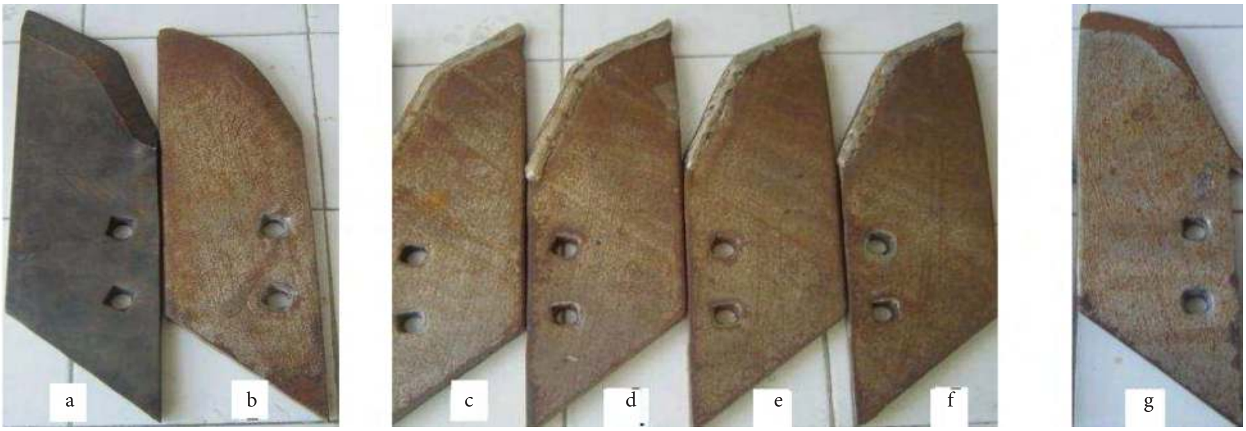

Figure 2. Specimens of: a) conventionally heat-treated ploughshare, before tillage; b) conventionally heat-treated ploughshare, after tillage; c and d) ploughshare conventionally heat-treated and hardfaced with HF-2, after tillage; e and f) ploughshare conventionally heat-treated and hardfaced with HF-1, after tillage; g) hot-stamped and heat-treated ploughshare, after tillage.

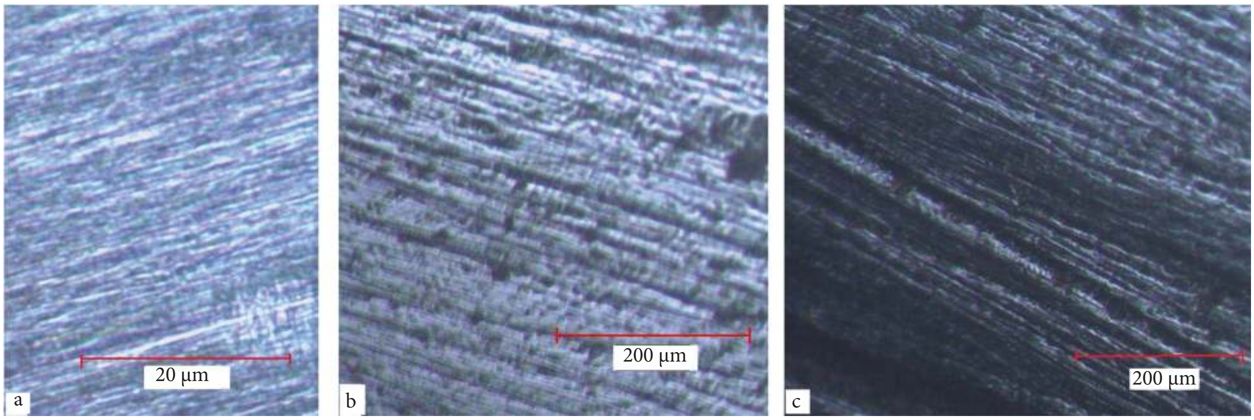

Figure 3. Surface morphologies of the zone: a) hardfaced by SMAW, b) hot-stamped and heat-treated, and c) conventionally heat-treated after tillage.

weight and the dimension losses were highest for the conventionally heat-treated ploughshares, followed by the hot-stamped and heat-treated and the CHT and hardfaced ploughshares, respectively (Table 6).

There were no significant differences between the SMAW and the GMAW hardfacing processes in terms of the wear losses. Less wear weight losses were recorded in comparison to the conventionally heat-treated ploughshares, and the experiment resulted in 46.31% less wear for the HF-1 and 36.90% less wear for the HF-2 for the hardfaced ploughshares. As can also be seen in Figure 3, the surfaces of the ploughshare specimens had fewer scratches, deep grooves, and gouges if they were treated by the SMAW and GMAW processes. With the mentioned processes, the dimensional losses were decreased by 86.77% and 88.17% for CHT + HF-1 and CHT + HF-2, respectively, in comparison to the conventionally heat-treated ploughshares. Hot stamping and heat treatment of the ploughshare decreased 19.03% of the total wear weight losses and 13.82% of the total wear dimension losses in comparison to the conventional heat treatment process under field operation conditions (Table 6).

The differences between the repetitions were significant with a threshold of 95% ($P < 0.05$). The wear weight loss was lower than the increase in the moisture content in the plots.

Discussion

The additional cost of the ploughshare hardfacing process with electrodes via the SMAW process was calculated as approximately \$1.7 for HF-1. This value was approximately \$1.4 for HF-2 via the GMAW process. With the HF-1 and HF-2 hardfacing welding processes, the life span of the ploughshare was increased. Considering the purchasing price of a conventionally heat-treated ploughshare as being \$10, by increasing the life span of the ploughshare approximately 2 times, these hardfacing protection methods can be recommended as an efficient solution for ploughshare wear protection. HF-1 and HF-2 can also be used as an effective solution. The GMAW process usually offers higher electrode efficiencies and therefore lower electrode costs and higher deposition rates than the SMAW process. On the other hand, the GMAW process can be easily mechanised and is easily adapted for high-speed robotic, hard automation, and semiautomatic welding applications. Other advantages of the GMAW process are that fewer operator skills are required, minimal postweld cleaning is required, and less welding fumes are given out in comparison to the SMAW process.

Bayhan (2006) reported that the hardfacing process with electrodes by the SMAW technique was effective in reducing the wear on the chisel ploughshare. According to Horvat et al. (2008), the dimension losses and the weight losses were lower for the shielded metal arc welding (SMAW) process and the high frequency induction welding (HFIW) of hardfaced ploughshares in comparison to the regular shares. Milos et al. (1993) reported that the ploughshare weight loss in sandy soil was 30-150 g ha^{-1}. The differences between our study and comparable studies (Milos et al. 1993; Bayhan 2006; Horvat et al. 2008) may stem from the differences in the soil composition, the working procedures, the chemical composition of the hardfaced material, and the heat treatment process conditions, as well as the diversity of the used materials.

The common point is the part of the ploughshare that was subjected to the greatest dimension loss, due to the stress concentration in the soil around this zone (Figure 2). As can be seen in Figure 2, the ploughshares kept their initial shape if they were treated by the SMAW or the GMAW hardfacing processes, owing to the presence of higher hardness values on the edge zone of the ploughshare. That allows better fulfilment of the ploughshare's function. On the other hand, as can also be seen in Figure 2, the differences between the weight and the dimension losses originated from the wearing on the thickness of the specimens.

The process of hot stamping and heat treatment for the ploughshare significantly decreased the total wear losses in comparison to the conventional heat treatment process under the field operation conditions. These values were obtained as a result of improving the mechanical properties of steel via the hot stamping process. These results are in agreement with the results of another study (Naderi 2007).

The differences between the repetitions were significant. In the third parcel, the 2% humidity content increased the wear weight loss in comparison to the other parcels, which had a humidity content of 6.70%. This result is also supported by other investigators (Natsis et al. 1999).

Conclusion

The wear losses were significantly lower for the stamping and heat treatment of the ploughshares compared to the conventionally heat-treated ploughshares. The stamping process can be recommended as an efficient solution for the decreasing of ploughshare wear losses. The studies in this area can be carried out for different materials and conditions.

The wear losses were significantly lower for the CHT + SMAW and the CHT + GMAW processes in comparison to the conventionally heat-treated ploughshares. The SMAW and the GMAW hardfacing processes were effective in reducing the wear on the ploughshare.

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