

Examination of Wear Behavior of NiMo, Citomangan Hardfacing Coated Electrodes and Hardfacing Deposits Formed by Liquid Nitriding

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ABSTRACT: Wear behavior of to the 30MnB5 quality steel (EN 10083:2006) which is used for surfaces contacting the soil in agricultural machinery production, was investigated in this study. The digging components of agricultural tools are exposed to abrasion during soil tillage. Hard surfacing with coated electrode and surface hardening through nitriding have been commonly employed for increasing abrasion resistance of such surfaces used for digging components. A 2 mm thick coating layer was formed on 8 mm thick, boron containing, heat treated and tempered steel surface by using NiMo and Citomangan Hardfacing electrodes. Liquid nitriding process was also applied to get hard faced surface at temperature of 650°C for 3 hours. The mass loss of coated specimens was determined by abrasion test that was conducted at 0.186 m/s rotational speed for a period of 60 hours in a container with mineral abrasives. The minimum mass loss was found for specimens coated with Citomangan hard facing electrode.

KEYWORDS: Wear behavior, Hard facing electrodes, Liquid nitriding

I. INTRODUCTION

Hard facing is defined as a coating on the parent material to reduce wear or reduce material lost due to wear mechanisms [1, 2]. The formation of hard facing surfaces deposited with the fusion arc welding method is one of the most commonly used methods in the industry and this method extends the service life of industrial products [3]. Some sections of the machinery parts produced for an industrial purpose, whether intentional or not, wear out due to the effect of one or more of abrasive mechanisms such as abrasion, adhesion, erosion or corrosion. Repairing parts that have lost their dimensions or broke during the course of work or by being affected from atmospheric conditions with welding also entails many advantages [3]. When depositing hard facing alloys on metal surface, the weld type and hard facing alloy should be selected in accordance with relevant standards [4]. There are two methods which are common in hard facing are done by using either one of fusion or solid state welding methods or by flame spraying method. Welding or thermally sprayed coating are methods used often during maintenance or production of new machinery parts [5, 6]. The selection and use of any of these methods is associated with the magnitude of abrasion and the abrasion performance of the hard facing deposit forming after the method is applied. S. Chatterjee et al. formed an abrasion resistant surface by using commercial electrodes and studied the impact of such surfaces on wear behavior [7]. Hard facing applications performed through any fusion welding method are used commonly for resizing of overly worn machinery parts. However, the flame spraying methods stand out in terms of formation of thin wear resistant layers and thus increasing corrosion resistance without requiring any secondary processes [8]. Today many methods are utilized to make the surface resistant against wear and improve the service life of the matrix. To minimize the damage resulting from working conditions is priority when matrix material cannot function on its own.

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By improving the surface of materials, low friction coefficient values, high wear resistance and improved corrosion resistance can be achieved [8, 9]. Installation and uninstallation times and loss of efficiency following the wear of parts hinder effective operation of facilities and equipment and result in the loss of millions of dollar every year [10]. One of the effective methods for improving the surface wear resistance is to increase wear resistance by hard facing deposits formed on surfaces containing nickel and chromium. Nickel has very little effect on abrasive resistance. It promotes austenite on the parent metal surface over which it acts as a thermal stress barrier and metallurgically tolerant layer [11]. S. Chatterjee et al. revealed the possibility of obtaining similar wear resistance with higher chromium and carbon without adding niobium and molybdenum [12]. Hard facing is applied to gray cast iron mill roller surfaces in the sugar cane sector to reduce wear and to improve wear resistant properties of surfaces. The reason for this is that such rollers work under the impact of a higher force using idlers to aid the crushing of sugar cane [13].

In the present study, a detailed investigation of understanding the effect of laser surface melting and hardening on wear and corrosion resistance of AISI H13 tool steel (in hardened and tempered condition) has been undertaken. Microstructural and phase evolution due to laser surface engineering (hardening or melting) and its influence on microhardness and tensile behavior of the surface engineered zone has been reported elsewhere [14].

Nitrided layer obtained after long processing time had a lower wear rate than the layer obtained at short process time. Özdemir and Erten [15] noted that the resulting hardness and wear resistance in the deposited material from the effects of alloy elements in hard facing electrodes, such as Cr, Mn, Co, Ni, V, Mo, and W, was due to the hard carbide formed by such elements or the cold deformation emerging as the parts operate during service as reported [7]. Materials cannot maintain wear resistance on their own and therefore, surface coating filler alloys can be applied where the wear is critical [16, 17].

The plow tip, which cuts its way through soil in agricultural tools, was examined in this study. A hard facing layer was formed on the material surface through nitriding method and using commercial filler electrodes containing various alloys. So, the mechanical and metallurgical properties of coated samples (plow tips) were investigated in detail.

II. EXPERIMENTAL PROCEDURES

Manual metal electrode for arc welding and nitriding methods were used for forming deposit hard facing layer on the surface of sample in this study. A 2 mm hard facing deposit was formed on the surface of 8 mm thick 30MnB5 material by using Citomangan and EIS 410 type commercial electrodes at a current of 155 A. Fillet weld was performed by establishing 20 mm bead width at 4.5 cm/min welding rate. Coated electrodes with a dimension of $\varnothing 4.00 \times 350$ (mm) were supplied from the producer. Interpass temperature of weld beads deposited with Citomangan hard facing electrode and EIS 410 electrode were set up 385°C and 450°C, respectively. The dimension of specimen used in nitriding is given in Figure 1. In this process, liquid nitriding bath containing standard salt and activation salt in a pot made of stainless steel were used. While standard salt provided the bath environment, activation salt carried out nitriding. In the process, specimens were held at approximately 650°C for 3 hours. The circulation of the liquid bath was enabled by providing compressed air into the bath. The specimens taken out of nitriding pool were cooled by submerging into water tanks at room temperature.

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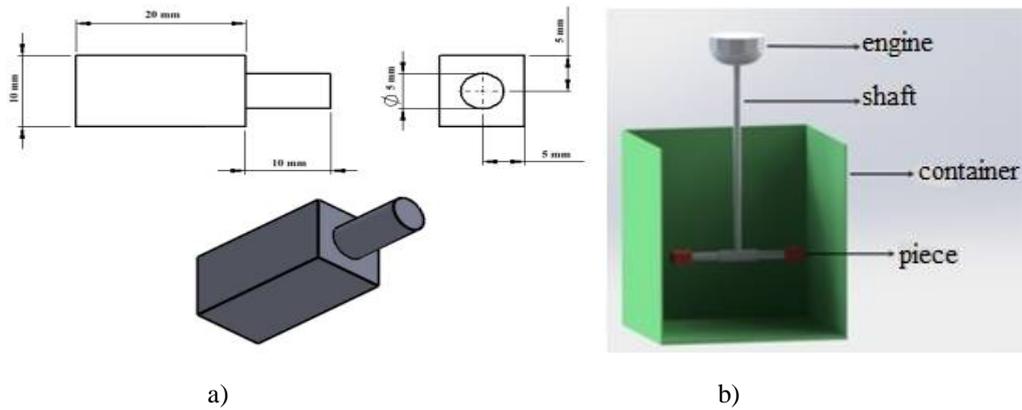


Fig. 1 a) Wear test specimen dimensions b) Abrasion test assembly

Abrasion test was carried out on a speed controlled columnar drill work bench shown in Figure 1b, which contained moisturized molding sand as an abrasive medium of 10 kg distributed load on abrasive sand. This process was performed at 50 rot/sec rotational speed for 1800 minutes. Specimens were later removed from the container and its mass loss value was calculated using a 0.01mg precision balance. The steel, produced with hot rolling of 5630 Erdemir quality steel, is also known as 30MnB5 quality steel according to DIN EN 10083-3:2006 standards. These quality steels are generally used for digging tips of agricultural tools for soil tillage.

Chemical compositions of the used steel and electrodes are given in Tables 1, 2and 3.

Table1. The chemical composition of 5630 quality steel (% wt)

C	0.27 - 0.33
Mn	1.15 - 1.45
P max.	0.025
S max.	0.035
Si max.	0.40
Cr	0.05 - 0.30
Ti	0.015-0.060
B	0.0008-0.0050

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Table2. The chemical composition of EIS 410 NiMo stainless steel electrode rod (% wt)

C	0.06
Si	0.75
Mn	0.80
Cr	12.00
Ni	4.00
Mo	0.50

Table3. The chemical composition of citomangan hard facing electrodes (% wt)

C	0.70
Mn	12.00
Ni	3.00
Fe	Remaining

III. RESULT AND DISCUSSION

III. I Hardness, wear and microstructure characterization

In order to report the properties before abrasion test, the hardness of 30MnB5 quality steel was measured as 179.66 HV_(0.5) by taking the average of hardness values recorded from different parts of the base metal. It is seen in Figure 2a that the hardness of NiMo (EIS 410) filler welded specimen increases from the parent metal to deposit metal. This increase becomes twice the hardness of the parent metal at the side of deposited weld. While the hardness of sample that was coated with Cito Mangan hard facing electrode displayed less increase from base metal towards deposited weld when compared to EIS electrode; the hardness at deposited region increases up to two folds, but then rapidly decreases (Figure 2b). The hardness change in hard facing deposited surface begins in the transition area, i.e. HAZ and reaches its highest value in deposited layer. The highest hardness value was measured in the layer made with NiMo(EIS410) filler alloy electrode.

Wear and hardness values between nitride and hard faced specimens were also compared. The wear resistance in nitride specimens was measured to be relatively high and appears to be decreasing with low hardness value. In hard facing layers, it was seen that the wear resistance also decreased in parallel to the decrease in hardness value (Figure 2d). Although the filler metal used led to an increase in the hardness of the base metal, the carbon values plays an important role in hardness increase of the hard facing layer.

In a similar study, the wear behaviors of hard faced deposits produced by Fe-Cr-B alloy based commercial electrodes were tested on gray cast iron surface[18]. Alloy composition of layers on which hard facing electrodes are formed, usually have a known composition.

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Primary carbides are formed during welding process and increase the wear resistance of the matrix structure as dispersed in a softer eutectic [19]. Also it is confirmed in other studies that primary carbides determined as a result of SEM / EDXA analyses and hardness values depend on carbides of M_7C_3 [20]. It was calculated that the hardness of the layer formed on nitrided material was nearly three times the hardness value of the base metal. Since the atomic diameter of the nitrogen in the liquid bath used in nitriding is 0.71nm, it can easily penetrate to the iron lattice easier when compared to carbon which has an atomic diameter of 0.77nm [15]. Nitrogen diffuses very quickly in solid phase of austenite at high temperatures. As a result of nitrogen compounds (i.e. nitride) forming on the surface, it leads to the formation of a fragile layer on the surface [21]. In addition, due to austenite-ferrite transformation, a change in volume occurs and the nitrogen diffuses into ferrite. In the meantime, a rather thin and fragile structure of nitrides forms in the region containing nitrogen. Alloy nitrides precipitate on cooling, which will lead to a high hardness value even higher than the hardness of martensite [21, 22]. Wear test results are given in Figure 2d and hardness values are also shown in Figures 2a, b and c. When the wear curves are examined, it is clearly seen that the amount of wear increases with time. The common characteristic for each specimen is the increase in total mass change for all specimens with respect to time. It can be said that electrodes used for hard facing are under the impact of additives such as manganese and chromium so, this is related to electrodes being more resistant against wear.

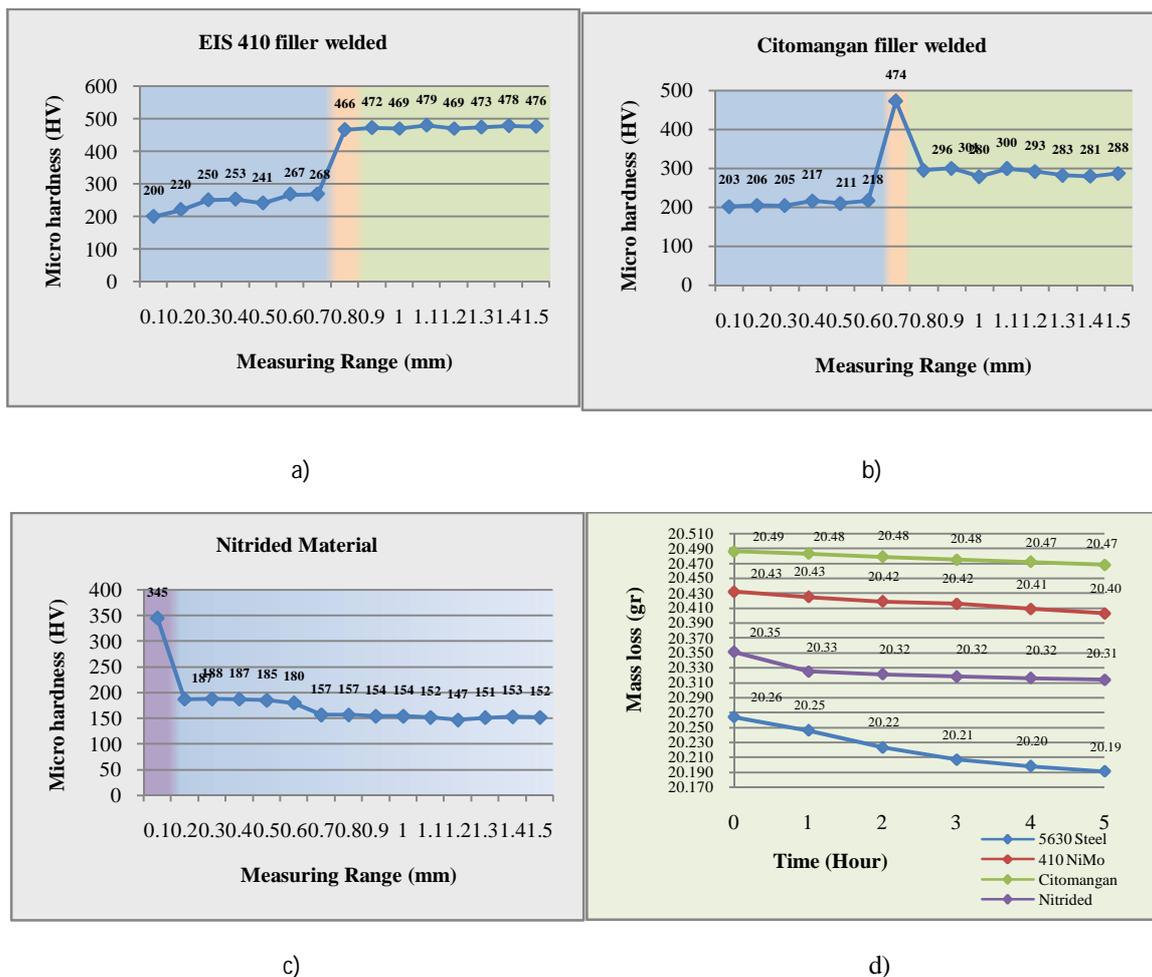


Fig.2 Hardness and mass change a) 410 EISA filler welded b) Citomangan filler welded c) Nitriding d) Wear mass change

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Phases formed on hard facing deposits and their particle and grain sizes are important factors that affect mechanical properties [23]. The microstructure of hard facing deposit metal and heat affected zones are notably different than base metal (Fig.3-5). Microstructure images of weld metal provide information on the cooling characteristic of the melted filler deposit. In this case cooling of sections near HAZ zone appears to be faster because columnar martensite structure is formed due to fast cooling. Direction throughout the length of the columns formed on weld metal points from the welding pool to the direction of the heat flow [24]. Hard face zone close to HAZ contains a columnar particle structure, whereas center of the weld has dendritic grains [25, 26]. In Figures 4, 5, microstructures due to high alloying can be observed in the microstructure of hard face coated specimens at the grain boundary in fusion line of base metal. Nickel, chromium and manganese in the composition of the electrode used can be suggested as the reason of such changes in microstructure.

Hard facing alloys usually have a highly alloyed certain composition and therefore primary carbides are formed during welding process and precipitate in the matrix of which its hardness and wear resistance increase by their presence in the microstructure [19].

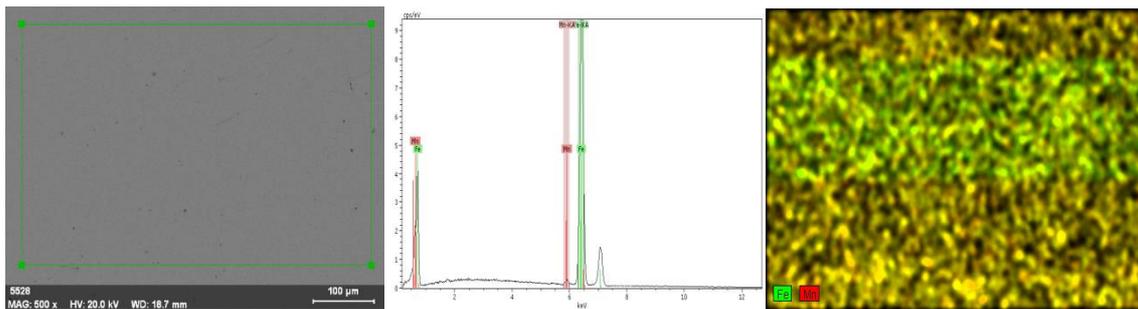
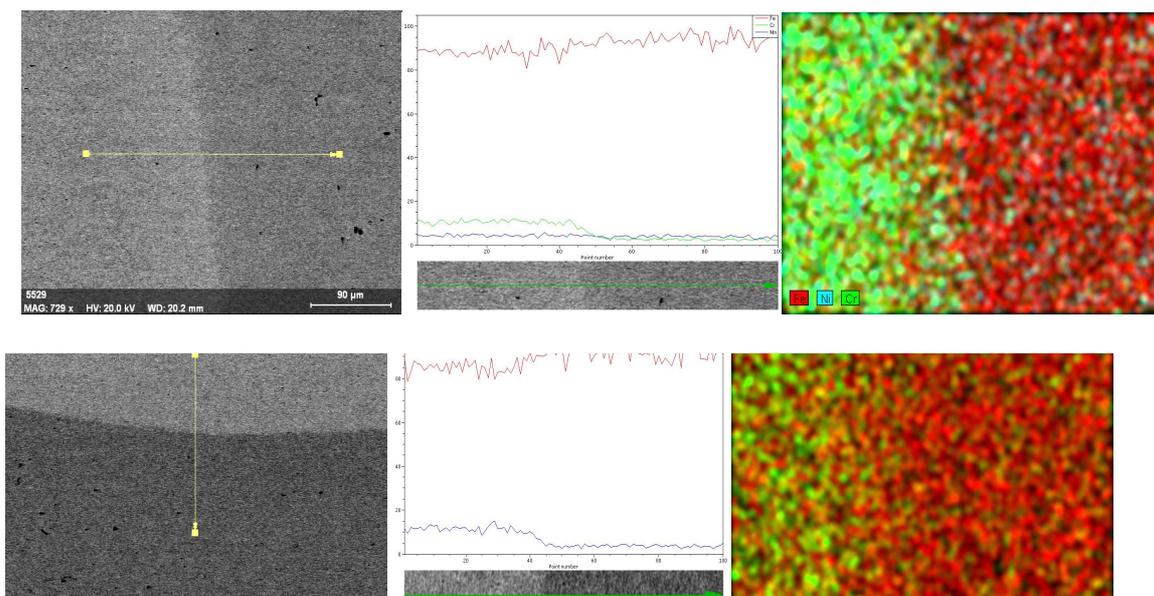


Fig. 3 SEM microstructure analysis of 5630 quality material



Manganese steels are employed in hard facing welding. Its resistance against impacts is high and the hardness of weld

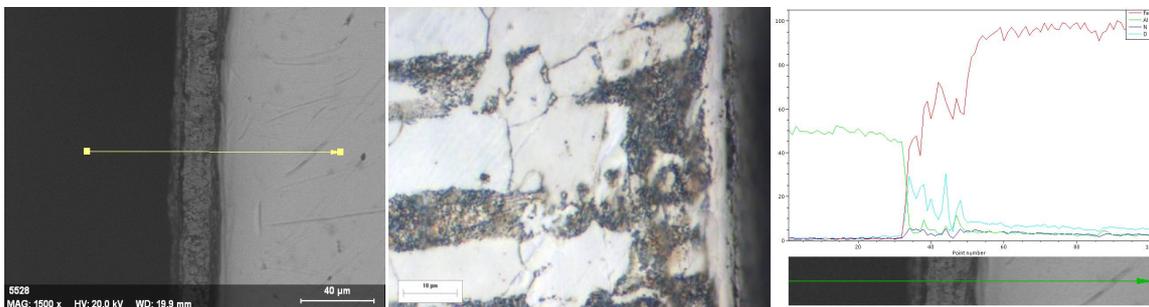
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metal increases with cold welding. It is particularly suitable for hard facing welding of components that have been abraded due to severe impact and shocking strains [27].

Alloy material used for hard facing can be reprocessed later. The welded surface may harden when submitted to cold metal transfer welding. More than one pass of hard facing weld can be done successively without requiring buffer. Hard facing welding can be used for crusher jaws, cone crusher mantles and worn excavator buckets.



For nitrogen concentration to be 0.42% solid solution of nitrogen in α -Fe should be raised up to a 590°C eutectoid temperature. At room temperature, this solubility drops to $C > 0.15$. γ phase is a Fe_4N based solid solution. γ phase contains 5.7-6% N at 450°C. ϵ phase is a Fe_3N based solid solution that contains 8.25-11.2% N. At the maximum amount of nitrogen for ϵ phase, there is also γ phase over 590°C. At 590°C α and γ phases undergoes eutectoid fragmentation. This structure containing 2.35% N is composed of a mixture of α and γ phases. Nitrogen dissolves both in α and γ iron; in addition, only a portion of the atomic nitrogen forming as a result of breakup of the ammonium gas sent to the system diffuses onto the surface of the steel [28]. At nitration temperature ammonium gas breaks up as follows:



The reaction starts turning left at 595 °C, however it is not fast under 580 °C



Resulting atomic nitrogen diffuses into the iron. If nitration process is carried out under eutectoid point, α phase would form at the first moment of saturation on the surface. After α phase reaches maximum saturation at the given temperatures, fragile phase would start forming at the same temperature (γ phase) [28]. Nitriding process is performed on components, for which it is desired that geometrical shapes such as precise, finely detailed, sharp corners are not lost and wear resistance thereof is high. Nitriding processes do not damage the surface of the material under suitable conditions. By submerging into a nitride bath, it is showing its effect on all surfaces that have come into contact with the liquid. After nitriding, the rolling lines formed on the microstructure of 5630 quality steel during production display completely the same properties. In the SEM line analysis N concentration decreasingly continues towards the depth of base metal. As seen in the analysis reflects from the base metal used in SEM device (Figure 6).

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III. II Fractured Surface and Fracture Mode

SEM images of surfaces formed after Charpy impact experiment are given in Fig.7-10 shows the fracture surface. In Figure 7, the highest fracture toughness energy was calculated for non hard faced 5630 quality steel. It is suggested that in the production of this steel, reduction in grain size due to hot rolling and existence of rolling bands in the microstructure causes high impact toughness. The lowest fracture toughness energy was for EIS 410 NiMo welded steel. Even though Ni present in filler alloy reduced ferrite formation in the weld zone, it accelerated martensite formation due possibly to fast cooling (Figure 9). In Figure 8, it is suggested that the perlitic phase is formed on Citomangan hard facing electrode not changing and also the effect of Manganese additive contained in filler alloy may cause the increase in impact toughness.

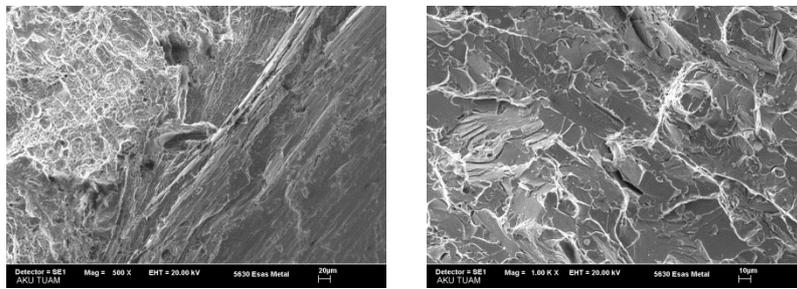


Fig.7 SEM image of fractured surface of parent metal

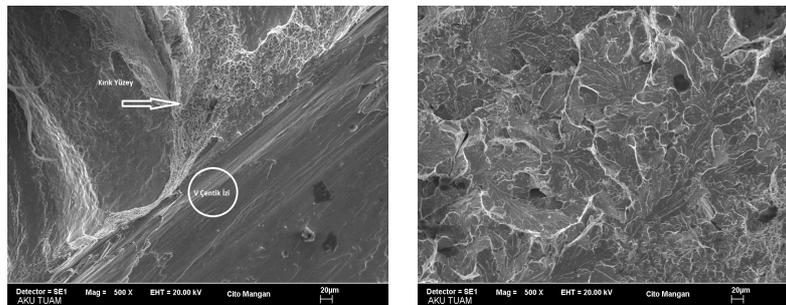


Fig. 8 SEM image of fractured surface of coating made with Citomangan hard facing electrode

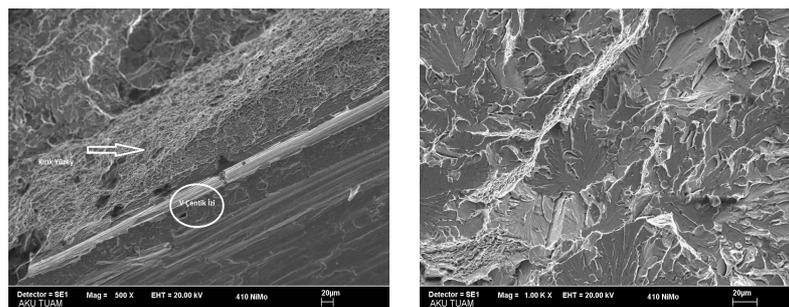


Fig. 9 SEM image of fractured surface of coating made with NiMo hardfacing electrode

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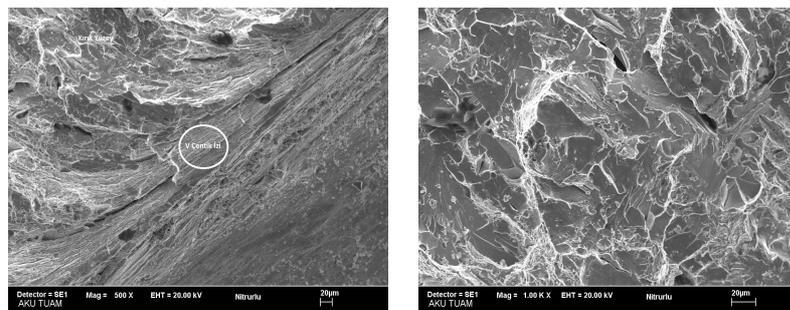


Fig.10 SEM image of fractured surface of coating made with nitriding

1. While microstructure and phase changes occurred at HAZ zone for Citomangan and EIS 410 NiMo hardfacing welded specimens compared with 5630 quality steel, for specimens submitted to nitriding at lower temperature phase changes resulting from diffusion can be seen on the surface of the material.
2. In the weld zone, dendritic areas progress into the parent metal and due to the effect of recrystallization resulting from high temperature, roll lines on the parent metal disappear. An approximately 0.1 mm thick nitride layer formed as a diffused straight line parallel to the surface of nitrided material. The nitride layer has an oxide layer that formed during cooling.
3. Impact toughness is measured as maximum in unprocessed 5630 quality steel and minimum in EIS 410 NiMo welded specimen.
4. Hardness is measured to be the highest in the weld deposit metal and it decreases from HAZ towards the base metal. The hardness in HAZ of EIS 410 welded sample did not diminish, whereas it decreased for citomangan welded sample. Even though the hardness on the nitrided specimen is found high, it displays a sudden drop down in base metal.
5. As for the results of wear due to mass loss, the highest mass loss occurred in the parent metal i.e. 0.366%. The least mass loss was observed as 0.087% for specimens coated with citomangan covered electrode. For the nitrided specimen, a rapid decrease due to the oxide deposit occurred on the surface was observed and then it was seen that the specimen displayed rather high wear resistance.

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