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Research Article

The Cryogenic Treatment of The Laser Weld Junctions of Automotive Steel

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Öz
Bu çalışmada, kriyojenik işlemin HSLA kalite ticari otomotiv sac kaynaklı birleştirmelerinin sertlik ve aşınma özelliklerine etkisi incelenmiştir. Lazer kaynak işlemleri; katı hal lazer kaynağı olarak, 1 kW lazer ışın gücünde ve 250 mm.s-1 ilerleme hızında uygulanmıştır. Bu kaynak işlemi alın (butt) pozisyonunda ve dolgu metalsiz olarak çift taraflı gerçekleştirilmiştir. Kriyojenik işlem, HSLA kalite çeliklere, kaynak öncesi, kaynak sonrası olacak şekilde uygulanmış ve bu şekilde gruplandırılmıştır. Kriyojenik işlemler -196 °C 24 saat süreyle ±1 oC/min. soğutma ısıtma hızıyla uygulanmıştır. Aşınma testleri lineer ileri geri aşındırma test cihazında 10N ve 20N yük altında toplam 600 m mesafe olarak gerçekleştirilmiştir. Adımlar 200 m olarak oluşturulmuş olup her adımda ağırlık ölçümleri ve sürtünme katsayıları tespit edilmiştir. Deneysel sonuçlarda lazer kaynaklı numune 10 N yük altında en iyi aşınma performansını gösterirken artan yük olan 20 N en düşüş aşınma performansını göstermiştir. İlave olarak artan yükte, kriyojenik işlemin de aşınma direncini artırdığını ve lazer kaynak işlem sonrası uygulanan DCT'nin aşınma için kaynaklı numuneler arasında iyi performansı gösterdiği tespit edilmiştir.

Anahtar Kelimeler
Lazer kaynağı, Aşınma, HSLA, Kriyojenik işlem

Abstract
In this study, the effect of cryogenic treatment on the hardness and wear properties of high strength low alloy (HSLA) quality commercial automotive sheet welded joints were investigated. Laser welding processes: It was applied as a solid-state laser source with a laser beam power of 1 kW and a feed rate of 250 mm.s-1. This welding process was performed on both sides in the butt position and without filler metal. Cryogenic treatment has been applied to HSLA quality steels before and after welding and has been grouped as such. Cryogenic processes -196°C for 24 hours ±1 °C/min. cooling was applied at the heating rate. Abrasion tests were carried out on a linear back and forth abrasion test device under 10N and 20N loads at a total distance of 600 m. The steps were created as 200 m and weight measurements and friction coefficients were determined for each step. In the experimental results, the laser welded sample showed the best wear performance under 10 N load, while the 20 N decreased wear performance with increasing load. In addition, it was found that at increasing load, the cryogenic treatment also increased the wear resistance, and the DCT applied after laser welding showed good performance among welded specimens for wear.

Key Words
Laser welding, Wear, HSLA, Cryogenic treatment

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1. Introduction

HSLA steels are preferred in the group of low-carbon steels due to their improved performance compared to their counterparts in various engineering applications due to their low alloying element content. As alloying elements Mo, Nb, Ti, and V, these steels have good rolling properties, good cold forming capacity, and good weldability [1]. Alloying elements added to the microstructure provide grain refinement, precipitation hardening, and solid solution strengthening to strengthen the ferrite phase. The weldability properties of this quality steel can be evaluated together with those of low-carbon steels [2]. With their high strength compared to carbon steels, they are beneficial in reducing the weight of the part and ultimately the vehicle weight [3]. It is preferred because of its effects on reducing the weight of automotive bodies, improving fuel performance, and improving safety standards [4]. For the last 30 years, attention has been paid to the effect of low-temperature treatment on the performance of steels, particularly as a treatment for tool steels [5-8].

The cryogenic process involves the cooling of objects to subzero temperatures. This process, which is divided into two classes, is defined as shallow (from -60 °C to -100 °C) and at lower temperatures as deep cryogenic treatment (DCT) [9]. On the other hand, cryogenic temperature is defined as -140°C and below by the Cryogenic Society of America [10]. In steels, the aim may include tempering at low temperatures to ensure the continuation of the martensitic transformation, reduce the amount of residual austenite as much as possible, and reduce martensitic brittleness [11]. Depending on the alloy components and pre-hardening cycles of the metals, the benefits can be shown as, respectively, increased strength, greater dimensional stability or microstructural stability, removal of residual stresses, and increased wear resistance [12]. With DCT applied to steels, high wear values can be obtained, especially in tool steels. In this process, martensitic structure is obtained by quenching after automatization [1], and this structure is developed with DCT [13]. Meng et al. [14] reported that cryogenic treatment improves the precipitation of fine-grained carbides and improves strength and toughness in tool steels. In addition, with DCT, carbon atoms move towards the nearest dislocation boundary due to the high bonding enthalpy at dislocations in -Fe and can grow there [15], [16]. Here, the dislocation density of the martensitic phase is higher than that of the cold-worked piece [17]. As the energy of the most intense dislocation boundary is high as a result of diffusion action, carbon atoms move here and thus create areas for the precipitation of thin carbides. Despite the reduction of carbon atoms in the martensite phase by diffusion, this results in improved wear resistance and toughness with negligible or almost no change in hardness [18]. In addition, studies have shown that hardness values have a direct effect on wear resistance and weight loss in cases of wear [19,20].

Welding processes are applied in the automotive body manufacturing process. Laser welding is used because of its high-power density, narrow weld effects, minimizing the mechanical weakening effects caused by heat effects, being a quality joining method, and also due to its efficient results in joining different quality steel types [21]. The laser welding process creates a martensitic structure in the steel and a narrow heat-affected zone around the weld zone. The martensite phase creates a brittle and hard structure in steels and is determined to be one of the main factors affecting wear resistance. In joining these steels, laser welding is rapidly becoming preferable because it is suitable for automation and is a high-quality joining method [22].
In the literature review, there is no study on the effects of DCT on automotive steel sheets. In this study, the wear resistance performance of the laser welding process applied to HSLA-quality steels was investigated.

2. Material and Methods

In this study, ERDEMIR HC420LA European norm and EN 10268 sheet steel supplied from ERDEMIR INC were used. The sample dimensions were adjusted to 227x65x1.5 mm with guillotine scissors for laser welding of sheets.

Table 1. HSLA steel chemical composition (%wt.)

C	Si	Mn	P	S	Al	Nb	Ti
0.14	0.50	1.60	0.030	0.025	0.015	0.090	0.15

The samples were combined with a solid-state laser welding (CW solid state laser) device for double-sided butt welding without filler metal. They are classified as untreated (N), cryogenic treated (CRY), laser cryogenically treated before laser welding (BCRY), cryogenically treated after laser welding (ACRY), and laser only welded (WN) , respectively, to find wear resistance performances in the study. Cryogenic processes -19 6°C for 24 hours ±1 °C/min. Cooling was carried out in the cryogenic treatment tank with a high heating rate.

Tablo 2. HSLA steel's mechanical properties [23]

Çelik	σ_a	$\sigma_ç$	A_0(%)	**BH2 min.**	**n-value min.**
HC420LA (HSLA)	390-500 MPa	460-580 MPa	18	30 MPa	0.14

The samples were sanded with 240, 400, 600, 800, 1000, 1200, and 2500 grit sandpaper for metallographic examinations and then polished with diamond suspension. Finally, the samples were successively etched with 2% nitric acid and 10% sodium metabisulfite in 90% distilled water.

Wear processes: for each sample, it was applied by making weight checks over a total of 600 m of sliding distance and 200 m of steps in a linear rebound abrasion test device. A load of 10 and 20 N was applied, respectively, in the wear test processes.
For the hardness measurements, the hardness values were taken linearly between the other non-weld regions, starting from the outside of the weld zone, and the hardness values of the weld zone were examined by determining the common hardness values. Hardness processes: the HV 0.5 standard was used in the Qness brand Vickers hardness measuring device.

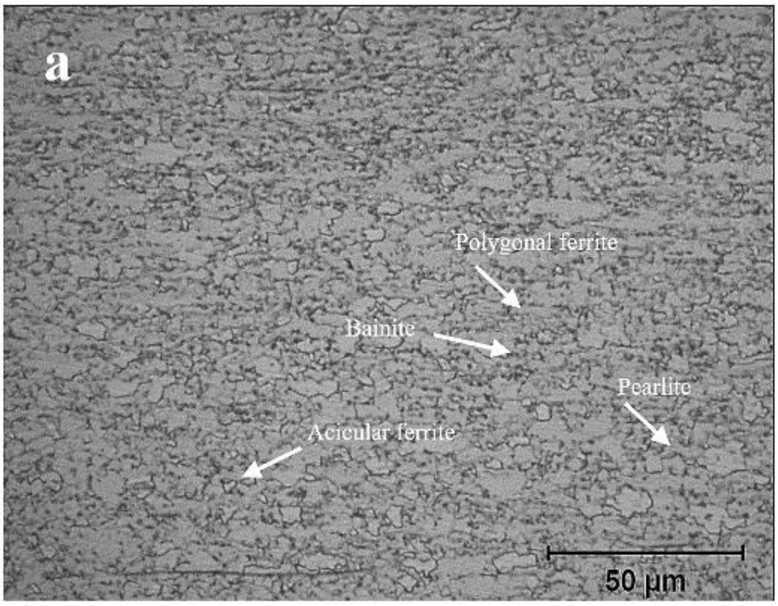
3. Result and Discussion

3.1. Microstructure Results

The laser profile obtained in this study was obtained as shown in Figure 1. There is also a small percentage of pearlite, as expected for a low-carbon steel. In addition, the resulting weld zone and HAZ and base metal microstructures are given in Figure. 2, respectively. Here, as a result of laser-welded joining, it is observed that martensitic transformation and a narrow HAZ have occurred in the inner structure in the first macro examinations. In addition, there is a decrease in the weld cross-sectional area due to the fact that double-sided welding and filler metal are not used in the microstructure images formed after laser welding. Figure 2. shows the different regions of the HSLA-laser welding profiles obtained in this study. As shown in Figure 2.a., it contains bainite and acicular ferrite micro components, with some polygonal ferrite in the base metal part.

Figure 1. HSLA laser welding zone images

As expected, the HAZ transition region is shown on the left in Figure 2.b. in the HAZ region. Here, it includes two different regions of coarse-grained (CG) and fine-grained (FG) microstructures. However, there is continuous grain growth towards the fusion zone with the microstructure where predominantly acicular ferrite transforms into polygonal ferrite and bainitic near the base metal. The weld metal structure, shown in Figure 2.c., is predominantly composed of Widmanstätten structured ferrites, acicular ferritic and bainite. Here, it can be said that the high cooling rate after laser welding affects the scale of primary austenite grain size and creates more nucleation sites at previous austenite grain boundaries, namely for phases with a nucleation preference such as bainite and Widmanstätten.



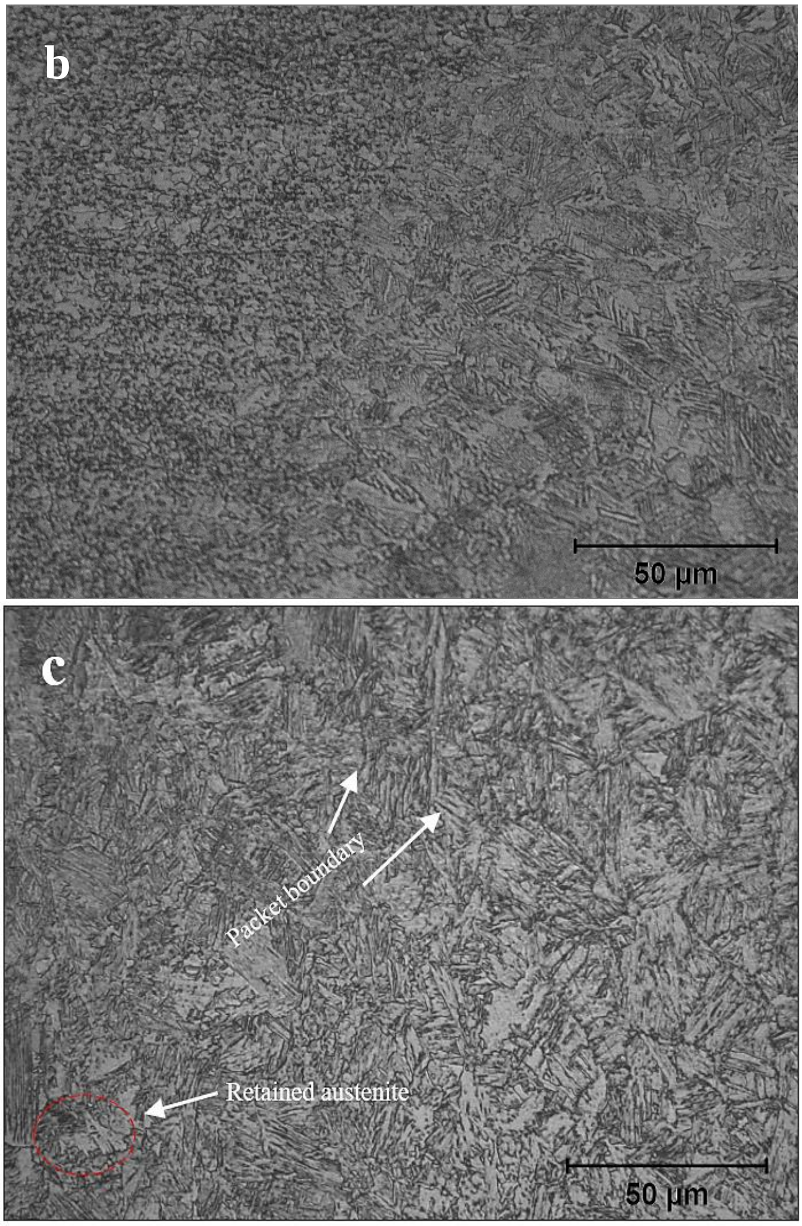


Figure 2. HSLA-laser welding sample, respectively (a) base metal, (b) Transation-HAZ and (c) Weld metal

3.2. Hardness Results

When the hardness values in the weld zones of the samples were examined in the study, the highest average hardness value was found in the BCRY sample at 337 HV. However, the hardness values in the sample were unevenly distributed, and the highest and lowest local hardness values were observed in this sample in the hardness measurements in the weld area among all sample groups. In the N sample, the hardness value was measured at 325 HV on average. In the ACRY sample, it was observed that the hardness value was approximately 320 HV, and the values were close to each other. Regarding the cryogenic process, it is reported that it provides a homogeneous hardness distribution after welding [24]. The hardness values in the base metal part were determined to be 187 HV on average in all metal groups. As a result, while the hardness value increased in the BCRY sample compared to the normal welded sample, it decreased in the ACRY sample.

3.3. Wear Results

In Figure 3., the wear test results obtained in this study are given. As a result, the highest result of the incremental test by applying a 10 N load was observed in the welded sample (WN). Afterwards, the untreated-original sample (N), only the original sample with cryogenic treatment (CRY), laser cryogenically treated before laser welding (BCRY) and cryogenically treated sample after welding (ACRY) showed the highest wear resistance, respectively. In the process under 20 N load, the highest wear resistance respectively is seen in the CRY sample, ACRY, N, BCRY and WN. Laser beam welding can generate high energy densities with very high thermal gradients. With these gradients, low heat input results in minimal heat-induced distortion, a narrow heat-affected zone, and a very finely solidified microstructure. In addition, as a result of rapid cooling and solidification as a result of the laser welding process, the grain structure is refined, and it is reported that it increases the wear resistance [18]. In the literature, there are not many resources related to the wear behaviour analysis of welded joints. The main subject of the research is the studies in which the structures formed by combining various types of welding with the structures with high abrasion resistance formed after melting and cooling on the surface are examined. M. Adamiak [20], who is close to these studies, has welded the wear-resistant layer applied to the S235JR constructional steel plate with MAG welding in his studies. As a result of his studies, he reported that wear resistance improved in the weld zone. He related this development to melting, solidification, and the transition and formation of carbides in the weld zone. In our study, the increase in performance for the welding zone caused rapid heating and cooling in the narrow zone due to the high energy density in the laser welding.

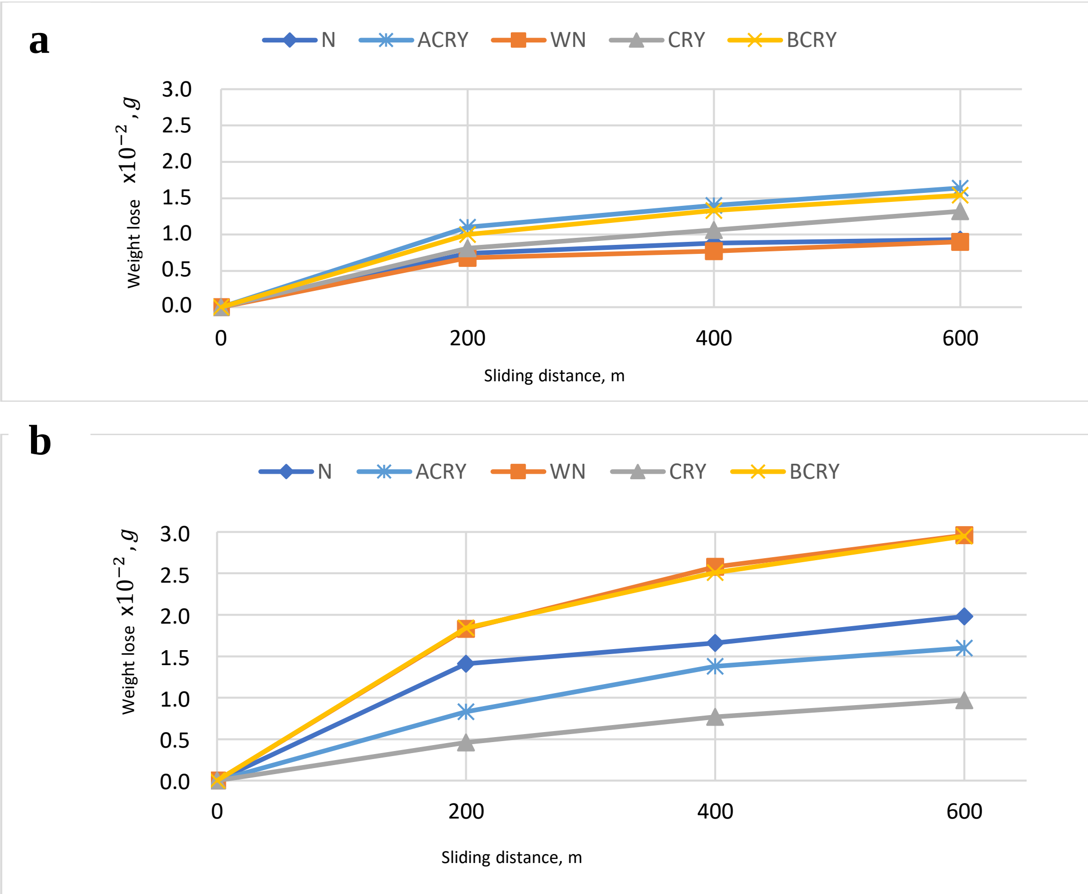


Figure. 3. (a) Wight loss vs. sliding distance under 10N load; **(b)** Wight loss vs. sliding distance under 20N load

It was observed that the highest resistance of 10 N was formed as a result of the martensitic, brittle, and hard structure formed in the laser welding region. However, when the load increased, the amount of wear in the welded sample increased drastically. Here, it is accepted that the reason for this increase is the wear resistance, which is related to hardness at light loads. However, at increasing loads, the amount of wear increased considerably as the weight limit for the hard but brittle structure in the weld zone was exceeded. The ACRY sample showed a common wear amount for both 10 and 20 N as wear resistance. The sample with the lowest wear resistance in the 10 N condition was the one that showed the second-best wear performance despite the increasing load. The lowest wear amount under a 20 N load can be associated with n carbides. These grains, which are formed by the diffusion of carbide elements in martensitic structures formed after welding, increase the hardness and wear resistance at the dislocation boundaries. In this context, it is ensured that it shows the same wear resistance at increasing hardness values.

In the BCRY welded sample, the amount of wear showed the same behaviour in both load conditions. Here, there was an increase in the amount of wear in parallel with the increasing load. When the hardness results of the cryogenic process before welding are examined, it is thought that the fluctuation in the hardness values accelerates the wear rate. Unlike other studies, it was observed that the amount of wear on the untreated original sample decreased with increasing load. As a result of the cryogenic treatment of the untreated original sample, it was observed that the amount of wear was lower despite the increased load.

3.4. Conclusions

This study, for the first time in the literature, investigated the change in wear resistance of steels in the high-strength low-alloy grade series under 10 and 20 N loads by applying both cryogenic treatment and welding processes for the first time. In fact, cryogenic processes have reached a point that attracts attention and is widely used with each passing day. The general results are given below:

- While the weld metal region has a predominantly martensitic structure, grain thinning is observed at the transitions to the HTA region.
- While it is expected that wear resistance will improve with cryogenic treatment, it has been observed that it decreases slightly under 10 N load, but wear resistance improves under increasing load.
- In the overall evaluation, the untreated cryogenically applied sample showed the highest wear resistance.

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