

## INVESTIGATION OF SURFACE PROPERTIES FOR AISI 4340 ALLOY STEEL BY BURNISHING PROCESS USING DIFFERENT PARAMETERS

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### Abstract

In this study, we have investigated the effect of burnishing process on surface properties of alloyed steels in different parameters, AISI 4340 alloy steel was used in this study. AISI 4340 steel is one of the alloy steels preferred in many fields in engineering because it gives good results in surface finishing applications and can be used, and parameters were determined for the burnishing application with 3 different pass depths and to be applied while keeping the other parameters constant.

In optical microscope images of the samples polished under P1, P2 and P3 conditions are shown, a change in the grain structure was observed after a plastic deformation effect on the surface area. It was seen in the SEM analysis that the layer thicknesses affected by the deformation increased as the processing intensity increased. As a result of EBSD analysis, the nanostructured and fine-grained region was determined together prominently. According to the tensile test results, it was observed that all polishing processes applied increased the strength and ductility properties together. According to the determined parameters, the processes were successfully applied to the samples. Microstructure analysis, XRD analysis, surface roughness measurement, microhardness and tensile tests were carried out to determine the surface qualities after finishing operations.

The aim of this study is improvements in surface properties of AISI 4340 steel by using burnishing process. Since the process is done cold, it is applied without changing the chemical composition of the part, since only the surface and a certain part of it under the surface are affected, without creating a chemical change in the structure of the part.

**Keywords:** Burnishing, surface roughness, residual stress, plastic deformation, polishing, Finishing. Full Width at Half Maximum (FWHM)

### الملخص العربي

في هذه الدراسة ، قمنا بالتحقيق في تأثير عملية الصقل والتلميع على خصائص السطح من سبائك الفولاذ في متغيرات مختلفة ، تم استخدام سبائك الصلب **AISI 4340** في هذه الدراسة. هذا الفولاذ هو أحد سبائك الفولاذ المفضلة في العديد من المجالات الهندسية لأنه يعطي نتائج جيدة في تطبيقات تشطيب الأسطح ويمكن استخدامه ، وتم تحديد المعلمات لتطبيق الصقل بثلاثة أعماق تمرير مختلفة ليتم تطبيقها مع الاحتفاظ بالآخر ثابت بدون صقل.

في صور المجهر الضوئي للعينات المصقولة P1 و P2 و P3 ، لوحظ تغيير في بنية الحبوب بعد تأثير تشوه البلاستيك على مساحة السطح. وقد لوحظ في تحليل SEM أن سماكة الطبقة المتأثرة بالتشوه زادت مع زيادة كثافة المعالجة. نتيجة لتحليل EBSD، تم تحديد المنطقة ذات البنية النانوية والحبيبات الدقيقة معًا بشكل بارز. وفقًا لنتائج اختبار الشد ، لوحظ أن جميع عمليات التلميع المطبقة تزيد من خصائص القوة والليونة معًا. وفقًا للمعايير المحددة ، تم تطبيق العمليات بنجاح على العينات. تم إجراء تحليل البنية المجهرية وتحليل XRD وقياس خشونة السطح واختبارات الصلابة الدقيقة واختبارات الشد لتحديد خصائص السطح. الهدف من هذه الدراسة هو تحسين خصائص سطح فولاذ AISI 4340 باستخدام عملية الصقل. نظرًا لأن العملية تتم على البارد ، يتم تطبيقها دون تغيير التركيب الكيميائي للجزء ، حيث يتأثر السطح فقط وجزء معين منه تحت السطح ، دون إحداث تغيير كيميائي في بنية الجزء المتأثر بعملية الصقل.

## 1. Introduction

The surface performance and quality have a direct effect on the life of the material, and makes surface finishing processes important. The surface properties of the material are important in all conditions in the industry. The use of polishing and grinding of surfaces is quite common because it provides improvements in the surface properties. Polishing application is a surface finishing process based on crushing that can increase the surface quality of the part by exposing the surface under a certain force. While the cold process provides improvements in surface properties and surface roughness by exposing the surface of the work piece to plastic deformation, it also slows down the damage of the part thanks to the compressive residual stress it creates on the part surface.

In engineering, the fatigue life of machine parts is an important factor in the life of the part. Many studies have been carried out to determine the fatigue life. Damages caused by fatigue occur in 3 stages as crack initiation, crack propagation and breakage of the part. When look at the literature, many studies have been done on crack propagation, but there are very few studies on crack initiation. In engineering, wear refers to the removal of material from the surface in some way due to relative shear in contact areas of solid surfaces of parts. It is a tribological type of damage. Wear; Material mechanics is a phenomenon that can be influenced by many fields including chemistry. Wear is one of the critical factors affecting the service life of parts. Predicting and optimizing wear in mechanical designs of parts is an important step in industrial applications. With the developing technology, an increase has been seen in the usage areas of the finishing application, which had a narrow usage area at first. It is the preferred surface finishing process due to its low cost and ease of use [1,2,3].

The average roughness of the material surface and the hardness of the surface are the most important parameters in evaluating the integrity of the surface. Considering the scientific studies, it is seen that the surface roughness improves between 40% and 90% after burnishing process.

Increases between 17% and 60% are observed in material surface hardness. The changes in these percentages vary depending on the parameters applied during the finishing process and the materials studied. Studies have been made in the literature on the parameters of the finishing process and researches continue to be made on the parameters that provide maximum improvements [4,5,6].

And we did a study on the burnishing process because; it is one of the preferred materials in the field of engineering due to the hardenability of alloy steels due to the amount of carbon, high tensile strength and toughness. burnishing process also will performs in reducing the surface roughness of the material. As a final finishing process, it helps to extend the life of the material by improving properties that are critical in predicting the material's life, such as wear resistance, fatigue, and corrosion. Burnishing is the mechanical surface hardening, which is tried to improve the surface roughness by plastic deformation and crushing with the help of polishing tools. By applying pressure to the surface of the part, a state of residual stress is created and improvements are made in the physical and mechanical properties of the part. Due to its easy application and low cost, polishing and hardening in many sectors such as the automotive, aircraft industry, machine production, hydraulic and pneumatic industry, heating and cooling industry, defense industry, health and electronics, and its use is increasing day by day [7,8,9].

In this research, it was investigated of surface properties for aisi 4340 alloy steel by burnishing process in different parameters. According to the determined parameters, the processes were successfully applied to the samples. The objective of this study is improvements in surface properties of AISI 4340 steel by using burnishing process.

## 2. Material and methods

### 2.1. Material Selection

Alloy steels have mechanical properties such as hardenability, impact and fatigue resistance, and high toughness up to certain loads. These features cause these

types of materials to be used in many areas such as aviation, automotive, gears, shafts, fasteners. The chemical composition of AISI 4340 alloy steel is given in Table 1 and its mechanical properties are given in Table 2, [10,11].

**Table 1: Chemical composition of AISI 4340 alloy steel**

Chemical Composition	C	Mn	Si	Cr	Mo	Ni
	0.43	0.8	0.30	0.90	0.3	2.0

**Table 2: Chemical composition of AISI 4340 alloy steel**

Elastic Modulus GPa	Tensile Strength MPa	Yield Strength MPa	Elongation %	Hardness HB
190-210	744	472	22	217

## 2.2. Finishing Kit

115CrV3 material (burnishing tool), also called mercury steel in the market, which can be easily processed, heat treated and resistant to wear, was used as the tool material. The design and manufacture of the polishing tool used in the processes was carried out within the scope of the research. 115CrV3 material is used as cold work tool steel in many areas such as guides, pins, punches, punches and shafts. [12,13].

The chemical composition of 115CrV3 is given in Table 3 and its mechanical properties are given in Table 4.

**Table 3: Chemical composition of 115CrV3 steel**

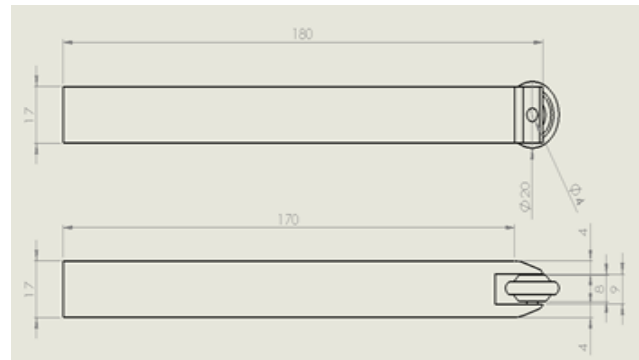
Chemical Composition	C	Mn	Si	Cr	V	P
	1.20	0.30	0.25	0.80	0.1	0.03

**Table 4: Mechanical properties of 115CrV3 steel**

Elastic Modulus GPa	Tensile Strength MPa	Specific Gravity kg/dm3	Poisson Ratio	Hardness HB	Section Narrow %
190-210	1157	7.8	0.30	220	52



**Fig. 1** polishing kit



**Fig. 2** Drawing of polishing tool

## 2.3. Samples Preparation

24 samples were prepared for tests and analyzes from the AISI 4340 alloy steel material determined for the experimental study. The untreated state of the prepared sample is shown in Figure 3 and its technical drawing is shown in Figure 4.



**Fig. 3** Untreated AISI 4340 alloy steel sample

Parameter	Depth of pass mm	Number of passes	Speed rpm	feed rate mm/min
P1	0.25	1	180	0.25
P2	0.50	1	180	0.25
P3	0.75	1	180	0.25

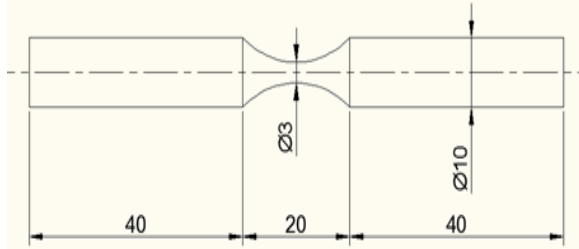


Fig. 4 Drawing of AISI 4340 alloy steel sample

### 3. Application of Mechanical Surface Treatments

Three different parameters, P1, P2 and P3, were determined for the surface finishing application. Burnishing was applied, provided that the other parameters with three different pass depths were kept the same. The parameters are given in detail in Table 5.

Application of each pass depth, polishing application was made on 8 samples on a lathe. In Figure 5, the region where the polishing process applied on the sample is shown schematically. Polishing application is shown in Figure 6.

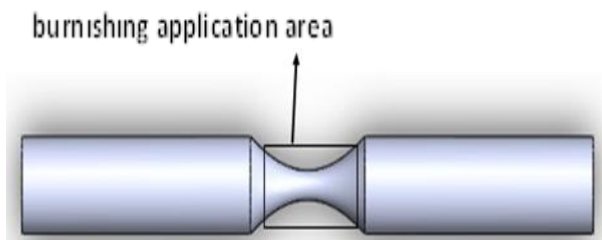


Fig. 5 The area where the polishing is made



Fig. 6 Application of finishing

Burnishing was applied to create compressive residual stress as a result of plastic deformation on the surface of the test materials. The polishing application was applied to the surface of the sample on the lathe. Table 5 shows the parameters applied according to the processes in the finishing process.

Table 5: Finishing process application parameters

### 3.1. Microstructural Studies

In this experimental study, it was aimed to determine the changes in the surface and under the surface after the studies carried out at 3 different pass depths. Optical microscopy, SEM and X-ray diffraction (XRD) analyzes were performed on the pieces taken from the samples in order to determine the microstructure characterization.

After pulling the analyzed parts, the parts were cut from the area where the part broke off, and the analyzes were made. The parts taken for analysis are shown schematically in Figure 7.

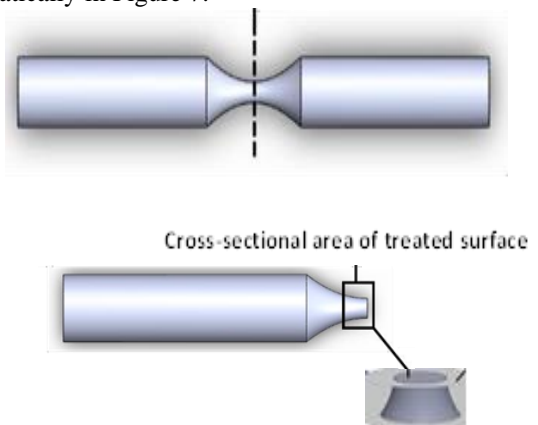
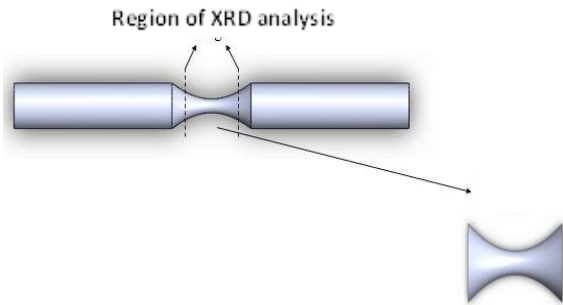


Fig. 7 Cross-sectional region perpendicular to the treated surface

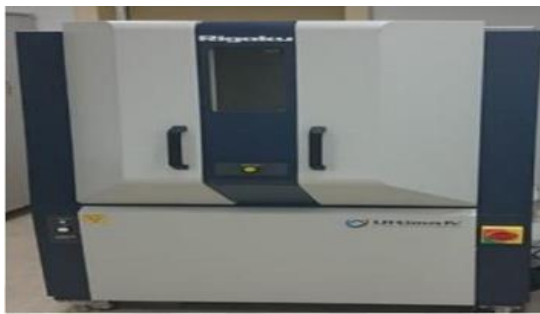
### 3.2. XRD Analysis

X-ray diffraction analysis was performed, and Analysis Measurements were made with a generator voltage of 30 kV and a current of 20 mA with X-ray diffraction at angles between 10° and 90°, with a step scan size of 0.02°, at a

speed of 3.5 degrees per minute. Figure 8 shows the region where the analysis was made and Figure 9 shows the device where the analysis was made.



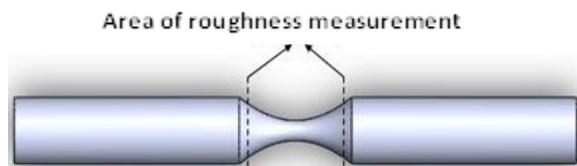
**Fig. 8** the region where XRD analysis was performed



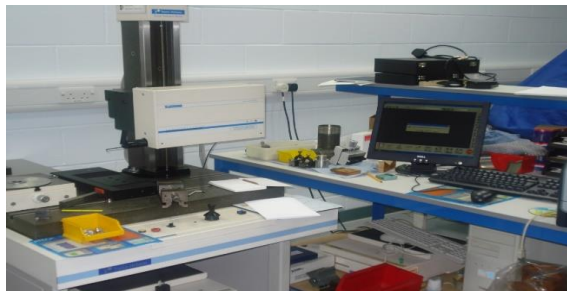
**Fig. 9** XRD device

### 3.3. Surface Roughness Measurements

Different tests were used to analyze the physical properties of the material after finishing. As a result of the roughness tests, Ra, Rq and Rz values were evaluated by taking the arithmetic average of the values at 3 different points. In Figure 10, the region where the roughness measurement of the sample is made is shown schematically, and Figure 11 shows Surface roughness measurement in the lab.



**Fig. 10** the area where the surface roughness is measured

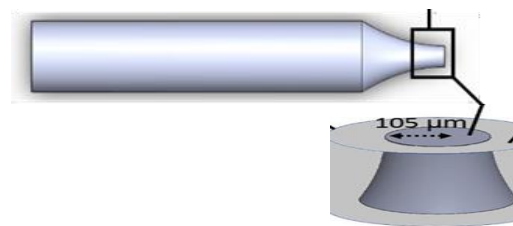


**Fig. 11** Surface roughness measurement in the lab

### 3.4. Measurement of Microhardness

Microhardness measurements were made from the cross-section region perpendicular to the AISI 4340 treated surface area, where P1, P2 and P3 processes were performed, up to a distance of 105  $\mu\text{m}$  with 15  $\mu\text{m}$  intervals from the surface of the material. In Figure 12, the microhardening region is shown schematically. For microhardness measurements, the applied load was set as HV0.005 and the application time was set as 15 seconds.

**Microhardness measurement area**



**Fig. 12** The surface area where the microhardness measurement is made

### 3.5. Tensile Test

The samples produced from AISI 4340 material were untreated and treated samples were subjected to the tensile test in order to detect the changes in the mechanical properties of the material after the finishing application. Tensile test was carried out at laboratory. After the test, the stress-strain graph, tensile strength, yield strength and elongation data of the samples were obtained.



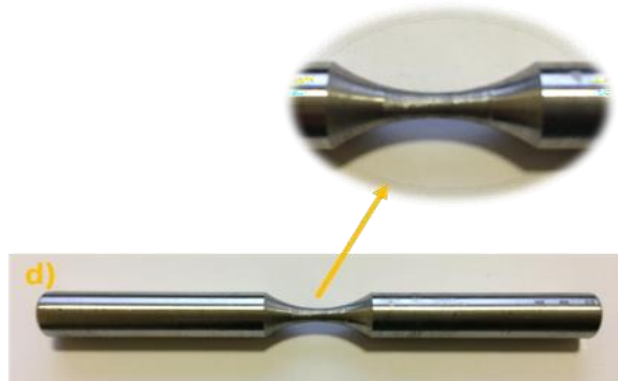
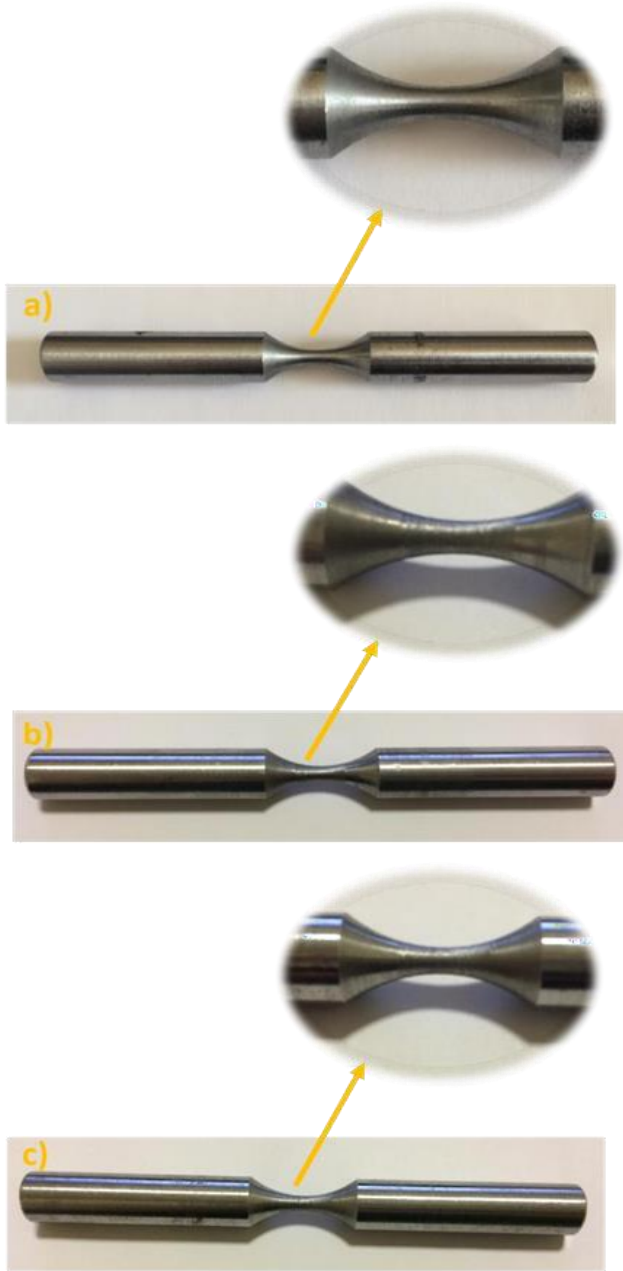
**Fig. 13** Tensile testing machine

## 4. Experimental Results and Discussion

### 4.1. Microstructural analysis

The macro changes in the untreated and treated surfaces of the samples before detailed analyzes of the microstructure are given in Figure 14. Tool traces of the

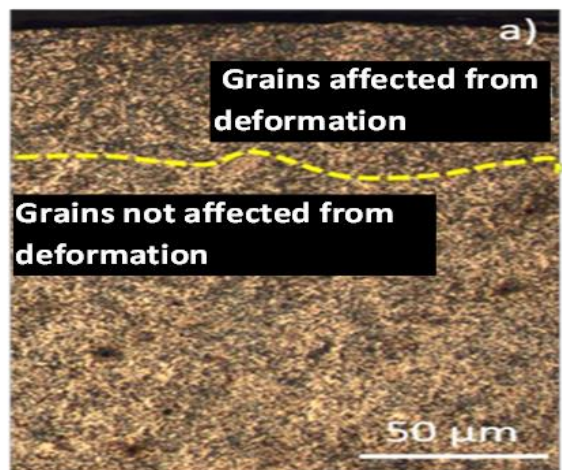
untreated sample after machining are shown in Figure 14.a. In Figure 14.b, Figure 14.c and Figure 14.d, the presence of movement traces of the finishing set is remarkable. It was observed that the presence of movement traces of the polishing tool was more pronounced with the increase in the depth of the pass.



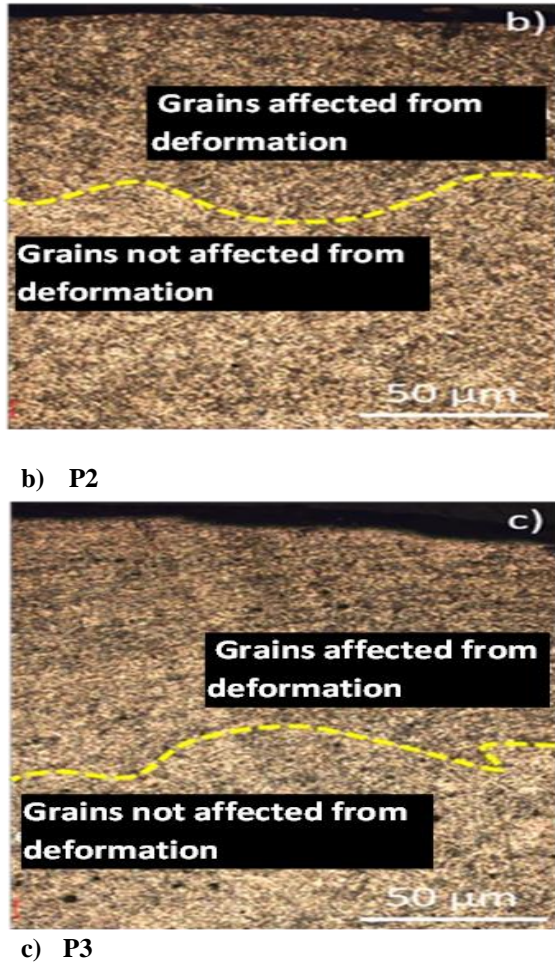
**Fig. 14** Photographs of a) Unprocessed, b) P1, c) P2 and d) P3 samples

In Figure 15, optical microscope images of the samples polished under P1, P2 and P3 conditions are shown in the optical microscope images. After the polishing process, a change in the grain structure was observed after a plastic deformation effect on the surface area. The structure affected by the process on the surface was printed more compared to the interior and the homogeneity of the structure deteriorated.

It was noted that the striking distributions of different colors in the interior structure intertwined and the distinctive structures began to disappear. At the same time, the thickness of the deformed region increased with the increase of the effect of the polishing process. It is seen that the grains are oriented from left to right after polishing at P3 intensity, which also indicates the polishing direction. Although process-induced deformation is observed in the surface line, it has been observed that the effect is more limited than excessive ball forging or surface mechanical deformation process [14,15,16].



a) P1



**Fig. 15** Optical microscope images from the cross-sectional region of the samples a) P1, b) P2 and c) P3.

In the SEM images in Figure 16, the compounds formed by the iron-based internal structure and alloying elements in the microstructure attract attention. In the SEM analysis, the deformed structure in general was distinguished from the internal structure as oriented. It was also seen in the SEM analysis that the layer thicknesses affected by the deformation increased as the processing intensity increased.

Layer thicknesses are compatible with optical microscope studies. This situation, in which the surface integrity and flatness is largely preserved after P1 and P2 applications, shows that the polishing process can be an important surface extreme plastic deformation method. However, as the processing conditions get heavier, the effect on the surface gets heavier. In the P3 application, the deformation effective layer thickness deepens considerably and it is thought that it may have an effect in terms of mechanical properties. Unlike the optical images, it showed the presence of a nebula structure on the surface with limited detailed characterization. Studies in the literature

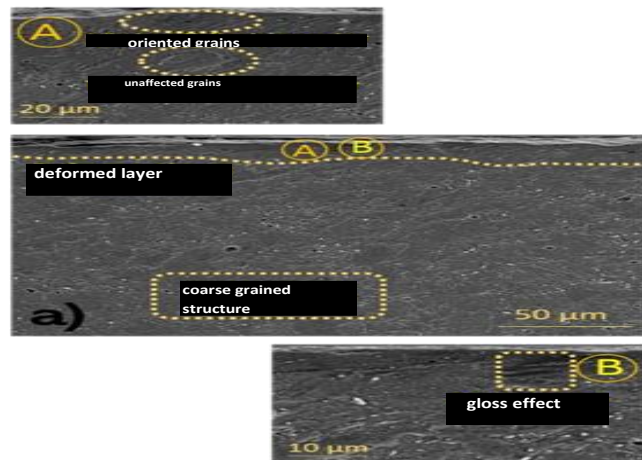
have shown that this structure is a deformed ultra-fine-grained or Nano crystalline structure.

EBSDB analysis was performed to determine the phase change, grain size change and layer differences of such structures and are shown in Figure 17. After the EBSD analysis, 3 different structures draw attention from the surface to the interior in general terms. Similar approaches are emphasized in gradient materials, which have just begun to be introduced in the literature [17,18,19].

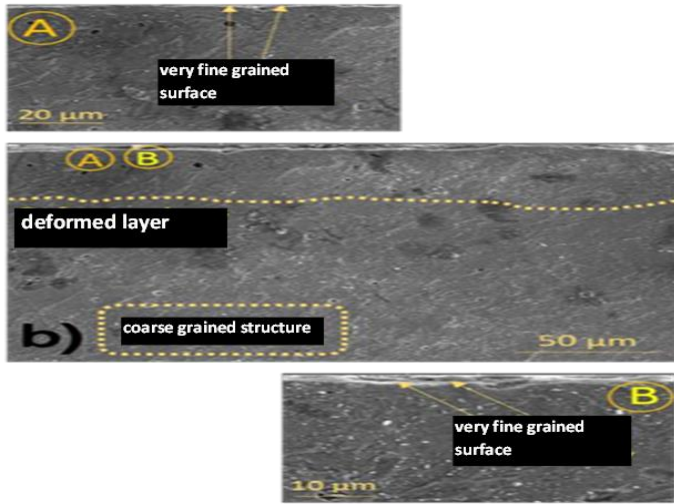
Due to the heterogeneous structure of the gradient materials with the surface deformations, significant increases in both strength and ductility properties have begun to be observed. It is thought that this situation will have a significant impact on the new type of material and the ductility-strength relationship. Three different structures emerged in the EBSD examination after P1, P2 and P3 procedures. In the outermost layer, which is faced with a large proportion of the deformation energy at the surface and below, the presence of three main layers: nanocrystalline (ultra-fine) grained layer, fine-grained, deformation-affected layer where the deformation effect gradually decreases but the effect is palpable, and coarse-grained structure that is not affected by the process.

As seen in Figure 17, a nanocrystalline structure was obtained in a very thin layer. Due to the low impact, the layer affected by any deformation in the lower part does not attract attention, and it was concluded that the thickness of the two layers is very close to each other. The reason for this is thought to be the increase in the distance between these two layer thickness boundaries with the increase in intensity. It was observed that the thickness of both nanocrystalline and deformation-affected, oriented fine-grained layers increased significantly as the processing conditions increased.

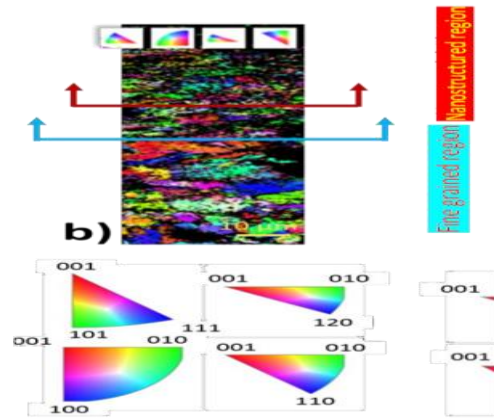
Although the application methodology is different in the studies, the existence of similar formations after extreme ball forging, surface mechanical deformation treatment (SMAT) and ultrasonic nanocrystal surface modification (UNSM) applications has attracted attention [20,21,22].



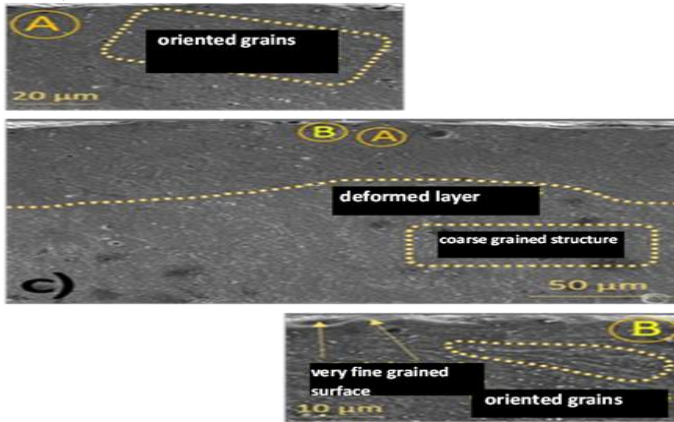
a) P1



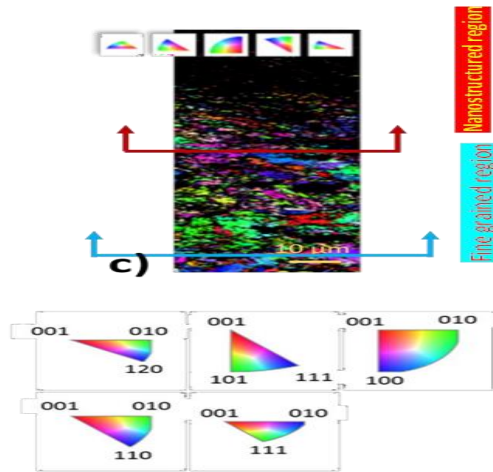
a) P1



b) P2



b) P2

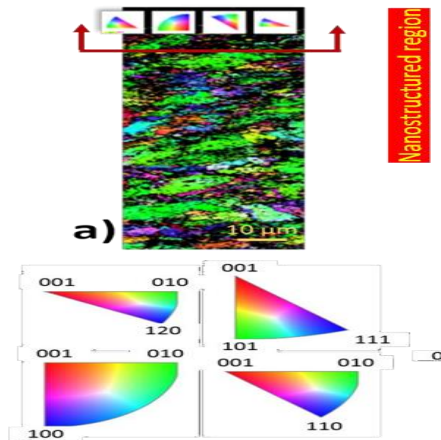


c) P3

Fig. 16 SEM images from the cross-sectional region of the samples a) P1, b) P2 and c) P3

c) P3

Fig. 17 EBSD images from the cross-sectional region of the samples a) P1, b) P2 and c) P3

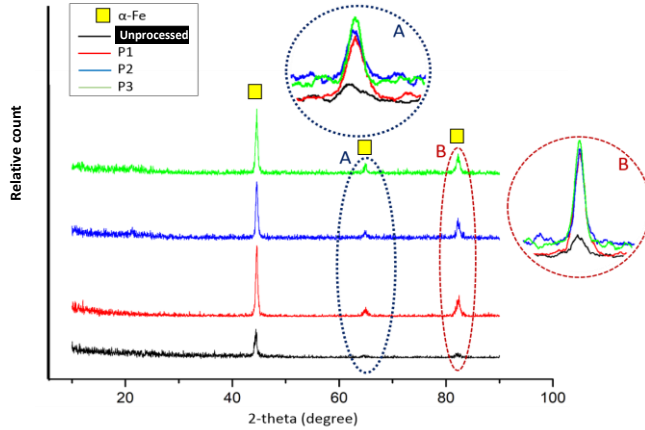


#### 4.2. XRD Analysis

When the X-ray diffraction graphs in Figure 18 are examined, only iron peaks are observed. Since the surface has undergone sanding and polishing processes, no oxide structure or impurity has been encountered. The same peaks were obtained after the polishing process, and no new peak formation was observed that could reveal the chemical change, since it is a mechanical surface deformation process due to the nature of the application on the surface.

In the images obtained from two different peaks, it was observed that the positions of all the processed peaks shifted to different degrees, and the shifting process tended to high angles. The shift of the peaks to different angles after the applied P1, P2 and P3 treatments has been associated with lattice distortions and residual compressive stress loading in

studies in the literature. At the same time, an increase was observed in the half-height peak width (Full Width at Half Maximum (FWHM) measurements, which provide significant approximations to the average grain size in the surface region, after treatment. The increase in FWHM revealed that the grain size decreased and the grains got thinner with deformation. FWHM values are given in Table 6 [23,24].



**Fig. 18** XRD analysis of unprocessed, P1, P2 and P3 samples

**Table 6: Values of peak width at half height of applied surface treatments**

		FWHM			
2θ	peak	Untreated	P1	P2	P3
44,50	110	0,47	0,435	0,41	0,48
64,82	200	0,466	0,76	0,405	0,477
82,26	211	0,466	0,74	0,405	0,477

### 4.3. Surface Roughness Test

In Table 7, the surface roughness values before and after the operations are given. It was observed in the measurements that the surface roughness increased after the finishing processes. Since the finishing conditions are quite different from each other, the rate of increase in roughness is high.

However, it has been revealed that the roughness of the polishing process remains constant after a certain level and does not increase as an important advantage over the others. This situation showed that polishing process can be an important preferable surface extreme plastic deformation alternative considering the surface properties.

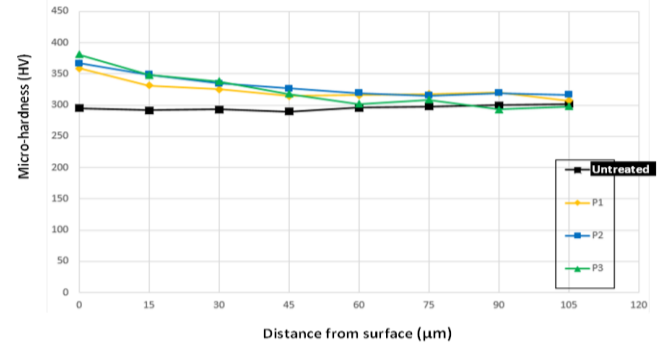
**Table 7: Surface roughness of samples**

Samples	Ra(μm)	Rq(μm)	Rz(μm)
Untreated	1,069	1,454	7,08
P1	2,815	3,490	15,978
P2	4	4,917	21,190
P3	4,116	5,04	21,773

### 4.4. Microhardness Analysis

Plastic deformation by compressive loading on the surface of the material creates a localized cold-worked zone on the sample surface. This formed region hardens with the effect of plastic deformation. By increasing the effect of plastic deformation, the layer thickness of the formed layer increases. This hardened layer also provides positive contributions to the improvement of corrosion resistance and wear resistance values. In Figure 19, the hardness values of the samples before and after the processes are given graphically. It is seen that as the effect of plastic deformation is increased, the hardness increases accordingly. In terms of hardness, it was observed that P1 and P2 changed and improved from the surface of the material to a depth of 105 μm, and P3 to a depth of 75 μm.

It is seen in the graph that the applied polishing applications make significant contributions to the hardening of the material and it is clearly seen that the polishing application can be an alternative to other surface improvement methods [25,26].



**Fig. 19** Hardness graph of untreated, P1, P2 and P3 samples

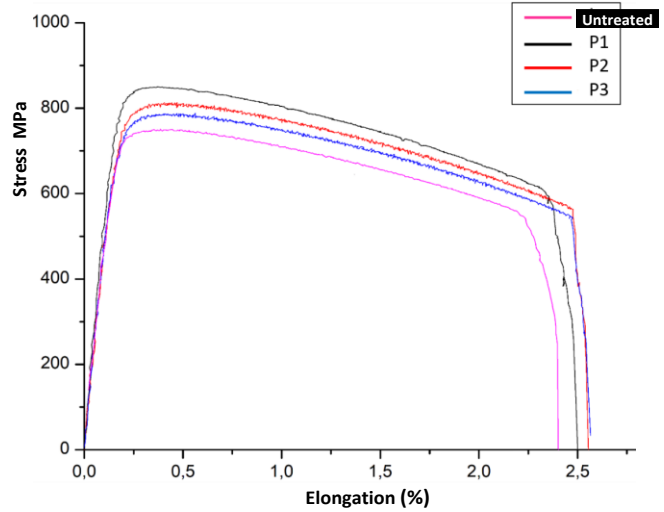
### 4.5. Tensile Test Results and Evaluation

The macro-level images of the fractures obtained by the tensile tests performed on all treated and untreated samples are given in Figure 20, the stress-strain diagrams are given in Figure 21 and the strength-ductility values are given in Table 8. The morphological behavior of rupture during tensile offers a specific approach to understanding the ductility and strength properties of samples. It has been observed that the outer surface undergoing plastic deformation shows the necking phenomenon compared to the inner surface. According to the tensile test results, it was observed that all polishing processes applied increased the strength and ductility properties together.

While the yield strength of the untreated sample was 720 MPa, values of 830 MPa, 795 MPa and 770 MPa were reached in the P1, P2 and P3 finishing processes, respectively. While the maximum tensile strength was 755 MPa in the untreated sample, it increased to 850 MPa, 815 MPa and 795 MPa in the P1, P2 and P3 treatments, respectively. While the most effective process was P1 in terms of strength values, P2 and P3 effects were dominant in terms of ductility. This situation has been shown both in this study and in other literature studies, which eliminate the strength-ductility balance construct by surface extreme plastic deformation applications and gradient materials.



**Fig. 20** a) untreated sample, b) P1, c) P2 and d) P3 Photographs of samples after rupture



**Fig. 21** Stress-strain curve of samples

**Table 8: Stress - strain curve values**

	yield strength (MPa)	Max tensile strength (MPa)	Elongation (%)
Untreated	720	755	2.40
P1	830	850	2.50
P2	795	815	2.55
P3	770	795	2.56

## 5. Conclusion

The results obtained from experimental studies are given below.

1. As the effect of plastic deformation in the processes is increased, there is an increase in the layer thickness affected by the processes, it was observed that the P1 and P2 treatments largely preserved the surface integrity and flatness, and no oxide layer and surface cracks were observed after the treatments.
2. As a result of EBSD analysis, only the nanostructured region was determined prominently in P1, while the nanostructured and fine-grained region was determined together prominently in the P2 and P3 processes.
3. The peaks obtained from all samples are congruent. This supports the fact that all of the processes are mechanically based and there is no chemical change. It was observed that FWHM values increased as the effect of the procedure was increased.
4. There was no improvement in the surface roughness after the procedures. It is noteworthy that the surface roughness deteriorates further as the effect of the processes is increased. This situation reveals important clues that the parameters of the calendaring process enter the

extreme plastic deformation area. It has been concluded that reducing and optimizing the parameters can have a positive effect on surface roughness.

5. The increase in the thickness of the layer affected by plastic deformation, where the processes have a positive effect in terms of effect on the hardness. The best hardness values in the processes are P3, P2 and P1 respectively.
6. It has been observed that after the processes, it provides positive contributions to the mechanical properties of the material. While the best treatment in terms of ductility was P1, the most effective treatments in terms of strength were P2 and P3.

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