# MICROSTRUCTURAL EVOLUTION DURING THERMOMECHANICAL PROCESSING OF Ti-6246 TITANIUM ALLOY

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*A Ti-6Al-2Sn-4Zr-6Mo (wt. %) alloy has extensively used in the aerospace applications due to its high mechanical properties. The present paper aimed at examining the changes in the microstructure of Ti-6246 titanium alloy during thermomechanical processes (TMPs). The alloy was subjected to a combination of TMPs comprising in the following stages: hot plastic deformation in the α + β field and normalizing heat treatment in the β field. The results showed that the effects generated by TMPs have a strong influence on the microstructural characteristics. All the samples were exhibiting various microstructural morphologies in different orientations. The microstructures features were highly improved by the normalizing heat process as compared to the initial material and the processed material by hot plastic deformation.*

**Keywords**: Ti-6246 titanium alloy, hot plastic deformation, thermomechanical processing, microstructure evolution

## 1. Introduction

Titanium alloys are used in various applied industries, especially in the aerospace one. These alloys are largely applied due to their good mechanical properties, low Young's modulus, high specific strength, excellent corrosion resistance, good mesothermal performance and non-toxic [1, 2].

Various types of Ti-based alloys are available and one of the most popular alloys is the Ti-6Al-2Sn-4Zr-6Mo (Ti-6246). It is considered as one of the indispensable structural materials of airplanes and it is used in advanced airplanes between the range of about 30% - 50% weight of the total structure, for example, 41% of total structure in F-22 fighters [3, 4].

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Titanium alloys can be classified into different groups such as α + β titanium alloys group, Near-β or "metastable β" alloys, and α type alloy. The α + β alloys are rich of both α and β stabilizers, comprising around 4 to 6% of β stabilizers which make them very desirable to develop high strength alloys. Near-β or "metastable β" alloys have less amount relatively of β-stabilizers that contains approximately (10% - 15%) in comparison with β alloys includes large quantities of β-stabilizers (around 30%) that stabilize β phase at an ambient temperature which is considered the very heavily β-stabilized alloys. On the contrary, Ti-alloys type α is single phase alloys i.e. they do not have β-stabilizers elements and near-α/super α alloys have a slightly higher response to the thermo-mechanical processes (TMPs) than α alloys. This is because they contain a slight percentage (up to 2 wt. %) of β-stabilizer leads to enhance their workability, ductility, and strength [5-7].

The β-transus temperature ($TT_β$) is a central point in the thermomechanical processing topic because it is working to an arrangement and separate of the alpha and beta phases [8]. It can be defined as the lowest equilibrium temperature at which the material is 100% β [9, 10].

Generally, α + β alloys required a combination of thermomechanical processes to change the microstructures and mechanical characteristics in comparison with β alloys that can be changed dramatically only by heat treatments [11, 12]. The paper aims to examine the microstructure changes of Ti-6246 titanium alloy during the thermomechanical processes (TMPs).

## 2. Materials and Methods

The examined alloy was obtained by Vacuum Arc Remelting (VAR) at Zirom S. A., Giurgiu, Romania. The chemical composition of the resulted alloy was Ti-6Al-2Sn-4Zr-6Mo (wt. %). The initial sample was cut by a precision cutter machine (model Metkon Micracut 200) into five parts in equal dimensions which are 27 mm, 11 mm and 4.2 mm. Fig. 1 shows the route of the thermomechanical processes of the Ti-6246 titanium alloy in detail. The potential energy (weight) for the deformation process was 117 Kg and free fall distance (high) of 1m in order to obtain a high degree of deformation and preserve the integrity of the alloy structure simultaneously.

Each sample was subjected to hot-mounted by a Buehler SimpliMet mounting press in a cylindrical sampler, and also subjected to the grinding and polishing processes by a Metkon DIGIPREP Accura (advanced high-end grinding and polishing system). The microstructure was examined for five samples by scanning electron microscopy (SEM) model TESCAN VEGA II–XMU and optical microscopy (OM).

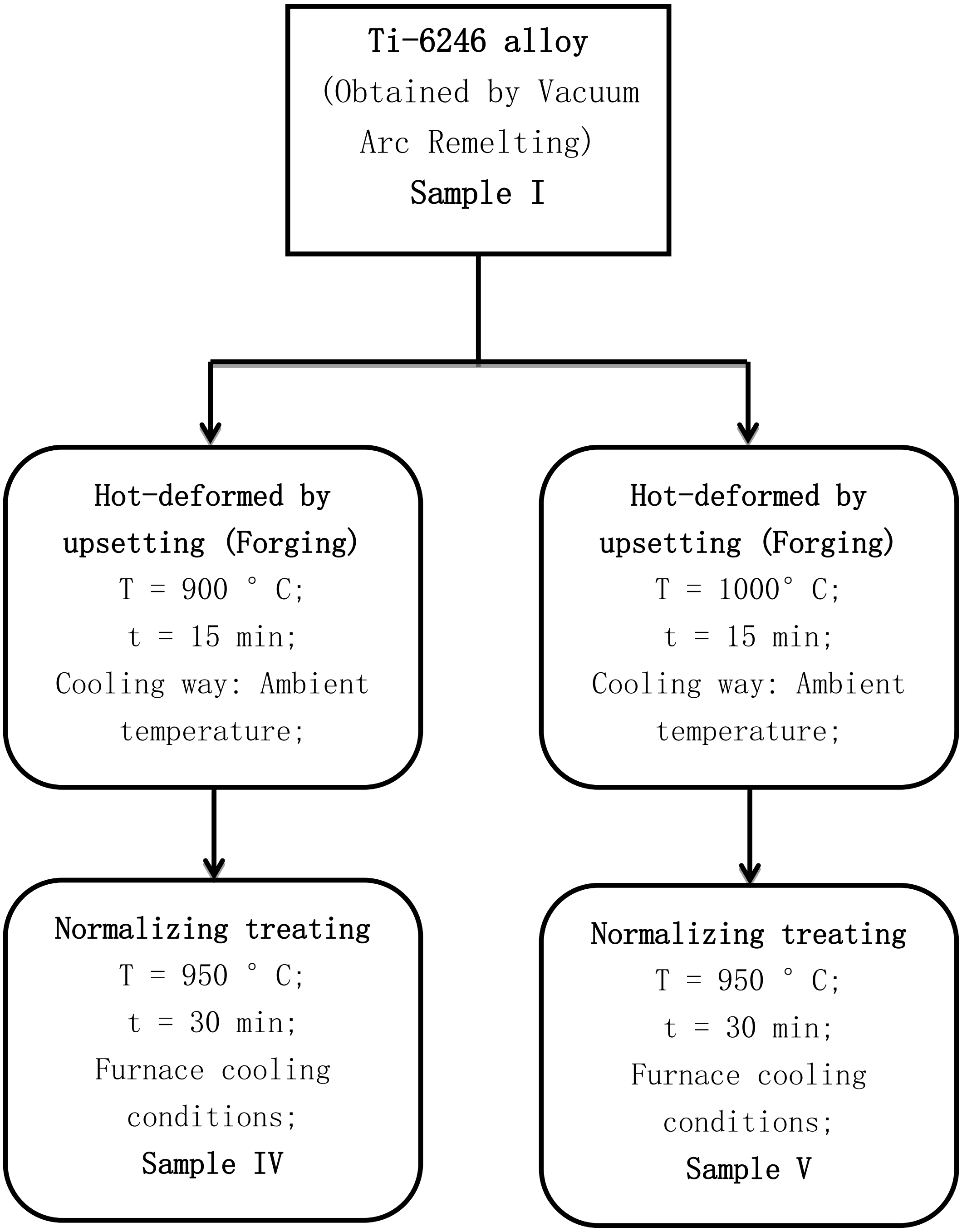


Fig. 1 The TMPs route of the Ti-6246 titanium alloy.

## 3. Results and Discussions

After the hot deformation process, the dimensions of the II and III samples changed. Table 1 presents the dimensions of the II and III samples after the hot plastic deformation process.

*Table 1*

**The dimensions of samples II and IV after hot deformation process**

| New dimensions, (mm) | Samples | |
|---|---|---|
| | Sample II | Sample III |
| Length | 35.3 | 36.7 |
| Width | 23.4 | 26.7 |
| Thickness | 1.7 | 1.6 |

The following equation has been used to calculate the deformation degree of the II and III samples:

$$\varepsilon = \frac{H-h}{H}\,100 \qquad (1)$$

where,
ε - the deformation degree (%);
H - the initial thickness in (mm);
h - the final thickness in (mm).

The degree of deformation of the samples II and III were 59.5% and 62% respectively. It should be pointed out that the temperature is proportional directly to the deformation degree, where the higher the temperature the greater the degree of deformation.

***Alloying elements observations***

The SEM-BSE and SEM-SE images and the observations of alloying elements in the microstructure for the initial sample are shown in Figs. 2 and 3. The microstructure contains α-lamellar colonies and β-Ti phase distribute between α-lamellar as shown in Figs. 2.a and 3.a. The high concentration of Ti is observed in α-Ti lamellar (Figs. 2.b and 3.b), followed by Al (Figs. 2.c and 3.c), because of α-Ti phase stabilizing the effect of Al, also the Mo content is observed in the sites between α-Ti lamellar (Figs. 2.d and 3.d), stabilizing the β-Ti phase. Usually, Sn and Zr (Figs. 2.e-f and 3.e-f); they have a modest diffusion in the stabilization of α-Ti and β-Ti phases, but Zr (Figs. 2.e and 3.e) showed a strong effect in the β-Ti phase stabilization. The EDS spectra lines of Ti, Al, Mo, Zr and Sn were observed within the initial sample (Figs. 2.g and 3.g), whereas the other relevant EDS lines were neglected due to their very meager content. The chemical composition was computed by designating five random microstructural images and EDS analyzed. Tables 2 and 3 illustrate the chemical composition data by SEM-BSE and SEM-SE detectors respectively which were statistically analyzed [5, 13].

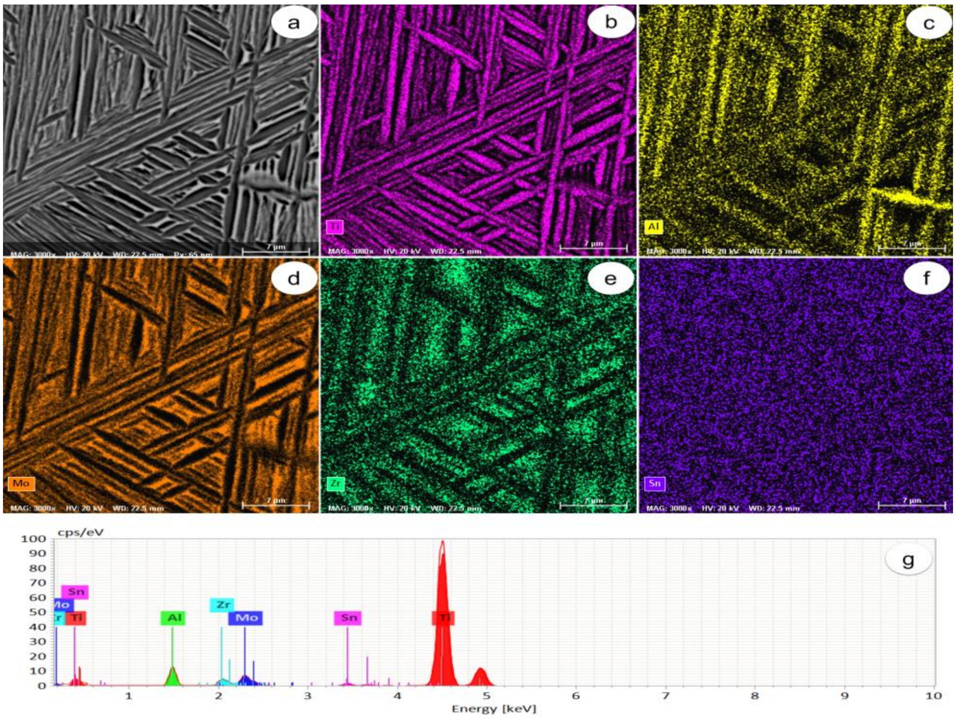


Fig. 2 Alloying element's observations in the initial sample (obtained at Zirom S.A. Giurgiu, Romania); a) high magnification BSE image of the initial sample microstructure; b) Ti observations; c) Al observations; d) Mo observations; e) Zr observations; f) Sn observations; g) EDS spectra of the initial sample.

*Table 2*

**The chemical composition by SEM-BSE for the initial sample**

| Element | Line | Mass [% wt] | Mass [% at] | Absolute error [%] | Relative error [%] |
|---|---|---|---|---|---|
| Ti | K-Serie | 81.53 | 83.57 | 2.51 | 2.79 |
| Al | K-Serie | 5.43 | 9.88 | 0.31 | 5.19 |
| Mo | L-Serie | 6.31 | 3.23 | 0.27 | 3.92 |
| Zr | L-Serie | 4.32 | 2.33 | 0.21 | 4.42 |
| Sn | L-Serie | 2.40 | 0.99 | 0.10 | 3.88 |
| Sum | | 100 | 100 | | |

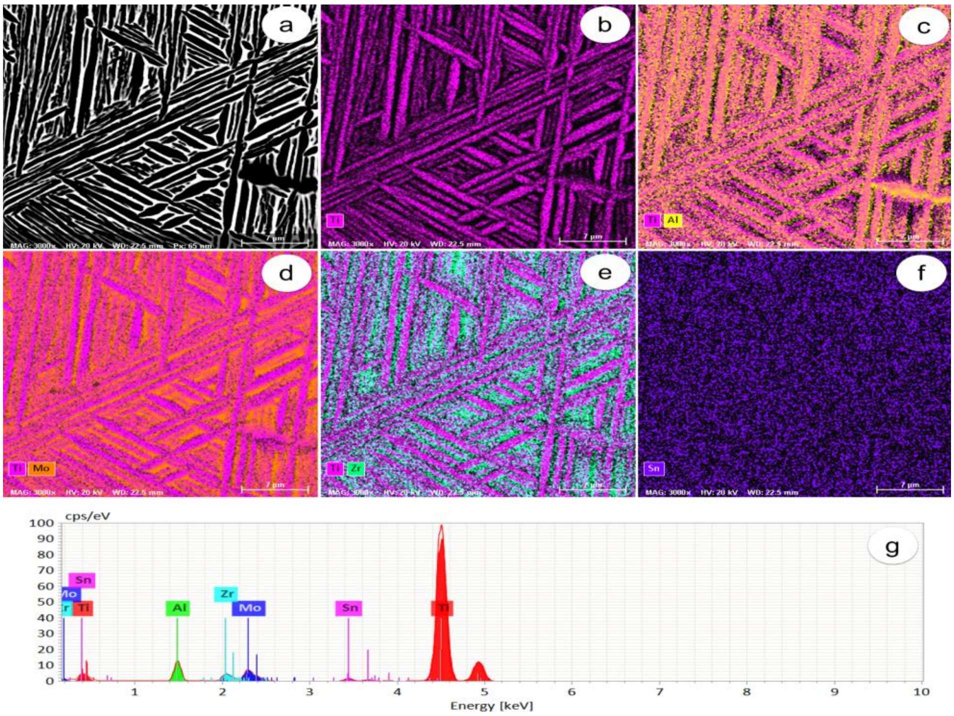


Fig. 3 Alloying element's observations in the initial sample (obtained at Zirom S.A. Giurgiu, Romania); a) high magnification SE image of the initial sample microstructure; b) Ti observations; c) Ti-Al observations; d) Ti-Mo observations; e) Ti-Zr observations; f) Sn observations; g) EDS spectra of the initial sample.

*Table 3*

**The chemical composition by SEM-SE for the initial sample**

| Element | Line | Mass [% wt] | Mass [% at] | Absolute error [%] | Relative error [%] |
|---|---|---|---|---|---|
| Ti | K-Serie | 81.53 | 83.57 | 2.50 | 2.78 |
| Al | K-Serie | 5.43 | 9.88 | 0.31 | 5.18 |
| Mo | L-Serie | 6.30 | 3.22 | 0.27 | 3.91 |
| Zr | L-Serie | 4.32 | 2.32 | 0.21 | 4.41 |
| Sn | L-Serie | 2.40 | 0.99 | 0.10 | 3.88 |
| Sum | | 100 | 100 | | |

## *Metallographic Analysis*

The microstructures were analyzed by SEM and OM for all samples. The structure observed by SEM-SE images has α-Ti phase and β-Ti phase, the black sites referred to the α phase and the white sites referred to the β phase. The microstructure is presented by OM image, the darker sites referred to the β phase and the brighter sites referred to the α phase. The microstructures of the initial sample consist of α + β lamellar as shown in Figs. 4a and 4b. The microstructure of OM in Fig. 4c has a crystal lattice of α + β lamellar.

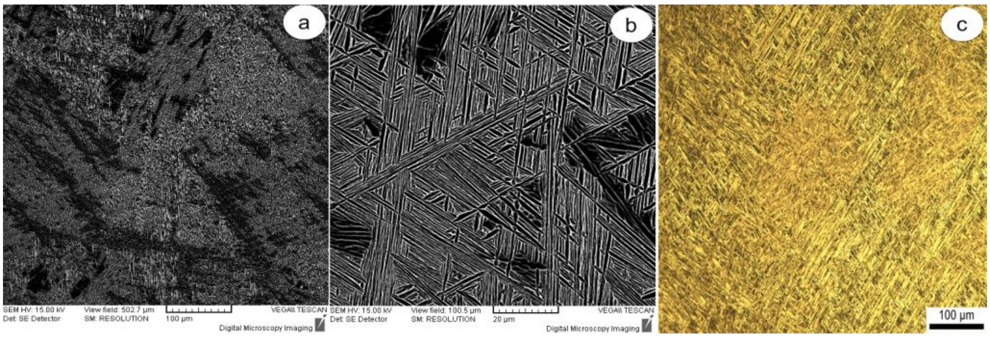


Fig. 4 SEM-SE and OM microstructures of the initial sample (sample I).

The microstructures observed in Figs. 5a and 5b are that α-lamlllar begin to the globularization within a β solution during the deformation process at 900 °C as compared to the α-lamellar which appeared in the initial sample. The observed structure in Fig. 5c is that β begin to the globularization within an α solution.

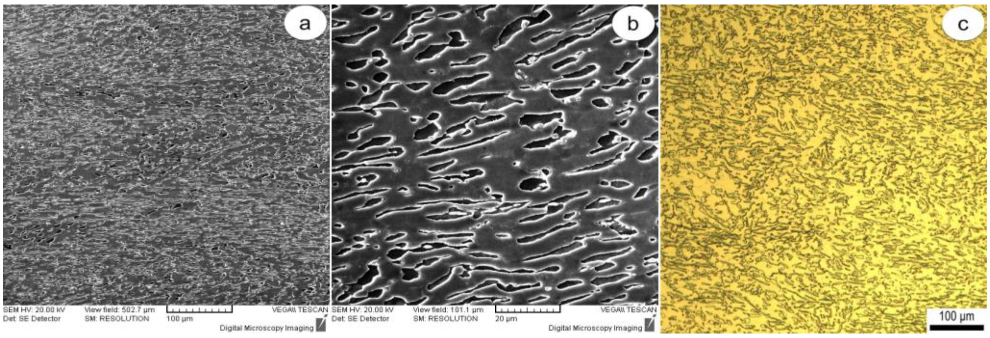


Fig. 5 SEM-SE and OM microstructures of sample II during the hot-deformed process at 900°C.

Figs. 6a and 6b show the microstructure contains α grains in multiple sizes and the fragments of the β phase on the grains boundaries in some sites. The structure in the micrograph (Fig. 6c) contains β grains in multiple sizes separated by grains boundaries of α phase.

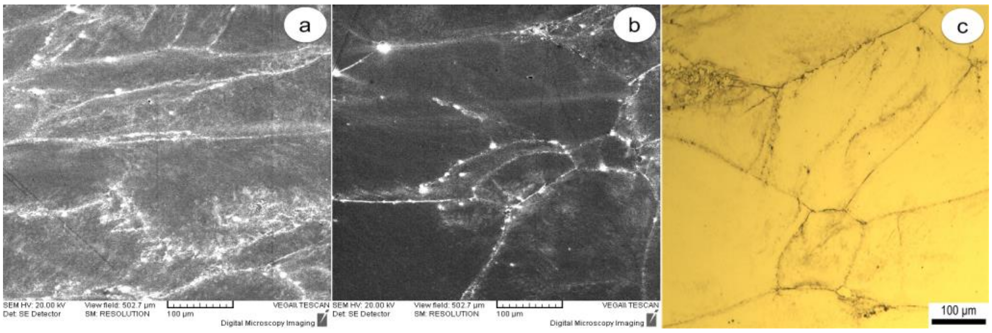


Fig. 6 SEM-SE and OM microstructures of sample III during the hot-deformed process at 1000°C.

In the normalizing heat treatment, can be observed the grain size has become small, the α + β acicular structure has been generated having a thicker than the initial sample as shown in Figs. 7a, 7b and 7c.

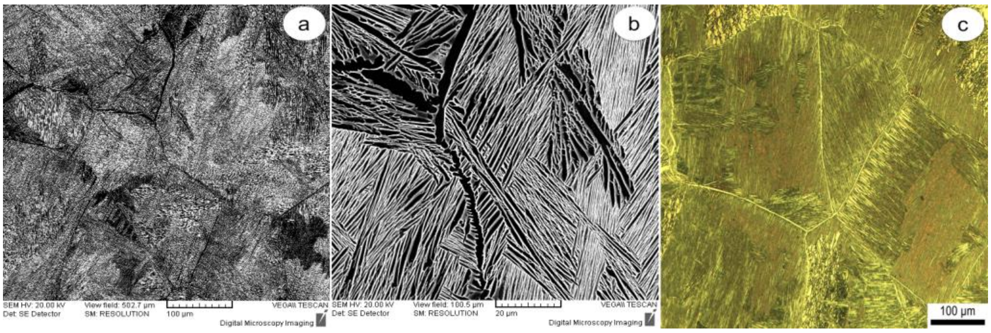


Fig. 7 SEM-SE and OM microstructures of sample IV during the hot-deformed process at 900°C and normalizing heat treatment process at 950°C.

The appearance of grains in the microstructure has improved which is displayed in Figs. 8a, 8b and 8c and regeneration α + β plates or lamellar structure also thicker than the initial sample. Moreover, the evolution of the α phase was reduced due to a slightly elevated temperature.

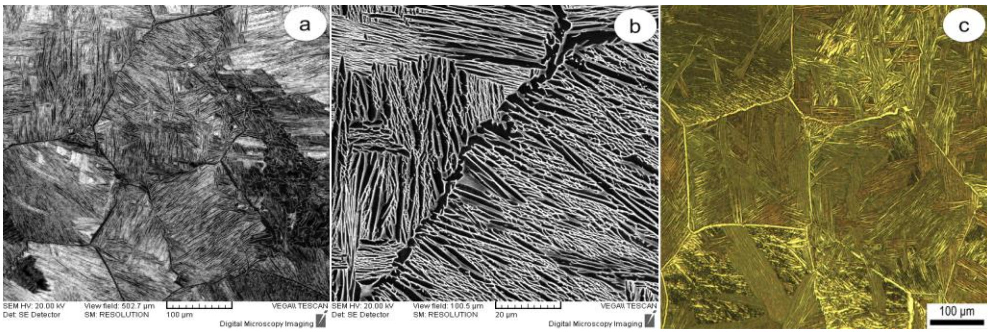


Fig. 8 SEM-SE and OM microstructures of sample V during the hot-deformed process at 1000°C and normalizing heat treatment at 950°C.

## 4. Conclusions

The paper aimed to explore the microstructure changes of the Ti-6246 titanium alloy that was subjected to a combination of thermomechanical processes. Different temperatures have caused significant changes in the microstructure of all samples. The preserve time for 15 minutes on the deformed samples at 900°C and 1000°C did not plays a strong role in affecting the microstructures like the temperature; the cooling rate at ambient temperature also makes the crystal lattice thicker as compared to the initial material. Moreover, the grains size is small as compared to the initial sample.

The normalizing samples which were heated for 30 minutes and cooled in the surrounding of the furnace; the grains size was smaller and finer in this process as compared to the initial material and the processed material by hot plastic deformation. Therefore, the microstructure has improved in the normalizing heat treatment. From the mechanical viewpoint, the small grains are desirable for the mechanical features.

R E F E R E N C E S

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