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Effect of Temper Rolling Reduction Ratio on Microhardness and Microstructure of DC04 Grade Sheet Material

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Abstract
With temper rolling, which is the final stage of the cold rolling manufacturing process, to the surface of sheet metal materials is transferred roughness with specially roughened rolls. In this study, microhardness and microstructural evolution occurring in the section along the thickness of DC04 grade sheet materials temper rolled with various reduction ratios were investigated. As a result, it was concluded that the microhardness distribution taken from the section along the thickness increases with the increase of reduction ratio and the microhardness distribution from the surface to the center in the section decreases. In the temper rolling process with a reduction ratio of 250 μm and 500 μm an increase of approximately 5% and 15% has occurred, respectively compared to before the temper rolling process. It was also concluded that with the increase in reduction ratio, the grains in the section along the thickness elongated and thinned on the surface and this change in the center compared to the regions close to the surface was less.

1. Introduction

DC04 grade sheet materials are often preferred in automotive applications (auto body panel) due to their good formability, high strength and high amount of ductility [1, 2]. Because of these advantages, the surfaces of DC04 grade sheet materials which are used extensively in automotive applications should have a standard range of roughness for painting and shaping [3].

Temper rolling (skin-pass rolling) is the rolling process used in the final forming stage of automotive sheets [4]. In the temper rolling process, the surface roughness profile is transferred to the materials through rolls with a special texture [5]. Thanks to the surface roughness profile obtained, the forming ability and paint adhesion of sheet materials are improved. [4]. Surface roughness transferred to sheet materials by rough rolls in temper rolling is affected by many rolling parameters (roll parameters, rolling speed, reduction ratio, rolling force, elongation, lubricant conditions, etc.) [6, 7]. Among these parameters in temper rolling, the reduction ratio is one of the most effective parameters to obtain the desired surface roughness on the surface of sheet materials [8]. As the reduction ratio rises, the roughness transferred to the surface of the sheet material increases [9, 10]. At the same time, the rise in the reduction ratio causes an increase in the rolling force [7]. Since the reduction ratio in temper rolling is miserable, the pressure in areas close to the surface is higher [11]. Temper rolling differs from cold rolling in that it takes place along a high friction and a large contact arc [12]. There are many studies characterizing the microstructure and microhardness in cold rolling, but there is a large gap in the literature on this subject in temper rolling. Grassino et al. investigated the surface microstructure and along thickness microhardness behavior in temper rolled materials with three different C content (low-C steel, ultra-low C steel, zinc coated C mild steel). In all three steels, the microhardness value was slightly higher in the parts close to the surface. They observed that the microhardness profile took an almost flat shape as a result of rolling elongation of more than 2% in the zinc coated C mild steel [13]. On the other hand, Koh

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et al. investigated the effect of the reduction ratio on the microstructural behavior of IF (Interstitial) and AK (Aluminum-killed) steels in the temper rolling process. They observed that while the middle layer of IF steel was less deformed than AK steel, there was more change in the surface layer [14]. There is limited literature that characterizes the microhardness and microstructure changes in the sheet material cross-section in temper rolling. This study was carried out to eliminate the lack of scientific study in the characterization of microstructure and microhardness in sheet material cross-section roughened by temper rolling. The results can be used in research and development studies. As well as there is a large gap in the literature, it was observed that the microhardness and microstructural behavior of DC04 grade material, which is one of the mild steels used extensively in the automotive field, has not been investigated.

In this study, to fill the gap in the literature, microhardness and microstructural evolution occurring in the section along the thickness of DC04 grade sheet materials temper rolled with various reduction ratios were investigated.

2. Material and Methods

2.1. Material

DC04 grade sheet material specimens were sliced from a 1.5 mm thickness plate in 30 mm width and 200 mm length. The chemical composition of the material studied was determined by Spectrolab brand optical emission spectrometer. The chemical composition of the material (in wt.%) consists of 0.027 C, 0.006 Si, 0.152 Mn, 0.015 P, 0.013 S, 0.033 Cr, 0.031 Ni, 0.044 Cu, 0.005 Mo, 0.045 Al, 99.629 Fe elements. The tensile properties of DC04 grade sheet material were determined by carrying out a tensile test with the help of an Instron brand universal tensile test machine on standard test specimens prepared in parallel to the rolling direction. The yield strength of DC04 grade sheet material was determined as 154±8 MPa, tensile strength 270±8 MPa and total elongation 39.2±0.3%. The arithmetic average roughness (R_a) value of the surface of DC04 grade sheet material before temper rolling is 0.890 μm.

2.2. Methods

Temper rolling experiments were carried out at room temperature with the help of a laboratory type rolling mill (2-high roll). All experiments were carried out under 10 rpm rolling speed, 75 mm roll diameter, 4.4 μm (R_a) roll average roughness and dry conditions. Two different reduction ratios are 250 μm and 500 μm. Details of the experimental study are shown in Figure 1a.

In order to examine the microhardness and microstructure evolution in the section along the thickness of the material, the specimen before temper rolling, the temper rolled specimens in 250 μm and 500 μm reduction ratios were cut 10 mm × 10 mm and then the bakelite was taken. Before microhardness measurements, the specimens were grinded with 1000, 1200 and 2400 grit SiC abrasive paper and then polished with a diamond solution. Figure 1b shows the points where microhardness measurement was taken from the section along the thickness of the DC04 grade sheet material specimen. In the microstructure studies, the specimens were etched in 2% nital solution after the grinding and polishing processes were repeated. Vickers microhardness measurements were determined by applying a 50 g load for 10 seconds using Struers Duramin-50 test device. Microstructural images were obtained with Jeol JSM-7001F field emission scanning electron microscope (SEM) operated at 20 kV.

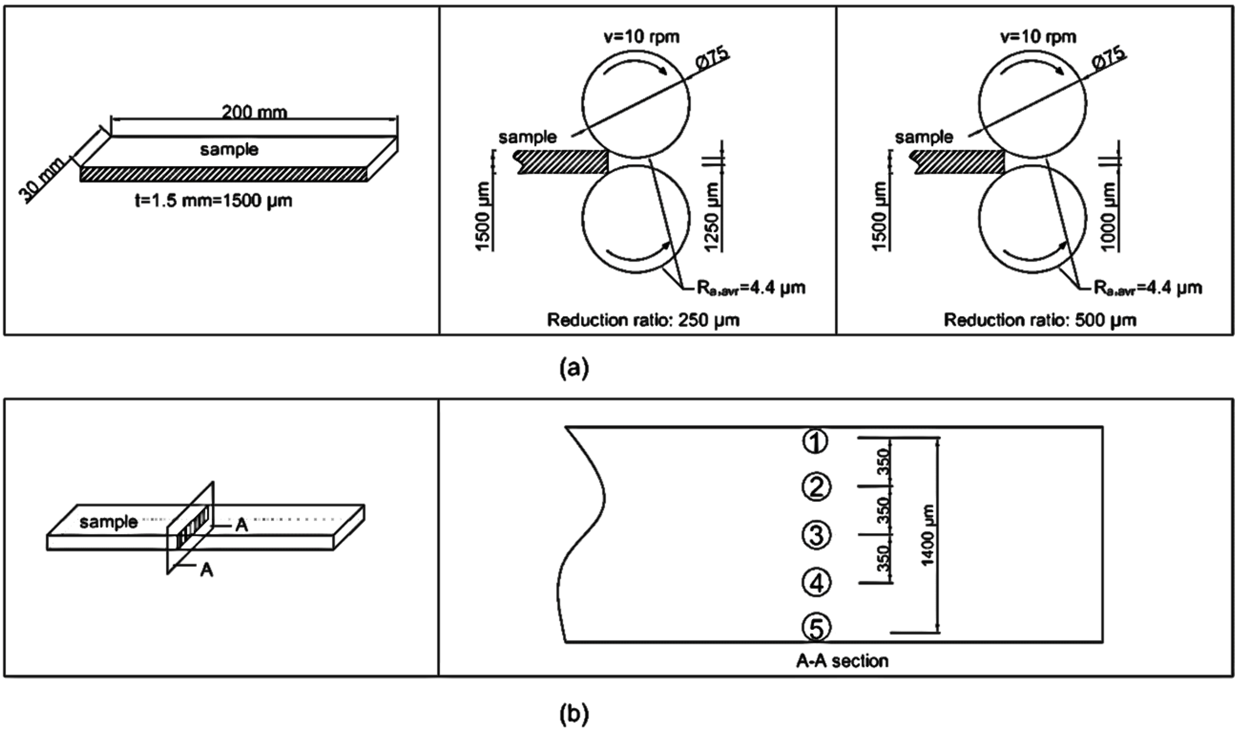

Figure 1. (a) Details of the experimental study, (b) the points where microhardness measurement was taken from the section along the thickness of the DC04 grade sheet material specimen

3. Results and Discussion

Figure 2 shows the graphical relationship obtained from Vickers microhardness ($HV_{0.05}$) measurements taken from the point numbers specified in the section along the thickness in Figure 1b.

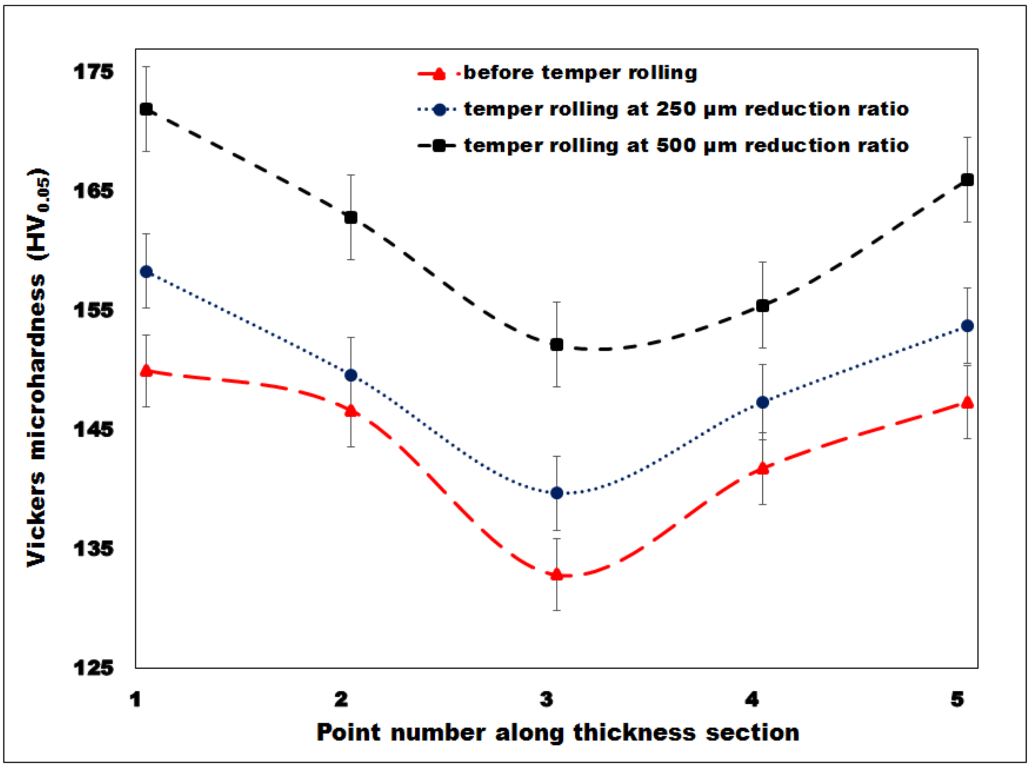

Figure 2. The graphical relationship obtained from Vickers microhardness ($HV_{0.05}$) measurements taken from the point numbers specified in the section along the thickness

In all the experiments performed in before temper rolling and skin-passed with 250 µm and 500 µm reduction ratios was observed that the microhardness value was higher at the points close to the surface and less values at the points near the center. In the formation of this situation, it was found that during the hot processing of the material, a finer-grained region was formed on the surfaces due to the faster cooling of the parts close to the surface compared to the center [13]. As the reduction ratio increased was observed that the microhardness value increased. While this increase was less (about 5-10 $HV_{0.05}$) than before temper rolling at 250 µm reduction ratio, it was observed more (about 15-20 $HV_{0.05}$) than before temper rolling at 500 µm reduction ratio. In the temper rolling process with a reduction ratio of 250 µm, an increase of approximately 5% has occurred compared to before the temper rolling process. In the temper rolling process with a reduction ratio of 500 µm, an increase of approximately 15% has occurred compared to before the temper rolling process. Therefore, it can be said that more thickness reduces at 500 µm reduction ratio and there is a similarity with the increase in the amount of thickness reduction in the occurrence of this situation. Indeed, Ko et al. stated that the most important factor in increasing the hardness value of the thickness reduction is due to the evolution of a fine grain microstructure and the formation of low angle grain boundaries [15]. At the same time, it can be said that the high hardness in the near-surface regions occurs due to the increase in dislocation density and the reduction in grain size, making the dislocation movement of the grain boundaries more difficult [16].

In order to examine the microstructure evolution as a result of the temper rolling, the scanning electron microscope (SEM) images taken from the section along the thickness of DC04 grade sheet material in before temper rolling and skin-passed with 250 µm and 500 µm reduction ratios are evaluated. The average grain size of the sheet material is about 20 µm [17]. In Figure 3a, the SEM images taken from region close to the surface in the section along the thickness of the DC04 grade sheet material before the temper rolling and in Figure 3b from the central region are seen. Before temper rolling, it is seen that the shape of the grains in the near surface and central regions has a spherical form.

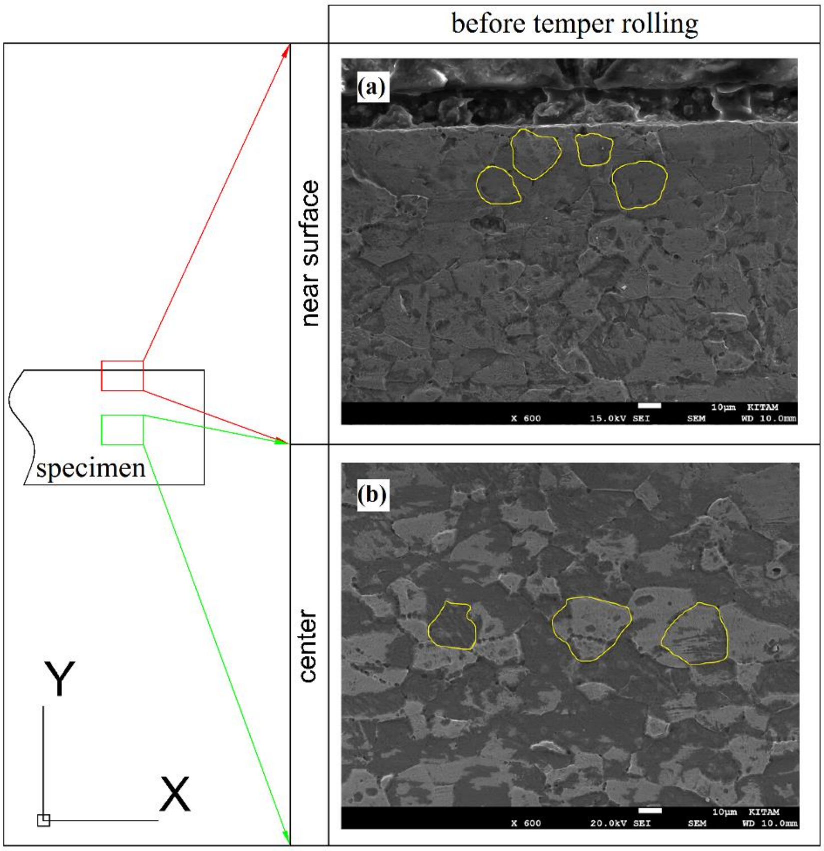

Figure 3. The SEM images taken from the section along the thickness of DC04 grade sheet material in before temper rolling; a) from region close to the surface, b) from the central region

In Figure 4a, the SEM images taken from region close to the surface in the section along the thickness of the DC04 grade sheet material with temper rolling at 250 µm reduction ratio and in Figure 4b from the central region are seen. In the temper rolling made with 250 µm reduction ratio, it is seen that the grains start to elongation in the "X" direction and the grains begin to shortening in the "Y" direction in the region close to the surface. In the central region, it can be said that this situation seen in regions close to surface has not yet fully formed.

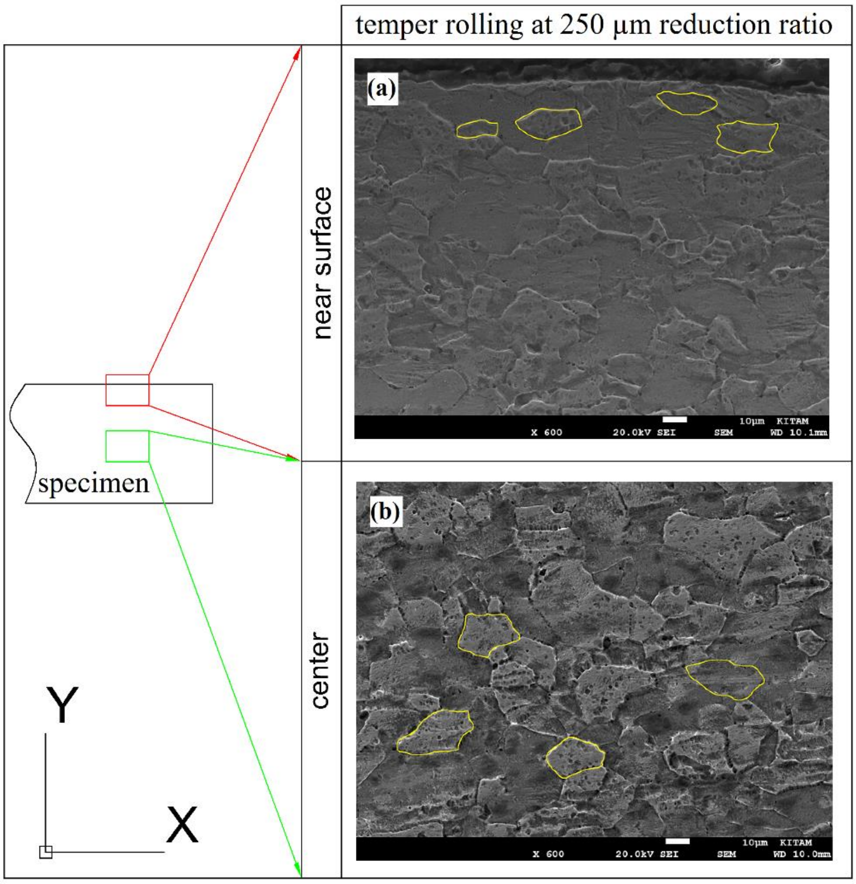

Figure 4. The SEM images taken from the section along the thickness of DC04 grade sheet material with temper rolling at 250 µm reduction ratio; a) from region close to the surface, b) from the central region

In Figure 5a, the SEM images taken from region close to the surface in the section along the thickness of the DC04 grade sheet material with temper rolling at 500 µm reduction ratio and in Figure 5b from the central region are seen. It is observed that in the region close to the surface, elongation of the grains in the "X" direction and the shortening of the grains in the "Y" direction occur in a very high amount in temper rolling with 500 µm reduction ratio. In the central region, it can be said that the elongation of the grains in the "X" direction and the shortening of the grains in the "Y" direction are less than the elongation and shortening in the region near the surface. In line with this informations, it can be concluded that as the reduction ratio increases, the grains are elongated and thinned in the regions close to the surface, and this change is less in the center compared to the regions close to the surface. Engler [18] found that the deformation of the grains increases with increasing the temper rolling degree. Koh et al. [14], on the other hand, found that in the regions close to the surface, the grains were elongated compared to the middle layer, and in the middle layer, due to heterogeneous deformation, full conduction could not be achieved and deformation did not occur to a large extent.

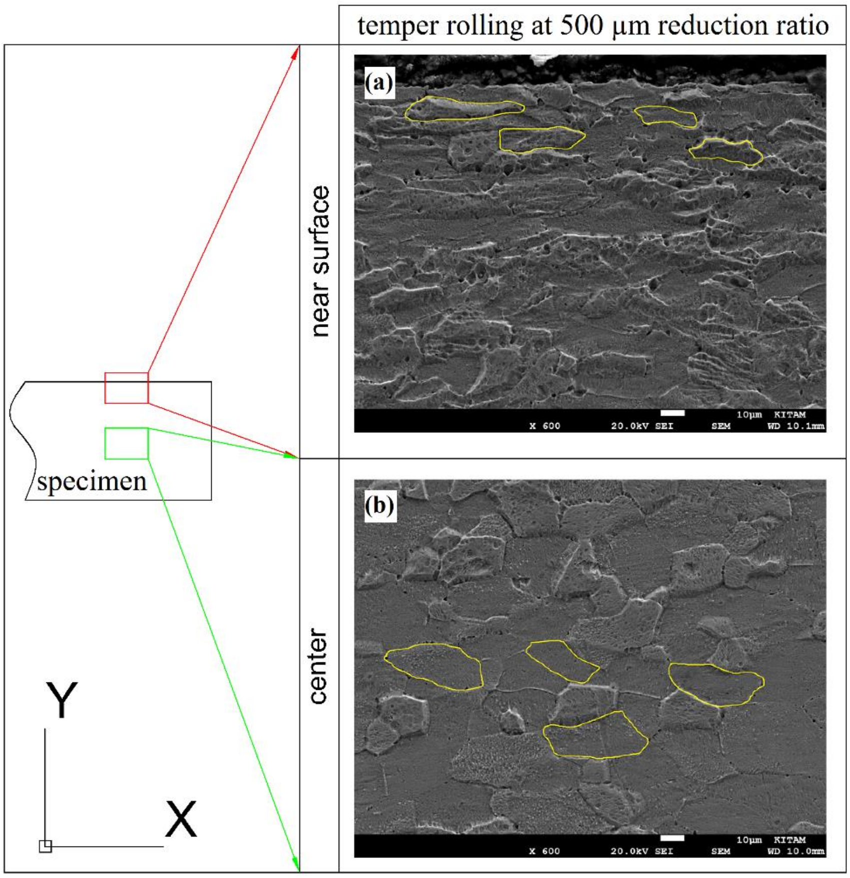

Figure 5. The SEM images taken from the section along the thickness of DC04 grade sheet material with temper rolling at 500 µm reduction ratio; a) from region close to the surface, b) from the central region

4. Conclusions

In this experimental study was investigated microhardness and microstructural evolution occurred along the thickness section of the sheet material as a result of temper rolling with different reduction ratios on DC04 grade sheet materials. The results of the investigation are presented below.

- With temper rolling process on DC04 grade sheet materials was concluded that the microhardness distribution taken from the section along the thickness rises with the increase of the reduction ratio and the Vickers microhardness ($HV_{0.05}$) distribution from the surface to the center in the section decreases.
- In temper rolling process to the DC04 grade sheet materials was concluded that with the increase in the reduction ratio the grains elongated and thinned on the surface along the thickness and this change is less in the center compared to the areas close to the surface.
- It was concluded that the findings obtained from this study can contribute to both the literature and the producers.

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Contributions of the authors

The contributions of each author to the article should be indicated.

Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics.

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