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Microstructure and Strain Hardening Behaviour of Iron Chromium Alloy Subjected by Severe Plastic Deformation

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ABSTRACT
Microstructure and strain hardening behaviour of iron-chromium alloy subjected to severe plastic deformation (SPD) have been investigated in grain refinement and deformation routes. Equal channel angular pressing (ECAP) was used in this SPD technique due to their un-change dimension billet. The purpose of this research is to investigate the structure and the strain hardening of iron chromium alloy subjected by ECAP process. The ECAP process was carried by routes A, Bc and C up to four passes at 423 K temperature. The strength of the material was measured by tensile testing with 3 mm gauge length, and the strain hardening behaviour was investigated based on the true stress-strain curve. The effect of the deformation route on microstructure and texture was observed by electron backscattered diffraction (EBSD) analysis at the normal, transverse and rolling direction. The result showed that route Bc showed the highest strength and ductility of the ECAP processed material compare to other routes due to their 90 degrees rotation of each ECAP passes number. The increased strength of materials was also associated with grain refinement and accumulation dislocation. It concluded that the ECAP process by route Bc could be used for further material treatment and application for industrial purposes.

Key words : Deformation, ECAP, SPD, Alloy

1. INTRODUCTION

Many researchers have been conducted to do the experiment and develop some techniques for introducing nanostructured or ultrafine-grained (UFG) structured metallic material for industrial application [1-3]. The nanostructured or UFG material can be achieved by the "up to bottom" or "bottom to up" research approach. The "up to bottom" approach is dependent on the bulk nanostructured metallic material concept, and the "bottom to up" is dependent on the powder metallurgy [1-3]. This material was improved its strength and electrochemical properties by microstructure evolution. The UFG structured material can be promoted by severe plastic deformation (SPD) [4-6]. The SPD technique can promote considerable strain energy into material without changing the material or sample dimension. Equal channel angular pressing (ECAP) is one of the popular SPD techniques that researchers use to carry out grain refinement by accumulation dislocation inside grain and grain boundary [7-9], like high pressure torsion [10-12] and accumulative roll bonding [13-15]. The parameter which is the most significant to promote dislocation is the deformation route of ECAP. There is the type of route there are route A (without rotation or billet), route Bc (90-degrees rotation of billet) and route C (180-degrees rotation of billet). The previous research is lack knowledge on the effect of the deformation route on strain hardening behaviour [16-19]. Subsequently, it needed to be clarified. Iron chromium alloy can be used to explain this strain hardening behaviour due to its pure crystal structure as body-centred cubic (BCC) and it also can be compred with other crystal structure [20-24]. This study investigates the strain hardening behaviour, microstructure and texture of UFG structured metallic material subjected by ECAP technique.

2. EXPERIMENTAL PROCEDURE

The iron-chromium alloy was used in this research due to its crystal structure as BCC. It contains 20% chromium and balances iron with less than 5 (five) ppm carbon and nitrogen. The billet was cut from iron-chromium alloy ingot by 8 $\times$ 8 mm square and 100 mm in length, and then it was heat-treated at 823 K for 1 hour. The ECAP technique was carried out at 423 K temperature by route A, Bc and C up to 4 (four) passes. The die channel of ECAP used 90-degree inner angle to make a large deformation level equal to 1.15 equivalent strain. The strain hardening behaviour was analysed by tensile testing Autograph 10 kN Shimadzu at room temperature. The microstructure was observed by JEOL FE SEM 7001F with equipped electron backscattered diffraction (EBSD). The EBSD provide the orientation and texture of the material. The shear deformation of the normal, transverse and rolling direction on the billet can be seen in Figure 1.

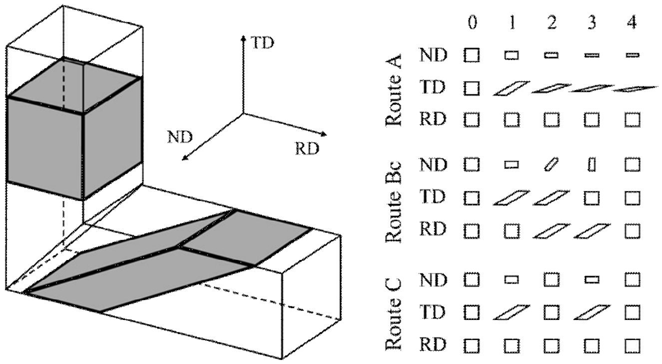

Figure 1. The Schema of shear deformation up to four ECAP pass on normal, transverse and rolling direction at Route A, Bc andC.

3. RESULT AND DISCUSSION

Figure 2 shows the effect of route deformation between stress-strain and strain hardening behaviour of four passes ECAP processed sample. The engineering stress and strain curve was used to analyze the strength of the material. Route Bc exhibited the longest ductility and the highest ultimate tensile strength compares to another deformation route due to its rotation of billet and homogeneous structure in the 3D plane. The stress-strain curve of the ECAP processed sample showed short plastic instability due to the early stage of deformation in the materials. Figure 3 confirms softening stage after necking occurred during testing at all deformation routes. The increment of the material strength on iron-chromium alloy was also confirmed on other materials, such as magnesium, copper, and titanium. The strength increment may sacrifice the ductility of the material due to the grain refinement process. The previous result also declared that the higher strength is the influence of grain orientation and texture [17,19].

Its already mentioned before that the ECAP processed sample is short ductility compared to the as-annealed sample. The formability of material can be seen from the strain hardening behaviour explained for the ECAP process. The strain hardening behaviour is associated with a uniform plastic region and homogeneous structure. The structure was observed by grain boundary misorientation, like low and high grain boundary. The grain refinement may influence dislocation movement inside grain and grain boundary. The microstructure evolution occurred during the ECAP process by increasing the high angle grain boundary fraction as our previous research result. Accumulation dislocation is also associated with this matter. With the increase of deformation level, the dislocation density is saturated accordingly. However, the work hardening continues by increasing strain energy on the sample. The strain energy was managed by dislocation density inside grain and grain boundary due to equilibrium grain boundary formation.

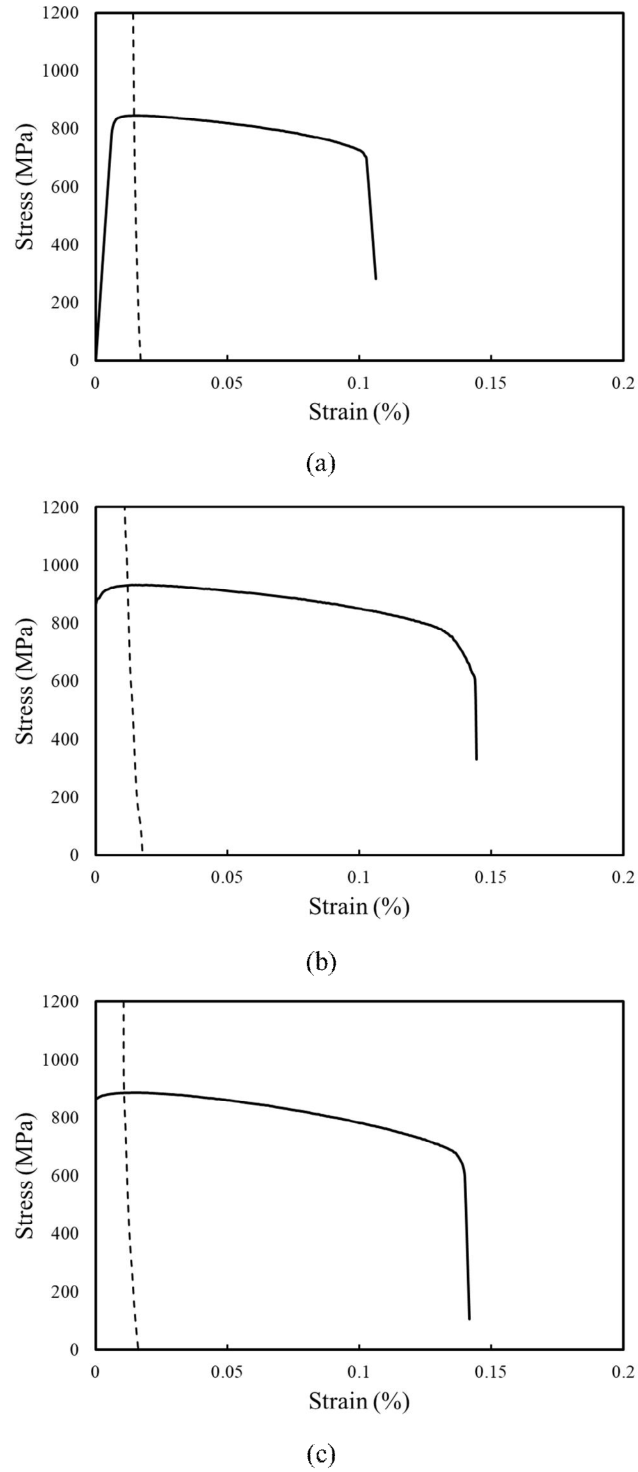

Figure 2. The stress-strain curve of iron chromium subjected for four ECAP passes via (a) route A, (b) route Bc and (c) route C.

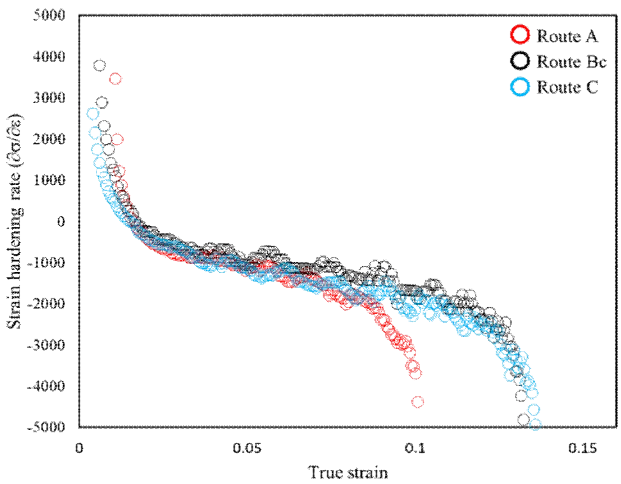

Figure 3. Strain hardening behavior of iron chromium subjected for four ECAP passes via route A, Bc and C.

The schema of strain hardening behaviour on the ECAP processed sample was initiated by the UFG structure with low dislocation density inside the grain. It may increase the flow stress of the material. The softening stage of the strain hardening curve is associated with dynamic recovery by increasing the flow stress until the occurrence of necking. This process showed a limited ductility occurred in the ECAP processed material; it also has been confirmed on the materials.

The microstructure was observed at three different planes for each deformation route, as seen in Figure 4. It seems the transverse plane has the most influence on the ECAP process. Route A has elongated grain along the rolling direction due to their repetition deformation process in the same pattern; however, Route Bc and C exhibited more equiaxed grain. Route C showed a similar orientation grain structure at normal and transverse planes due to rotation angle, followed by microstructure evolution and recrystallization stage during the ECAP process.

The grain fragmentation still can be seen in four passes ECAP processed sample by subdivided grain formation. Figure 5 shows the texture of the ECAP processed sample on different planes and deformation routes. The 110 plane showed the random texture among another plane due to the crystal structure of the material. Texture contours also confirmed it at the EBSD analyser, which route A showed a random texture contour along with all directions due to repetition deformation in the same direction. It concluded that the deformation route affects mechanical properties and microstructure significantly. The choosing of the deformation route is depended on the application of the material.

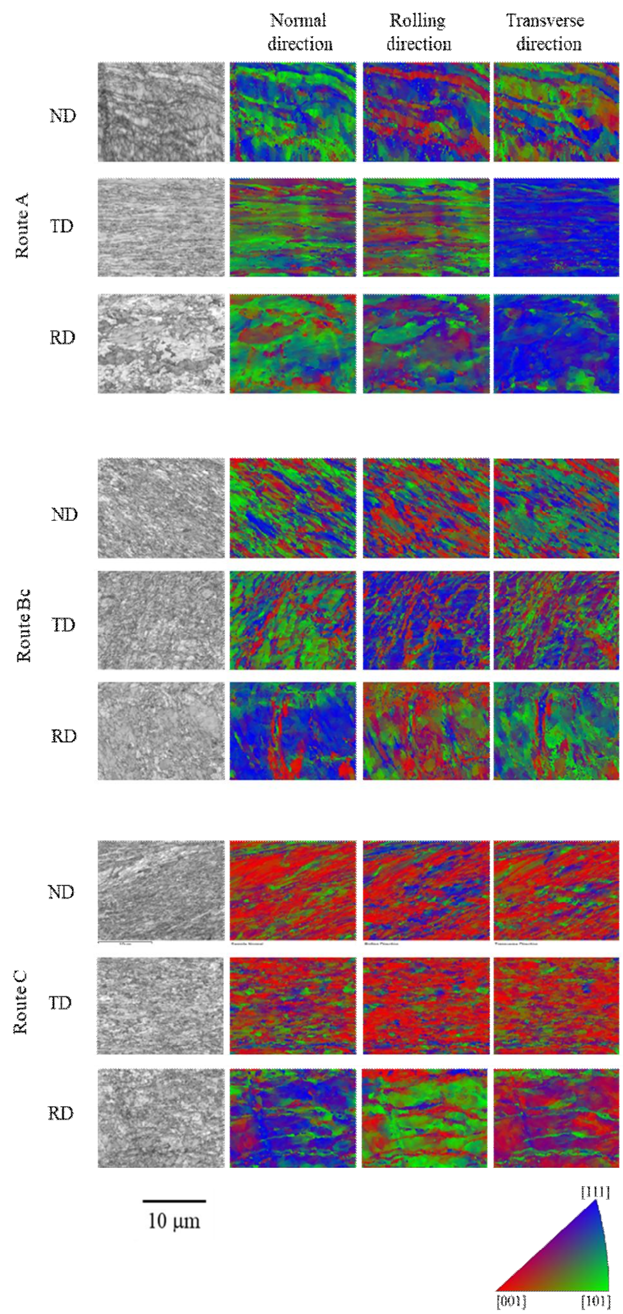

Figure 4. Orientation map of iron chromium subjected for four ECAP passes via route A, Bc and C.

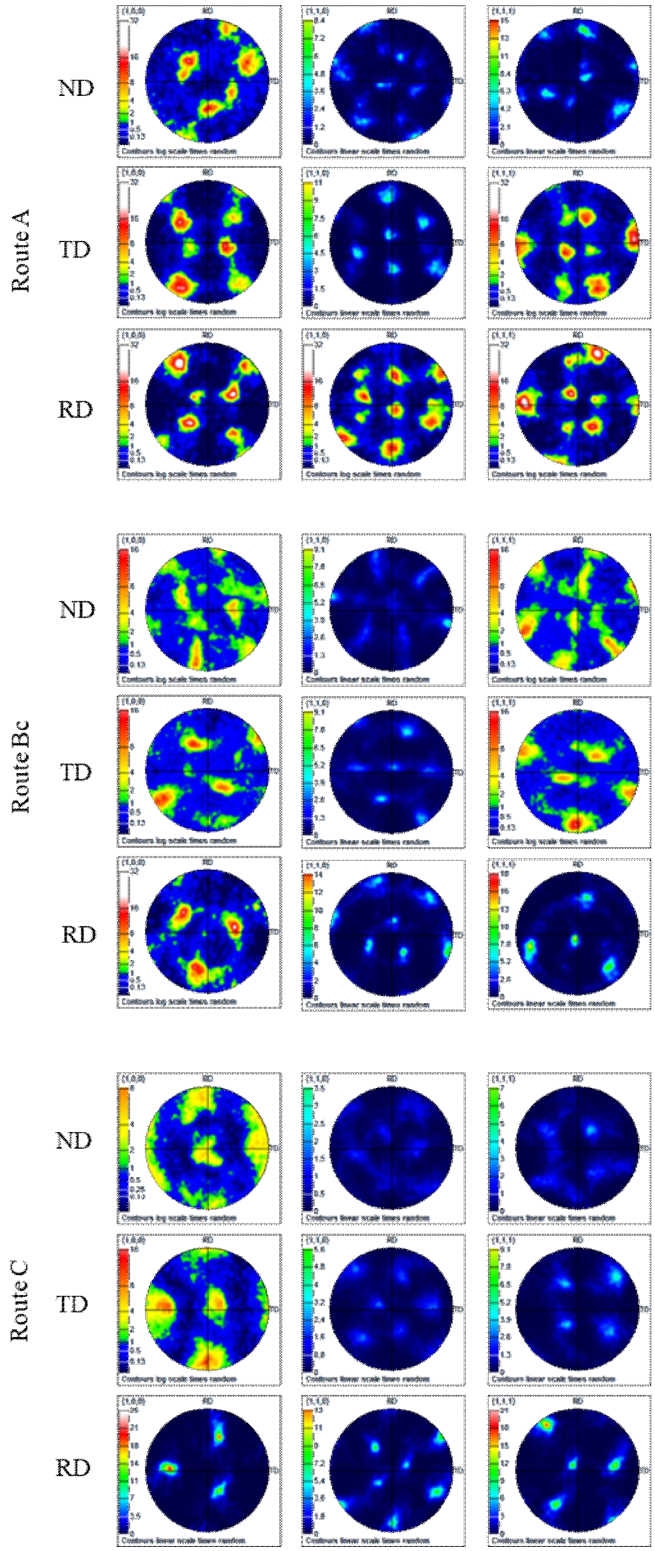

Figure 5. Texture of iron chromium subjected for four ECAP passes via route A, Bc and C.

4. CONCLUSION

The grain refinement process has occurred on the iron-chromium alloy prepared by the ECAP process. Route Bc exhibited the highest strength and longest ductility at 423 K ECAP temperature, four times higher than as an annealed sample. The strain hardening behaviour is associated with a uniform plastic region and homogeneous structure. The strain energy was managed by dislocation density inside grain and grain boundary due to equilibrium grain boundary formation. It concluded that the deformation route affects mechanical properties and microstructure significantly.

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