UTILIZATION OF THE PROCESS OF SEVERE PLASTIC DEFORMATION IN INCREASING THE QUALITY OF THE CU SHEET METAL STRIP

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Abstract

Achieving a very high degree of deformation in sheet metal forming is a very complex problem. It is the main prerequisite for achieving an ultra-fine grain structure in the material. For the extrusion of the sheet of Cu with the DRECE method, at least 8-10 passes through the forming tool must be performed to achieve sufficient refinement of the structure. This is in contrast to a much smaller number of passages to achieve an equally high degree of deformation in the ECAP method when we use the passage type marked as "C". This method is used for continuous extrusion of a strip of sheets. The paper analyzes the increase of mechanical properties and the refinement of the structure on the newly developed forming device (three-roll feed of the material combined with extrusion) for the Cu sheet metal strip, when choosing the "C" deformation path (rotation of the strip of 180° after each pass).

Keywords: Severe plastic deformation (SPD), DRECE method, pure Cu, microstructure, mechanical properties

1. INTRODUCTION

Scientific research results show that graded ultrafine grained Cu-based materials offer technical advantages by possible material property improvements (e.g. yield strength, corrosion resistance) especially when applied to heavily stressed components.

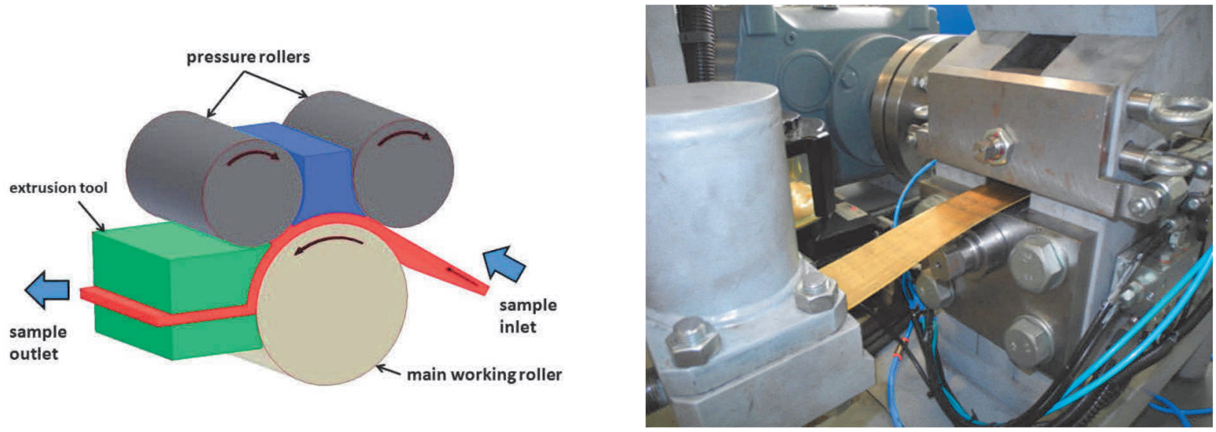
During last two decades great attention was paid to materials with grains of diameter smaller than 1 μm. These materials were classified as Ultra Fine Grain (UFG) materials with diameter of grains of the order of 100 to 1000 nm and nano-materials with mean diameters of grains smaller than 50 nm. This research concerned the whole production of UFG materials, using Severe Plastic Deformation (SPD). Use of these materials is very versatile - either directly as semi-products for subsequent further processing with lower number of operations (created structure is preserved in final products) or for production of final products from semi-products [1].

Technologies of severe plastic deformation can be defined as processes, which create in material high degree of deformation in order to achieve grain refinement [2-6]. These new technologies for production of semi-finished products with ultra-fine grained structure differ from conventional technologies. While in classical technologies change cross-section of the processed material, the cross-section of material processes by SPD remains unchanged. Several types of SPD technologies serving for production of UFG metals was developed already at the beginning of the nineties [5-10].

The goal of this study is to investigate the microstructure and mechanical properties of DRECE-processed Cu. The results obtained on the strip of sheets processed by DRECE are compared with the microstructure and mechanical properties of Cu in an initial state. Cu sheets processed by DRECE method are suitable for mass production [9].

1.1. The concept of DRECE method

The process of forming of material using the DRECE technique is based on making use of the material's intensive plastic deformation, i.e. that this process is a combination of two known technologies, ECAP [4, 7] and CONFORM [10-12, 19]. As it has already been mentioned earlier, the equipment is a prototype possessed by the Faculty of Mechanical Engineering of the VŠB - Technical University Ostrava. The equipment consists of a NORD gearbox and an electromotor with speed frequency converter, which gives us the option to change the deformation rate even during the process, and thus allows us to flexibly react to the process progress. Other components include a plate clutch, a drive roller, two pressure rollers and a bottom and top forming tool. The pressure applied on the front pressure roller is controlled by a pair of hydraulic cylinders; the pressure applied on the rear pressure roller is controlled mechanically. This combination has so far proven itself when controlling the pressure in both non-ferrous alloys (on Al, Cu basis), as well as in sheet steel (DC01, C55). The machine's design of course allows application of hydraulic control also to the rear pressure roller [13-15, 20]. The entire DRECE equipment is shown in **Figure 1**.



(a) (b)

Figure 1 Schematic illustration of DRECE method (a), real forming DRECE device (b)

2. EXPERIMENTAL PROCEDURE

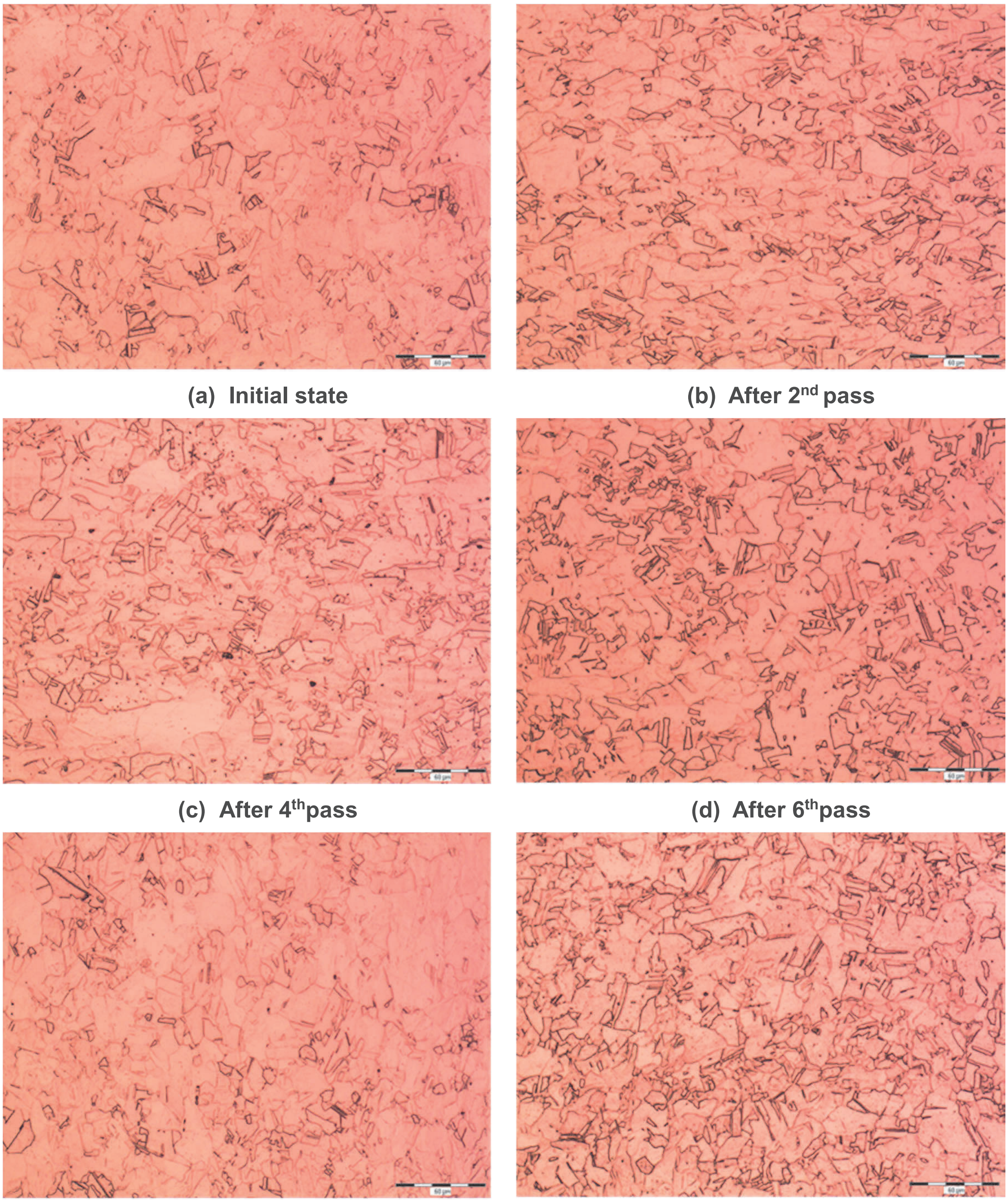
The initial material was commercial pure copper, with the purity of 99.5%. This investigated material was supplied in a cold-drawn state. An annealing treatment was performed to the as-received material (600 °C for two hours), giving a grain size of ~ 40 μm. The mechanical properties of Cu are given in **Table 1**. The initial Cu samples with dimensions of 58 mm × 2 mm - 2000 mm were subjected to DRECE processing up to 10 passes. Specimens were processed by DRECE with a tool angle α = 118° at room temperature (RT). Route "C" was applied, i. e. the samples were rotated about 180° between subsequent DRECE passes. The extrusion velocity of DRECE process was 3 $mm \cdot s^{-1}$.

Microstructures were observed through optical (OM) and transmission electron microscopy (TEM) using specimens taken from sliced discs from the samples processed by DRECE method. Optical samples were prepared following the grinding sequence 400, 600, 1200 and then electro-polished and electro-etched with the solution of 30% Nital and 70% Methanol. These samples were observed through an optical microscope NEOPHOT 2. TEM samples were prepared using a Tecnai G2 F20.

Hardness was measured using a vickers hardness tester al load of 5 kg for 20 s. Tensile tests were carried out using the tensile specimens with length of 80 mm at the strain rate of 1 s^{-1} at room temperature, the specimens for tensile testing were cuted from longitudinal (DRECE) direction.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1. Microstructure of pure copper



(a) Initial state (b) After 2nd pass

(c) After 4thpass (d) After 6thpass

(e) After 8thpass (f) After 10hpass

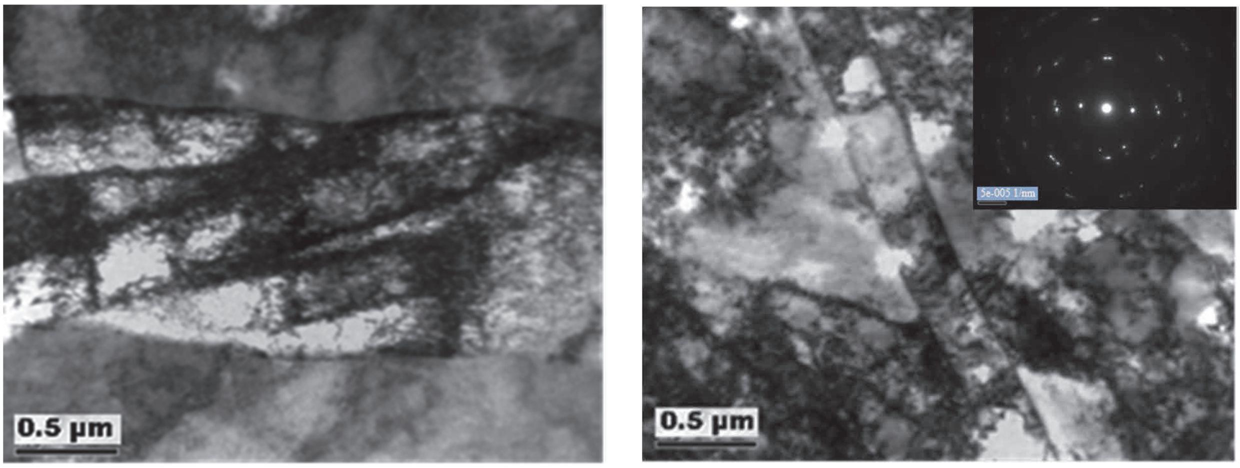
Figure 2 Microstructure of pure copper: initial state and processed by 2, 4, 6, 8 and 10 passes

The light optical microscope images in **Figure 2** show the microstructure of the samples in the initial state and processed by 2, 4, 6, 8 and 10 passes. A significant grain refine microstructure was developed even after the

2nd pass of DRECE, the average grain size was ~ 19 μm. The average grain size of investigated pure copper slightly decreases during increasing number of passes by DRECE device, but not significantly.

Optical observation was carried out for all samples along the longitudinal section (DRECE direction). After the second pass through the DRECE (**Figure 2b**), the grains are severely deformed according to the shear plane direction as clearly shown in optical and TEM images. In the consecutive passes, at the deformation is increased, the microstructure becomes finer only slightly. However, some large grains are still present in the 4th pass as illustrated in both optical images (**Figure 2c**). Further passes promote an extremely distorted microstructure, and it is almost impossible to clearly differentiate the morphology of individual grains by optic microscopy (**Figures 2d-f**).

Figure 3 shows the microstructure of the Cu (99.5) sample after the 10 DRECE passes. In the tested material prevails the dislocation substructure, which is characterized by clusters of dislocation and initial grains are longitudinally deformed by slip bands. One can see that the grain refinement is rather negligible, only growth of dislocation density and slip bands can be observed (**Figure 3a**). As indicates the shape of the extinction contour, no formation of subgrain boundaries can be seen (**Figure 3b**).



(a) **(b)**

Figure 3 TEM micrograph of Cu after processed by 10 DRECE passes

Figure 4 shows a schematic description of the evolution of the microstructure during severe plastic deformation, presented by E. Bagherpor and co-authors in [17]. A random dislocation distribution (**Figure 4b**) is considered as a start point, which is not a low-energy configuration. To lower the energy, this homogeneous distribution of dislocations rearranges itself into elongated dislocation cells. By applying more deformation, the misorientation increases and these cells become elongated subgrains (**Figure 4c**). These elongated subgrains are characteristic features of copper or more FCC metals under deformation. As seen in **Figure 4d**, by further straining these elongated subgrains are, in their turn, plastically deformed, leading to further breakup. By shear deformation, inducing during DRECE process, the dislocation fluxes on both sides are reversed, leading to first, reduction of the stored excessive dislocations introduced in the boundaries by the activation imbalance, and second, disintegration of misfit dislocations. Therefore, strain reversal might lead to diminishing the misorientation angle and/or to eliminating the dislocation boundaries (**Figure 4e**). Finally, by more strain, more boundaries diminish and the final microstructure consists of the larger sizes with lower fraction HAGB's and dislocation density (**Figure 4f**). Conclusions, presented by E. Bagherpor and co-authors in [16-18], were confirmed by our experimental and investigated results (see **Chapter 3.1.** and **Chapter 3.2.**).

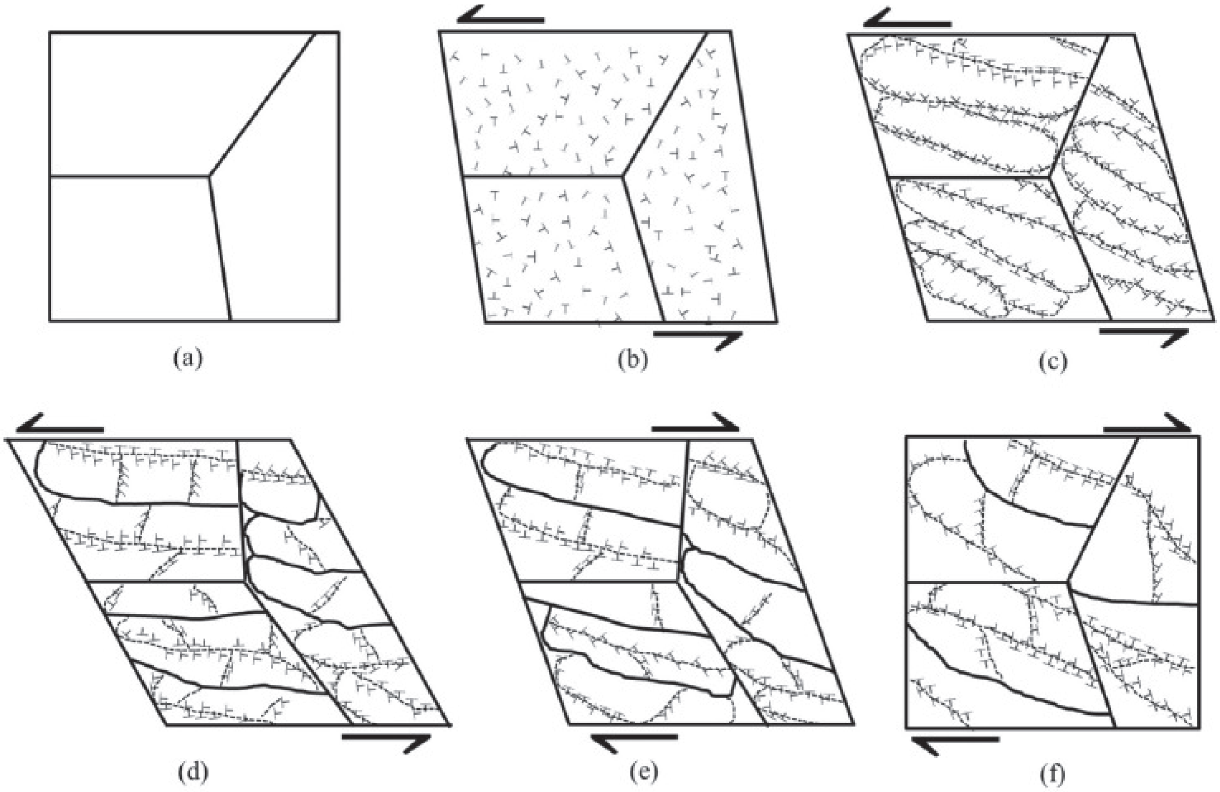


Figure 4 Schematic illustration of microstructure evolution during severe plastic deformation: (a) Initial cell structure, (b) Homogeneous distribution of dislocations, (c) elongated cell formation, (d) dislocations blocked by subgrain boundaries and break up of elongated subgrains, (e) diminishing of misorientation angle and/or to complete elimination of the dislocation boundaries, (f) final microstructure [17]

3.2. Mechanical properties of pure copper

The Yield stress ($R_{p0.2}$), the Ultimate tensile strength (R_m) and the elongation to failure (A_{80}) as a function of the number of DRECE passes are shown in **Figure 5** and in **Table 1**. The yield stress increased from ~ 135 to 252 MPa while the Ultimate tensile strength raised from ~ 250 to 374 MPa even after the second pass of DRECE. Further DRECE passes yielded only a slight increase in both the Yield stress and the Ultimate tensile strength. The maximum values of $R_{p0.2}$ and R_m were about 255 and 390 MPa, respectively. Concerning the ductility of the DRECE-processed samples, the elongation to failure decreased from ~ 40 to ~ 15 % immediately after the second pass. Additional DRECE passes did not result in a considerable change in the elongation to failure.

Table 1 Mechanical properties of pure copper

	Yield stress $R_{p0.2}$ (MPa)	Ultimate tensile strength R_m (MPa)	Elongation to failure (%)	Vickers hardness HV_5 (-)
Initial state	135	250	40	59
2nd pass	252	374	15	108
4th pass	255	385	10	115
6th pass	253	385	10	115
8th pass	255	386	10	115
10th pass	255	390	9	118

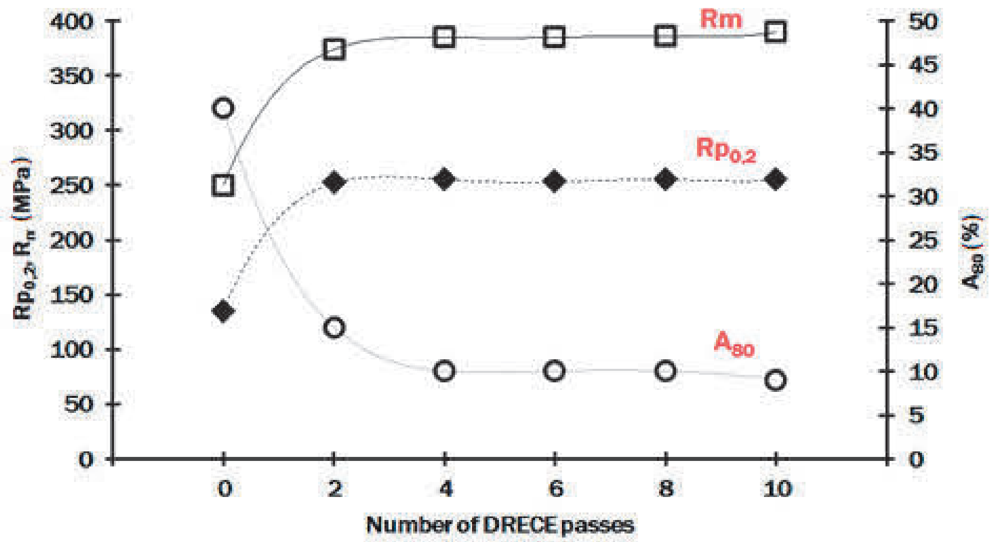


Figure 5 The Yield stress ($R_{p0,2}$), the Ultimate tensile strength (R_m) and the elongation to failure (A_{80}) as a function of the number of DRECE passes

The dependence of DRECE process on the Vickers hardness shows **Figure 6.** The hardness increased from ~ 59 to 108 after the second pass. Additional DRECE passes has not a significant influence on the Vickers hardness. Maximal value, 118 HV_5, of hardness was obtained after the 10th pass.

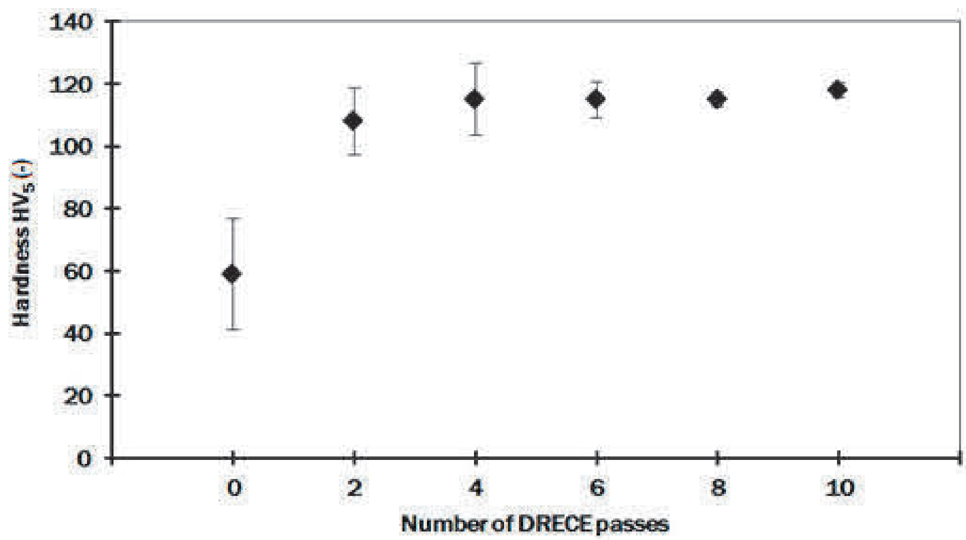


Figure 6 The Vickers hardness HV_5 as a function of the number of DRECE passes

4. CONCLUSION

The commercial pure copper (99.5 %) was processed by DRECE up to 10 passes at room temperature. The microstructure and the mechanical properties were studied as a function of number of DRECE passes using OM, TEM and tensile testing. The following conclusions have been drawn:

- The Yield stress and the Ultimate tensile strength saturated at a value of about 255 MPa and 390 MPa, respectively. The value of Yield stress indicates that dislocations give the major contribution to the strength.

- The strong grain refinement observed after the 6th pass (15 µm) is in good agreement with results from tensile testing.
- The average grain size evolution corresponds with tensile properties. Grain size of sample after 6th and more passes is remained same.
- More DRECE passes increases the strength properties of copper based on an increase the dislocations density.

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