2021 International Nuclear Atlantic Conference – INAC 2021
Virtual meeting, Brazil, November 29 – December 2, 2021

ISBN: 978-65-594-1256-3

Grain Refinement through Severe Plastic Deformation using Multiaxial Forging

R.G. Silva[1], J. Peressinotto[2], and J.J. Vilela[3]

[1] *re.janegsilva@hotmail.com.*
[2]*jonnas.peressinotto@cdtn.br, CDTN/CNEN, Caixa postal 941, CEP 30161-970.*
[3]*jjv@cdtn.br, CDTN/CNEN, Caixa postal 941, CEP 30161-970.*

1. Introduction

A new group of metals are characterized by a nanoscale structure. They can be obtained by various processes, including severe plastic deformation [1]. These materials generally provide improvements in their mechanical properties, such as increase ultimate tensile strength (UTS) and yield strength, and contribute to better product performance in the nuclear, automotive, aerospace, and defense industries. The steel with ultrafine grain is a strong candidate to be applied in pressure vessels of kind generation IV nuclear reactors.

Severe plastic deformation (SPD) are being applied to obtain ultra-fine grain materials [1]. The main SPD techniques are equal-channel angular pressing – ECAP, high pressure torsion – HPT, accumulative roll bonding – ARB and multi-axial forging – MAF [2].

The MAF is the technique that the material is sequential compressed in all its directions (FIG. 1). Each compression is called one pass and this process can be done cold, warm and hot [3]. When the shape of the specimen is a cube, each three passes in one in each direction (X, Y and Z) corresponds to a cycle. After each complete cycle, the sample dimensions approach the initial dimensions. In this work, the evolution of the microstructure of the material, investigations of the mechanical and microstructural properties were evaluated after the cubes were subjected to multiaxial forging schemes of three, six and nine passes.

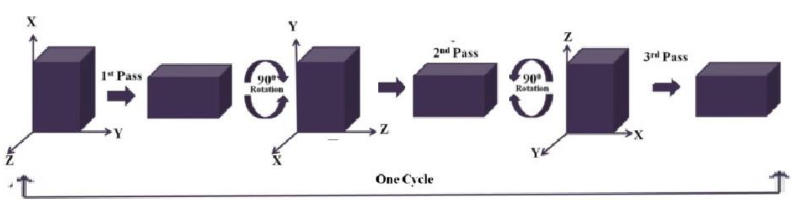

Figure 1: Representation of the multiaxial forging scheme (MAF). Source: R. Kapoor, 2012[3].

The general objective of this work was to refine the grain of a low carbon steel using severe plastic deformation in different multiaxial forging schemes. The specific objectives were to survey the conditions of severe plastic deformation using a low carbon steel, through multiaxial forging, and an analysis of microstructures and grain sizes for different processing conditions.

2. Methodology

The cubes made of 1020 steel were subjected to multiaxial forging schemes of three, six and nine passes. The cube edges were 8 mm. The mechanical properties were evaluated through the hardness test and the microstructural analysis through the optical metallography. The multiaxial forging was carried out cold (room temperature) using the universal machine INSTRON, model 5882, located at the Mechanical Testing Laboratory from CDTN. Each axis of the specimens (X, Y and Z) were identified with numbers 1, 2 and 3, respectively, to guide the process, as shown in Fig. 2.

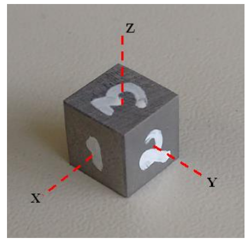

Figure 2: Identification of the specimen's compression axes. Source: authors.

The compression speed and the height to be compressed were adjusted in the program. The specimen was placed in the machine and the X axis was the first to be compressed. Then, the specimen was removed then their dimensions were measured. The specimen was rotated so that the next pass was carried out in the Y direction. The dimension of the Y axis after the first pass became the initial height for the second pass. The process was continued in each sample according to the number of passes to each one designated. Each axis had its height compressed by 3 mm, at a deformation rate of 1 mm/s. The lubricant was graphite. With the initial and final heights, it was possible to calculate the logarithmic deformation accumulated in the specimen. Stress-strain curves and the value of the yield stress in each pass were obtained.

The hardness tests were carried out on a Wolpert Wilson Instruments machine, model Universal 90. Three impressions were carried out on each axis. Vickers hardness tests 5 kN (HV5) were used in specimens free of deformation and in those submitted to multiaxial forging schemes.

The specimens free of deformation and with nine passes were prepared to the visualize their microstructures. The samples were sanded, in ascending order with sandpaper: 220, 400, 600, 1200 and 2000 Mesh. Polishing was performed on the same machine using 6 µm, 3 µm and 1 µm diamond paste cloths. The polished surface was etched with a 3% Nital solution for 5 seconds. Then, the sample was dried with hot air and observed under a microscope. Photographs were taken from different regions of the surfaces of each sample. The microscopy equipment used was the optical microscope of LEICA model DM4500 P.

3. Results and Discussion

Table I presents the logarithmic deformation accumulated at the end of each forging scheme. Table II presents the averages of hardness of the specimens. It is observed that there was an increase in the hardness of the material as the number of passes in the samples increased. In cold forming (or room temperature), as previously mentioned, the material had its hardness value increased as a result of plastic deformation. The hardness values obtained indicate that the material has been work hardened.

The average grain size of 1020 steel deformation free was 15,4 ± 5,3 µm (FIG 3) and it was 15,4 ± 5,0 µm after being submitted to multiaxial forging of nine passes at room temperature (FIG. 4). The average grain size was calculated by the software Quantikov, a system developed for the analysis of microstructural images. The images with different magnifications indicate that the material was work hardened.

Table I: Accumulated deformation for the different multiaxial forging schemes.

Number of passes	Accumulated deformation
3	0,868
6	1,787
9	2,699

Table II: HV5 hardness values for different multiaxial forging schemes.

Specimen	Pass	Hardness
0	0	154 ± 10
1	3	223 ± 5
2	6	234 ± 10
3	9	233 ± 10

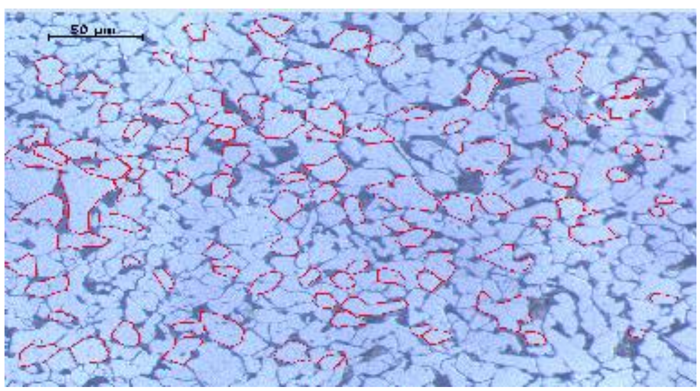

Figure 3: Optical microscopy images of 1020 steel as received deformation free with a magnification of 200x.

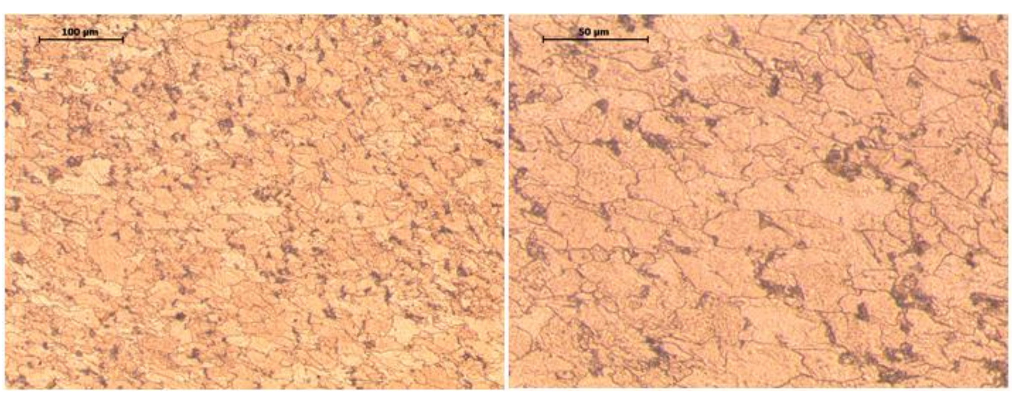

Figure 4: Optical microscopy images of 1020 steel after nine plastic deformation passes with a magnification of A) 100x and B) 200x.

4. Conclusions

The multiaxial forging process caused an increase in hardness, in 1020 steel, at room temperature, indicating that the work hardening mechanism was dominant during the deformation. The severe plastic deformation process did not reduce the grain size. But the material is work hardened, the introduction of a recrystallization followed freezing microstructure in the process is possible produce a fine grain.

Acknowledgements

The authors are gratefully for the support of the Fundação de Amparo à Pesquisa de Minas Gerais (FAPEMIG), the Centro de Desenvolvimento de Tecnologia Nuclear (CDTN/CNEN) and the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq).

References

[1] CALADO, W. R. Ultra refino de grão através de deformação plástica severa por ensaios de torção: simulação do processo ARB. 2012. 259 f. (Engenharia de Materiais) - Tese de Doutorado. Escola de Engenharia, Universidade Federal de Minas Gerais (UFMG), Belo Horizonte, 2012.

[2] MENDES FILHO, A. A. Deformação plástica severa em temperatura ambiente e criogênica em Ti comercialmente puro. 2015. 160f. Tese de Pós Graduação (Ciência e Engenharia de Materiais) - Universidade Federal de São Carlos (UFSCAR), São Paulo, 2015. [1] A. Author, "Article," *Journal Name*, vol. 1, pp. 1–199 (2013).

[3] KAPPOR, R., SARKAR, A., YOGI, S. K., SHEKHAWAT, I., CHAKRAVARTTY, J. K. Softening do Al during multi-axial forging in a channel die. Materials Science & Engineering A, número 560, pp. 404-413, 2013.