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COMPARISON BETWEEN FOUR DIE FORGING DEVICE AND CONVENTIONAL FORGING PROCESSES OF COLD WORK TOOL STEEL

Abstract

Four Die Forging Device (4DFD) is a known equipment to improve the productivity at the forging shop when compared with conventional forging process. Despite the improvement of productivity it is supposed that the quality should be at least similar. In fact, previous finite element simulation showed the forging process using 4DFD produces less effective strain in the forged bar due to less forging passes than the conventional forging process with two dies. However, the amount of shear strain obtained with 4DFD should improve the forged bar microstructure quality. To corroborate that scenario, the following study compared the metallurgical quality based on carbide distribution between 4DFD and conventional forging processes. Experiments were conducted in order to obtain round bars from cold work tool steel forging ingots. The carbide distribution at the final product was analysed for both forging processes. In parallel, finite element simulations were performed to analyse the strain components, e.g. normal and shear, and to correlate with the microstructure obtained in the real process, supporting the comparison analysis. The results showed that 4DFD process promotes a similar or better carbide distribution around the cross section area, depending on the applied process.

Keywords

Hot Open Die Forging, Four Die Forging Device, Cold Work Tool Steel, Finite Element Simulation.

1. Introduction

Hot open die forging process is an important stage of special steel production, mainly, in the forming process for cold work tool steels, because the initial carbide network is broken and refined during this process [1]. Changing this process from a conventional forging with plane dies to a new forming process with four-die forging device (4DFD) requires a deep investigation about the effectiveness of metallurgical quality, in case of cold work tool steel is the carbide distribution.

4DFD is a known equipment created by Lazorkin *et al*[2], it was presented at International Forgemasters Meeting since 2006, introducing a new concept for the forging process. Their studies reported the use of a 4DFD ensures high process productivity and a lot of benefits such as save energy and increase metal yield.

In previously investigation [3], using finite element simulation, it is observed that always the forging process using 4DFD produces less effective strain than the conventional forging process.

[1] Villares Metals S.A.

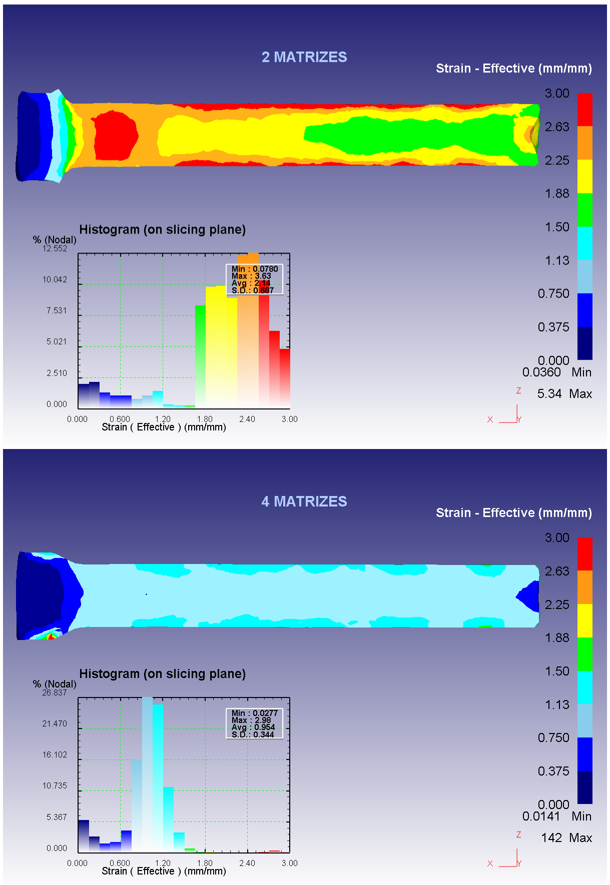


Fig. 1 – Comparison of effective strain result between 2-dies and 4-dies forging processes.

And one question emerges: how the metallurgical could be similar or better using 4DFD, if the effective strain is smaller? The 4DFD inventor's already published a paper showing a comparison between 4DFD and a conventional Radial Forging Machine [2,5]. González *et al*[4] used finite element simulation to show that the 4DFD produces a state of stress more favourable to improve the removal of defects of metallurgical origin.

This paper proposed to compare the 4DFD forging process and the conventional forging process using two planes dies, regarding a cold work tool steel production. The real forging processes were performed in order to analyse the resultant carbide distribution and a Finite Element Method Simulation was conducted aim to investigate the strain components and to understand the mechanism of breaking carbides and improving its distribution.

2. Materials and Method

The cold work tool steel grade selected to this study was the AISI D2 which chemical composition is described in the Table 1:

Table 1 – Nominal chemical composition for AISI D2 Steel (wt%).

C	Si	Cr	Mo	V
1.50	0.30	12.0	0.95	0.90

The ingot used in the experimental procedure was a squared shape with 525 mm of average side and 2,5tons of weight, it heated up to 1150°C before the forging process and the final diameter forged round bar was 263mm.

Both the forging processes were performed in a Hydraulic Press with maximum load capacity of 3,000tons, installed at the Villares Metals forging shop. For the conventional forging process were use two plate dies (450mm width) in almost whole process and two V-dies shape (350mm width) were used in the final forging passes in order to produces the most roundness bars. The Four Die Forging Device utilized in the experiment started to operate at Villares Metals since July 2014, the dies utilized in the experiment had 230mm as effective width.

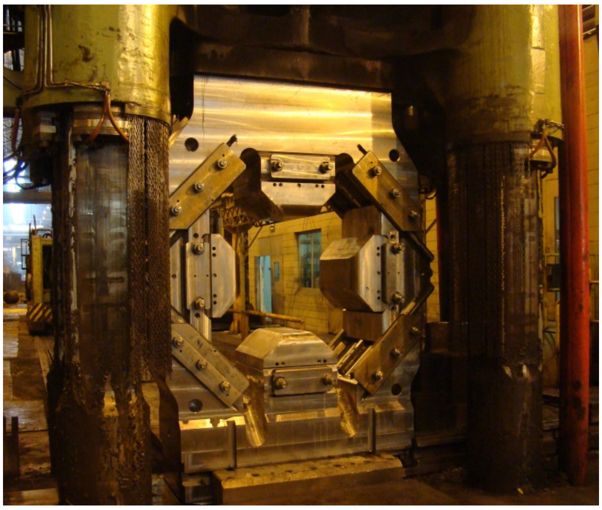


Fig. 2 – Four Die Forging Device installed at Villares Metals S.A.

After the forging process, the bars were full annealed and tree samples of each bar were collected: Near to Surface, Mid Radius and Centre. The micrographs were prepared in the longitudinal direction and the samples etched with Nital 4% solution for a time enough to leave the matrix in a dark color and carbides were best visible in a white color.

In order to evaluate in a quantitative way, the carbide distribution the freeware software Image-J[6] was used calculate the average carbide size in each sample.

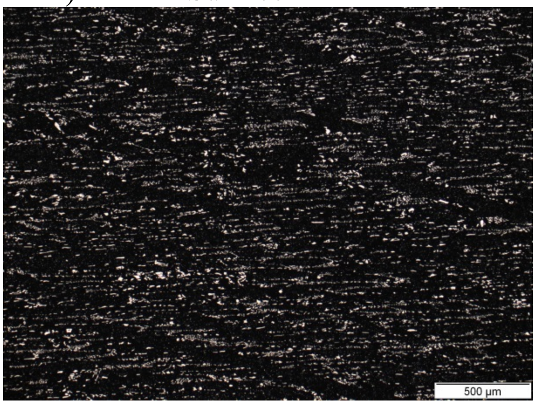
The Finite Element Method Simulation was run in software DEFORM^{TM}3D reproducing as much as possible the forging processes applied in the experiment, mainly the forging passes plan. The finite element simulation employed a rigid-viscoplastic formulation with thermo-mechanical coupling parameters, then simultaneous heat transfer and deformation analyses were performed. The room temperature was 30°C, the ingot initial temperature was 1150°C and was assumed 200°C for die temperature. The convective heat transfer coefficient on the free surfaces was estimated to be 15 W/m^2°C for ingot. At the contact region between the ingot and the dies, the interface heat transfer coefficient was 5 kW/m^2°C and the shear friction coefficient (m) was set 0.7.

The materials properties used in the numerical simulations were supplied by the DEFORM^{TM}3D library. The ingot material was AISI D3 (the most similar to AISI D2 available) whose flow stress was characterized as a function of strain, strain rate and temperature. Die material was AISI H13 with rigid condition.

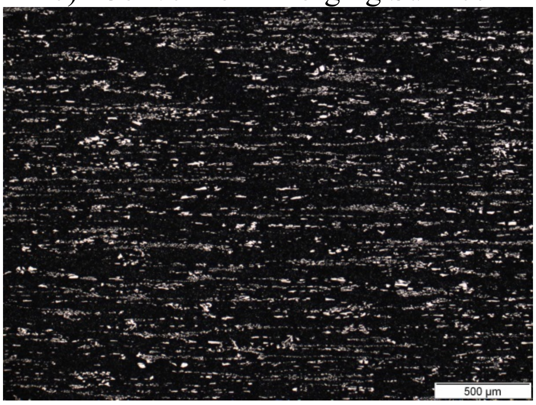
3. Results and Discussion

Next in Figure 3 are the results obtained with the metallographic analysis of the samples extracted from the forged bars at the experiment. Micrographs are shown with deep etching on annealed structure in order to visualize the carbide distribution.

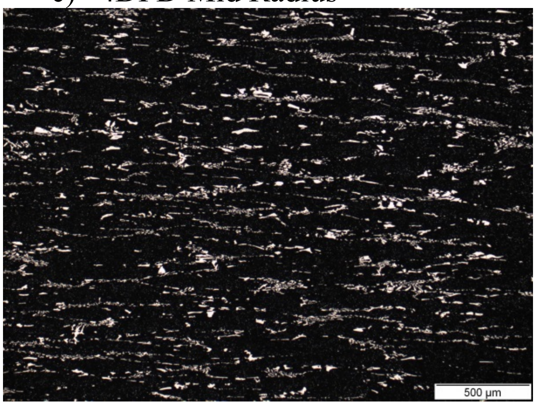
a) 4DFD Surface



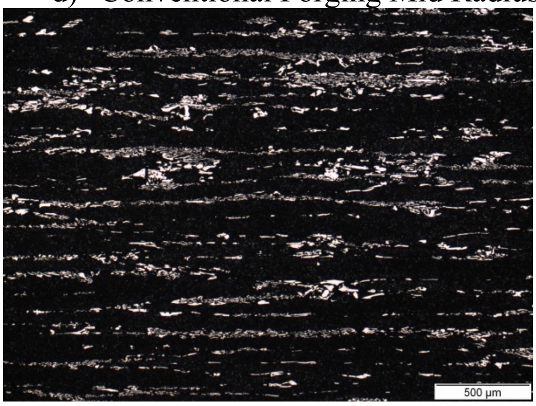
b) Conventional Forging Surface



c) 4DFD Mid Radius



d) Conventional Forging Mid Radius



e) 4DFD Centre

f) Conventional Forging Centre

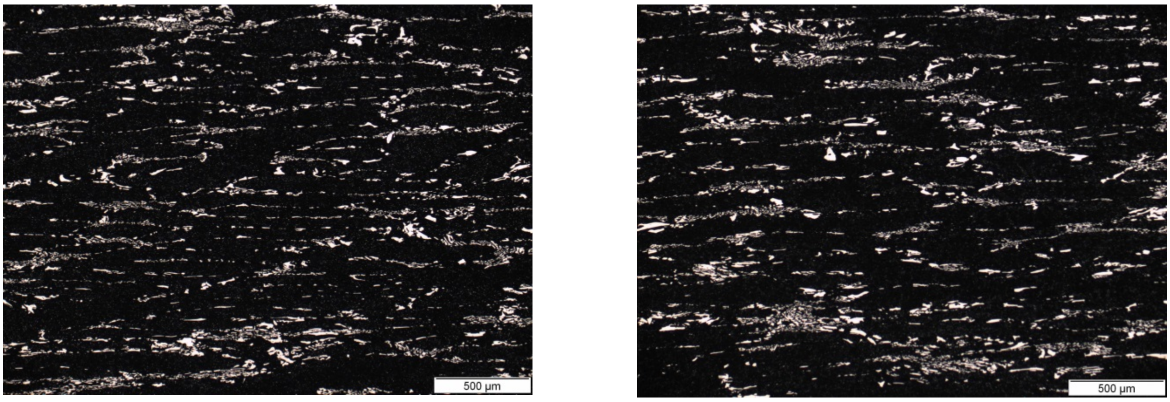


Fig. 3 – Microstructural comparison between Four Die Forging Device (4DFD) and Conventional Forging Processes. Magnification 50x.

Observing the micrographs, it is possible to affirm that the 4DFD process produced better carbide distribution and smaller carbide particle size. The difference is more evident at surface, however it is not important because this region is more susceptible to deformation variations. At mid radius and centre bar, maybe the difference is more difficult to evidence, thus following Table 2 contains the comparative values of the carbide size measurement calculated by the Image-J particles analysis.

Table 2 – Results of carbide size measurement comparing both forging processes.

Forging Process	Sample Position	Size Area Average (µm²)	Width Average (µm)	Thickness Average (µm)
Conventional	Surface	56.4	10.5	4.6
	Mid Radius	104.9	14.1	5.3
	Centre	142.6	16.8	6.3
4DFD	Surface	42.1	9.1	4.3
	Mid Radius	92.2	13.6	5.3
	Centre	115.6	15.2	5.7

It can be observed that all values obtained with 4DFD forging process are smaller than the Conventional forging process regarding same sample position. The difference is not large, but it can confirm that the 4DFD forging process reduced the carbide size, consequently, it improved the quality of the final product.

Following the comparison analysis, Finite Element Simulation results are presented in the next figures. Figures 4 and 5 illustrate the final result of effective strain in longitudinal cross section sliced bar and one more time showed that 4DFD produces less effective strain than the conventional forging process, as it was commented at the introduction paper. These figures considered the top and bottom discards, removing them from the strain analysis.

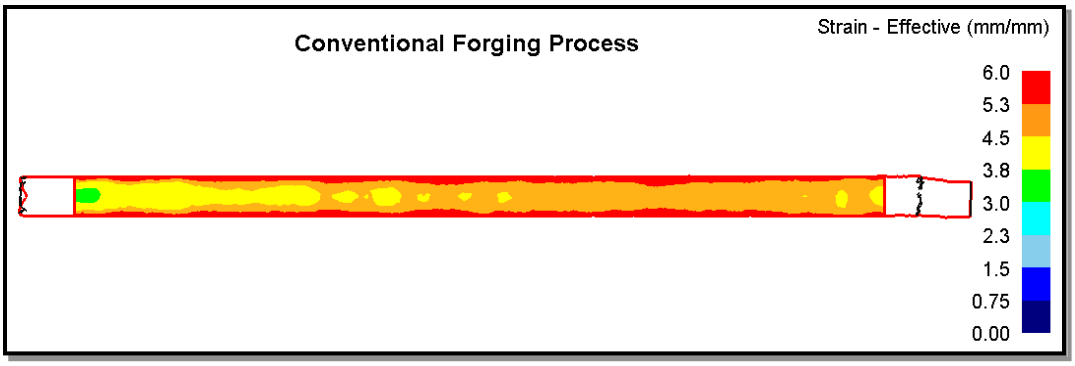


Fig. 4 – Effective Strain for the Conventional Forging Process.

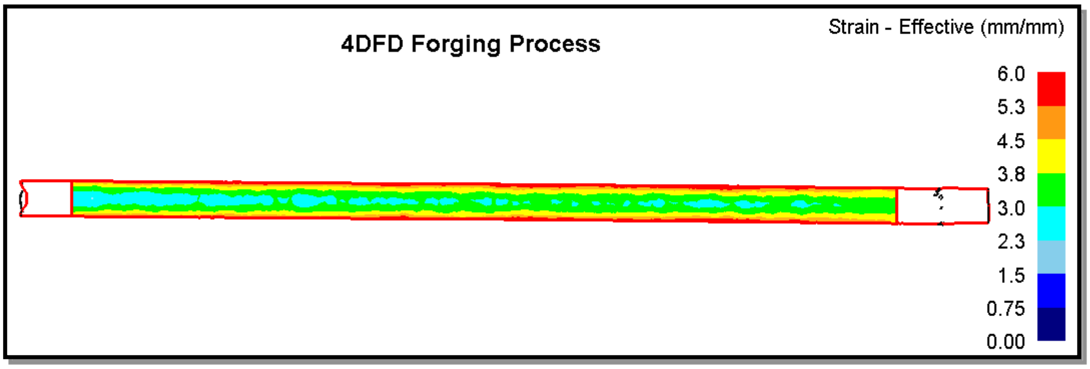


Fig. 5 – Effective Strain of the 4DFD Forging Process.

In order to analyse the strain components, it was used the DEFORM^{TM}3D tool called "State Variable Between Two Points" to extract the strain components profile at the bar centreline. Figure 6 shows an example of tool application using 500 points.

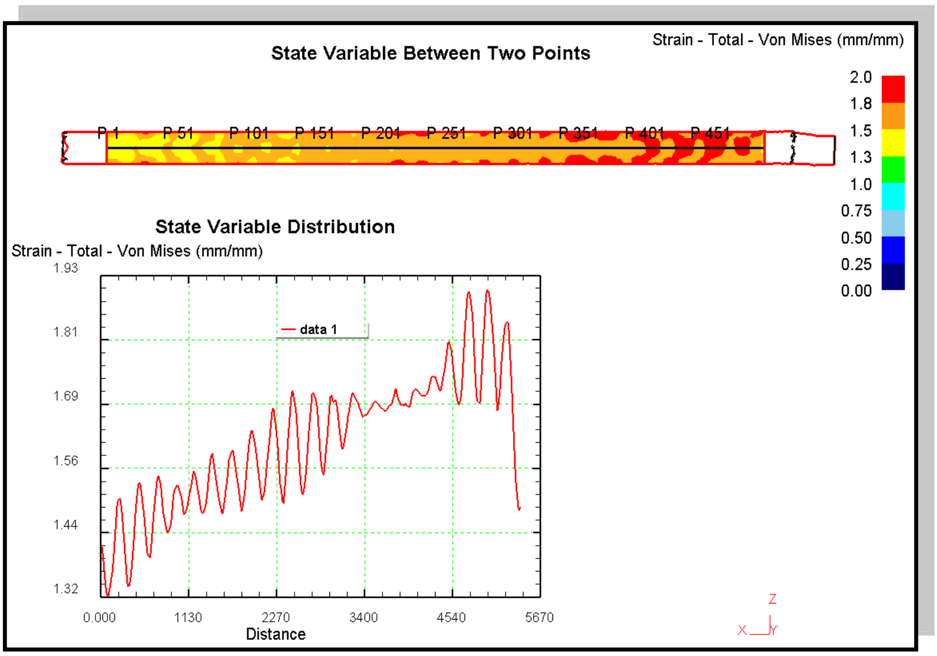


Fig. 6 – Example of State Variable Between Two Points analysis with DEFORM^{TM}3D.

The graphic points are exported to an MS Excel Sheet and it compared in the same chart both forging process. First result to be compared is the Von Mises Total Strain (Figure 7). Here, it is important to explain that the effective strain is an accumulative variable and the Von Mises Total Strain is calculated using the strain components and its results is more dependants of the initial and final bar dimensions, and generally, its value is smaller than the effective strain.

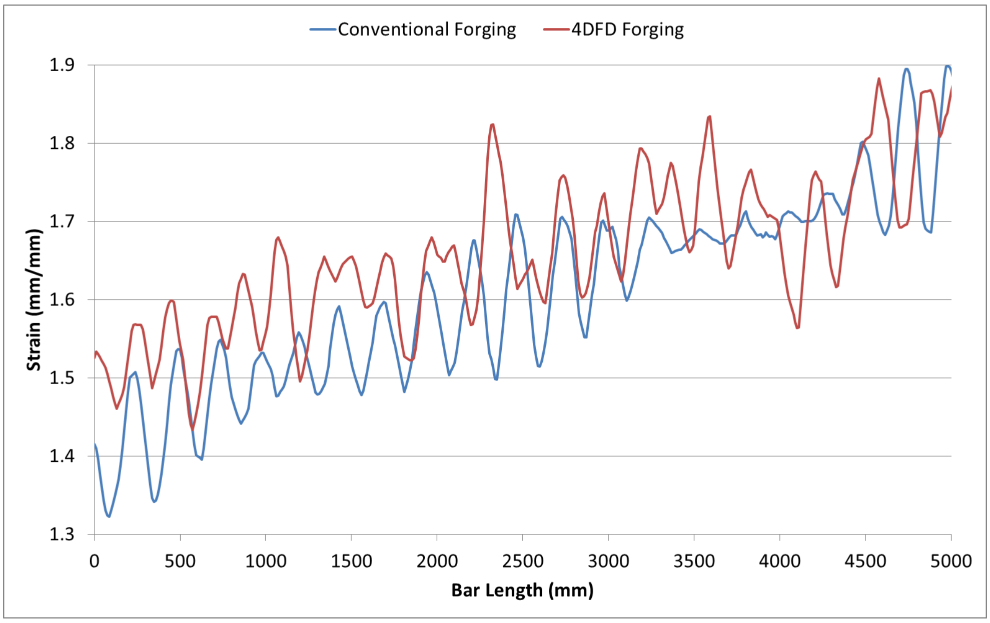


Fig. 7 – Von Mises Total Strain at the bar centreline.

Comparing these results of Von Mises Total Strain, they are similar for both process, the values are little bit superior for 4DFD forging process, this occurred probably because of more penetration and deformation at the bar centreline than the Conventional process. However, the best carbide distribution could be explained by the shear strain component. Thus, using the same technique of State Variable between two points at the centreline, the maximum principal strain (ε_1) and the minimum principal strain (ε_3) are extracted and plotted at the same graphic (Figure 8).

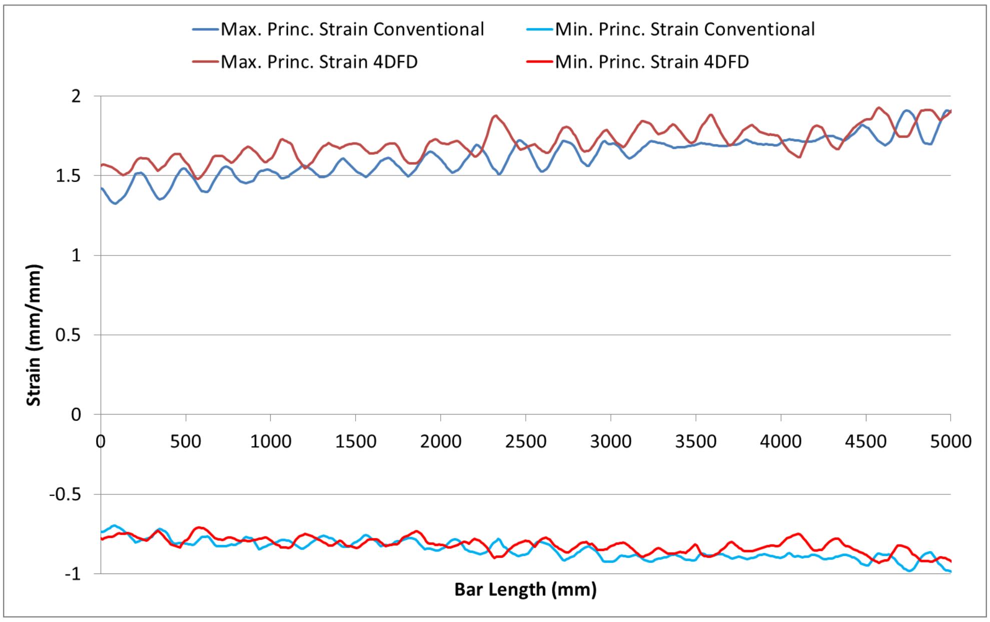


Fig. 8 – Comparison between maximum and minimum principal strain for both forging processes.

Additionally, the maximum shear strain (ε_s) was computed by the formula ($\varepsilon_s=\varepsilon_1-\varepsilon_3$), it is plotted in Figure 9.

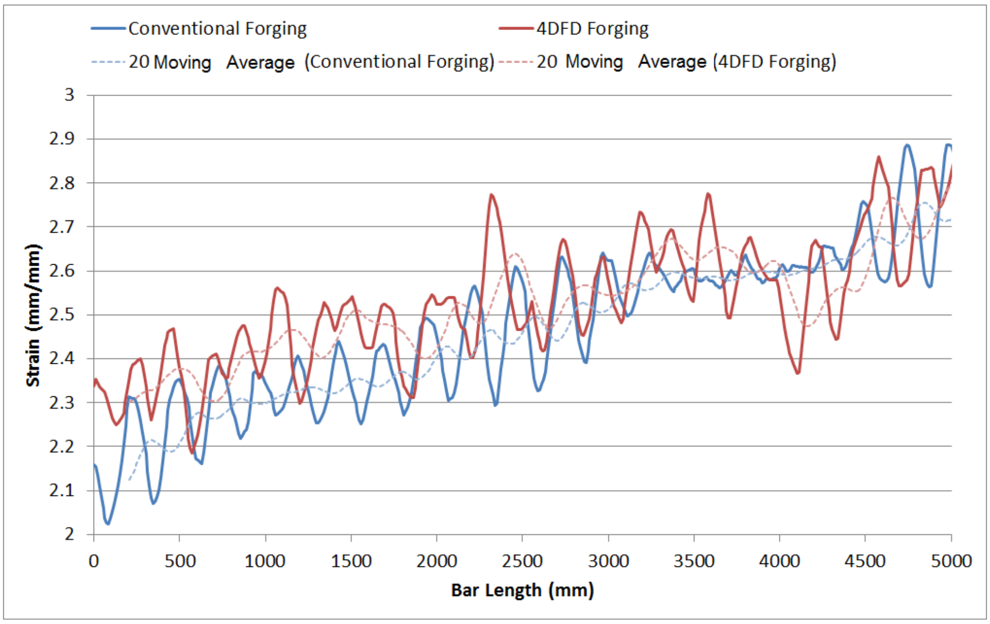


Fig. 9 – Maximum Shear Strain at the bar centreline.

The minimum principal strain is quite similar and the maximum principal strain is larger for 4DFD forging process, thus the shear strain is larger also for 4DFD, this comparison is also showed by the moving average plotted in the chart with dotted line. Those results indicated that there is more breakdown carbide structure refining and distributing over the matrix. This result is not much different, in this way, it could corroborate the similar microstructure, but with a slight improvement to the product metallurgical quality using 4DFD forging process.

4. Conclusion

Comparison between 4DFD and Conventional forging processes was performed evaluating the carbide size and distribution by means of microstructural analysis and Finite Element Simulation.

According to the microstructure observation, it was noted a reduced carbide size and best carbide distribution at samples produced with 4DFD forging process, for all locations: surface, mid radius and centre. After, with a utilization of image analysis software Image-J the quantification of the carbide size was confirmed the observation analysis.

Finite Element simulation showed that the Conventional forging process produced more effective strain, but in terms of shear strain the 4DFD forging process the result had a slight improvement.

A subject for future works suggest, it would be perform some application test such as AISI D2 steel tool wear experiment in a laboratorial or industrial scale, in order to prove and quantify that the carbide size and distribution generated by 4DFD forging process produced a better product quality than the Conventional forging process.

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