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RESEARCH ARTICLE

The Effect of Multiaxial Forging on the Grain Refinement of Low Alloyed Steel

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Abstract

Ultra fine grained low carbon low alloyed steel was formed by multiaxial forging. Altogether five passes of forging were made with decreasing temperature. The first two passes happened in the austenitic state of the steel, the third was made at the austenite-ferrite transition temperature. The fourth occurred in the austenitic-ferritic region, while the last pass was made in pure ferritic state. The intensive plastic deformation caused the austenite-ferrite transition temperature to be lowered, thus the undercooling was larger, and very small ferritic cores were produced. The following deformation made the grain structure even more fine.

Keywords

multiaxial forging · Gleeble 3800 simulator · ultra fine grain · electron back scattering diffraction

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1 Introduction

One of the most promising research field in materials science is a production of ultra fine grained (UFG) or nanostructured (NS) materials. In the engineering practice, however, a very important point of view is the productivity and cost efficiency of the production of such materials (mostly metals). It is important therefore to develop methods, by which simple basic materials can be transformed into UFG or NS state. In the NS materials, dislocation cells are formed with high dislocation density in the cell walls and low one in the cell interiors. The typical cell size is about 10 nm. This structure is produced mostly by severe plastic deformation (SPD), which can be az equal channel angular pressing, multiaxial forging, caliber rolling, etc. In the UFG materials there are thin high angle grain boundaries, which form an angle of approximately 120 degrees. The typical grain size in the UFG metals is about 1 mm. Both the nanostructured and the ultra fine grained metals have high strength and high formability. This paper introduces results, which were obtained after multiaxial forging (MF) of low alloyed carbon steel. After MF, a very fine grained material was obtained.

1.1 examination methods

Multiaxial forging is a forging process in which the specimen is rotated by 90 degrees after each forging pass. Fig. **??** shows the arrangement before and after the first pass, and before the second pass. It can be clearly seen that the shape of the specimen changes as a barrel. The rate of plastic deformation is very high, so it is a dynamic deformation process. After for example five passes the total equivalent strain exceeds the $f = 3$ value. The microstructure of the specimens was evaluated by electron backscatter diffraction (EBSD). Electron backscatter diffraction is a microstructure facility for obtaining electron diffraction data from bulk samples in the scanning electron microscope. It gives more accurate parameters of microstructure than any other imaging process (e.g. grain size, shape, orientation and the type of boundaries) [1]. Tilting the specimen in the scanning electron microscope at 70 degrees, electrons which penetrates the surface of the material will be diffracted according to Bragg's Law. The diffracted electrons leave the surface along diffraction

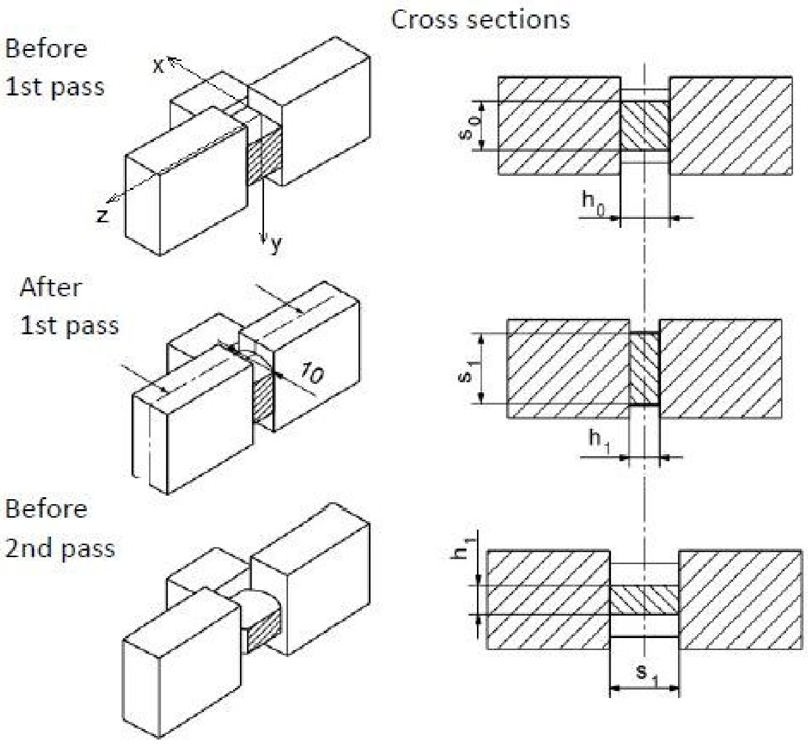

Fig. 1. Arrangement of multiaxial forging before and after the first, and before the second pass, respectively

cones (Kossel-cones) (Fig. 2). [2].

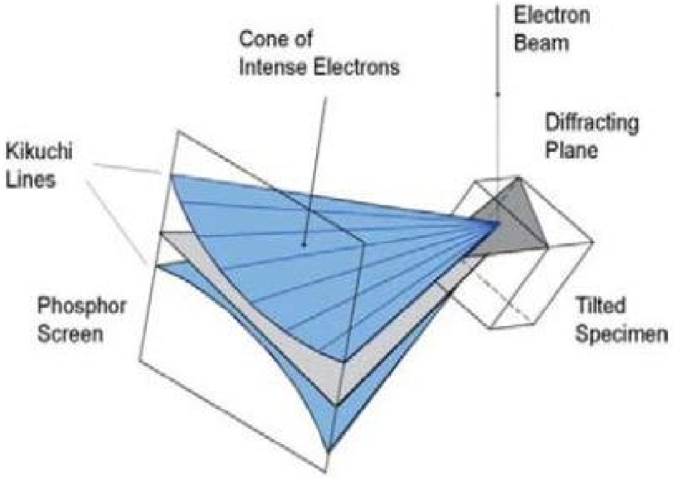

Fig. 2. Diffraction cones

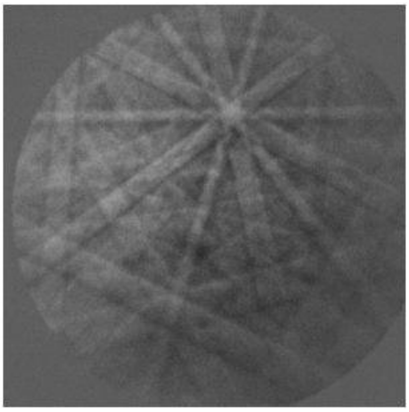

Fig. 3. Kikuchi-pattern

The intersections of these cones and an appropriately positioned fluorescent screen give the so-called Kikuchi-lines, which refer to the crystallographic structure of the specimen. The Kikuchi-lines build the Kikuchi-pattern. Fig. 3shows the Kikuchi pattern of a steel sample. From these data the properties of grains (grain size, grain orientation, grain interior misorientation) and indirectly those of grain boundaries can be calculated, as well as texture development can be traced.

1.2 experiments

A low carbon low alloyed steel was used for multiaxial forging, the concentrations of the five most important components are given in Tab. 1.

Tab. 1. Alloying element concentration in the steel specimens, wt%

C	Mn	Si	S	P
0.071	1.50	0.28	0.007	0.013

A Gleeble 3800 thermomechanical simulator with MAXStrain Multi Conversion Unit (MCU) was applied for multiaxial forging. In this equipment, the temperature of the specimen can be adjusted by Joule-heating and water cooling. Thermocouples provide signals for accurate feedback control of the specimen's temperature. Altogether five passes were made at different temperatures. The decrease of the temperature and the magnitude of the applied stress are summarized in Fig. 4. In the insert of the figure, the exact temperature values at which the individual forging passes were done, can be seen.

The specimen was then cut parallel to the last pass. Sample preparation started in a traditional way, *i.e.* the sample was

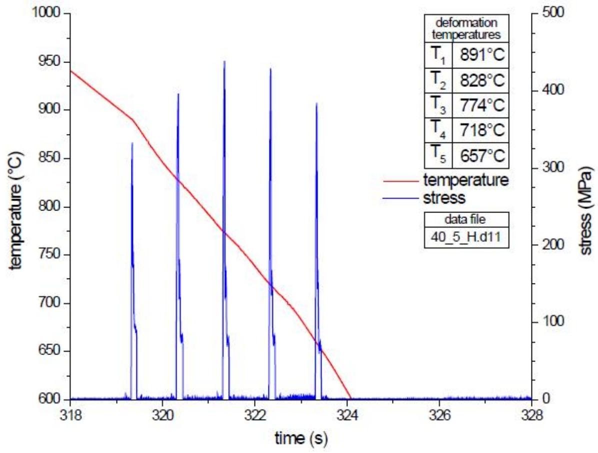

Fig. 4. Decrease of the temperature and the magnitude of the applied stress

grinded and polished, and finally a very fine polishing (with 0.05 mm colloidal silica) was performed for 30 minutes. EBSD measurements were done by a Philips XL-30 scanning electron microscope equipped with an EDAX-TSL Orientation Imaging system. An area of 90*x*70 mm was scanned with 0.3 mm step size, which means that altogether cca. 81000 data points were measured. The most important results obtained from these data points are the inverse pole figure map, the image quality map, the grain average misorientation map, the average grain size, the pole figure and the inverse pole figure. In the inverse pole figure map each point is coloured according to its crystallographic orientation, which was colour coded by the unit triangle of the inverse pole figure. The image quality map (which is very similar to a scanning electron microscopic image) shows the quality of the Kikuchi-pattern measured in each point. Where the quality of the Kikuchi-pattern is better, there the brightness of the pixel is high, while where the quality of the pattern is bad, there the pixel is darker. The average misorientation map shows the average misorientation between neighbouring pixels within a grain. The colour code was adjusted in such a way that red belongs to the maximum of 5 degrees of misorientation, while blue belongs to the zero degree misorientation.

1.3 results

Fig. 5a and Fig. 5b show the inverse pole figure map and the image quality map of the specimen.

It can be seen in these figures that a very fine grained structure was obtained. The average grain size is 1.9 mm, but it should be noted that most of the grains are smaller than 1 mm, and the value of the average is due to some large grains.

Fig. 6a shows the grain average misorientation map of the specimen. The bluer a grain, the smaller the average misorientation. It can be observed that small grains, *i.e.* smaller than 1 mm are blue, thus they have a smaller misorientation, while larger grains have larger misorientation. This means that larger grains contain subgrains, with low angle boundaries, which increase the average misorientation. These low angle boundaries in the larger grains are showed in Fig. 6b.

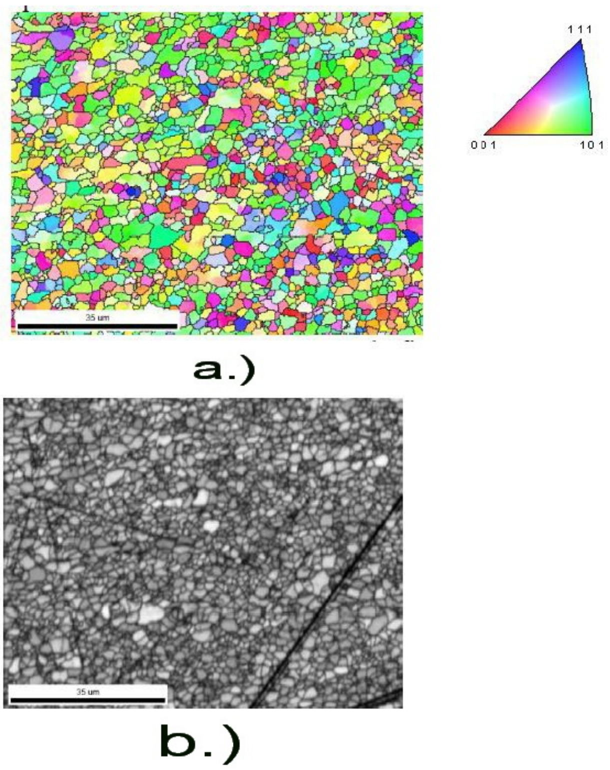

Fig. 5. Fig. 5a Inverse pole figure map Fig. 5b Image quality map.

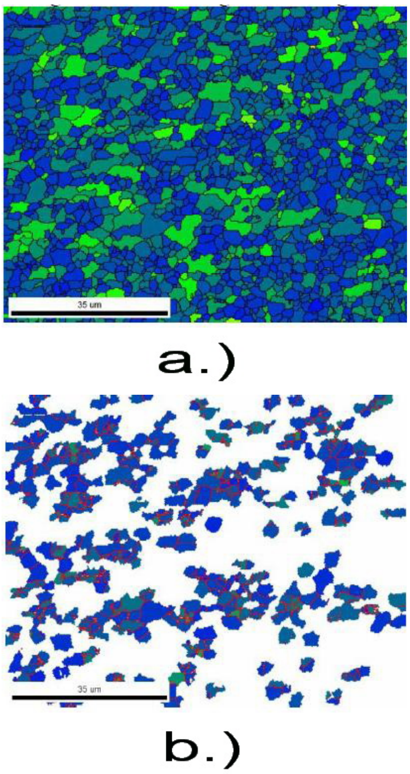

Fig. 6. Fig. 6a Grain average misorientation map Fig. 6b Low angle boundaries in large grains.

After the multiaxial forging a weak texture developed in the specimen, namely a ND//<210> texture, which can be seen in Fig. 7, where the inverse pole figure of the specimen is shown.

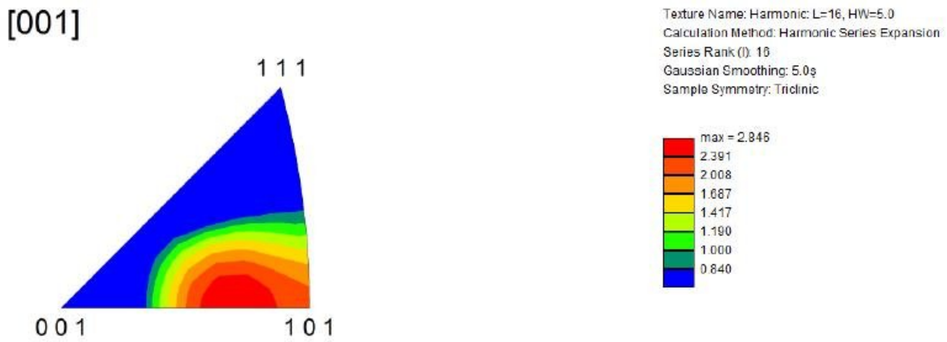

Fig. 7. Fig. 7Inverse pole figure of the specimen and the colour coding of multiplicity of random orientation.

1.4 conclusion

Low carbon low alloyed steel was subjected to severe multiaxial forging. The temperature of the forging decreased continuously between the forging passes. Finally a very fine grained material was obtained. The first two passes of the forging happened in the austenitic state. This caused a lot of dislocations formed in the austenite, and these dislocations formed low angle boundaries. Thus the austenite, from which the ferrite was formed, had a lot of subgrains. The third pass occurred at the austenite-ferrite transformation temperature. Since the rate of deformation was very large, there was no time for the ferrite to produce grain growth, so the ferrite which was transformed from the austenite has very fine grains. The fourth pass occurred in the heterogenious $a - g$ field, the remaining austenite was more deformed having a lot of subgrains, while the ferrite, due to dynamic recrystallization, was avoided from grain coarsening. The last pass occurred in pure ferritic state, and the final grain size was adjusted by the dynamic recrystallization of the ferrite.

References

1 *OIM Analysis Manual*, 2001.

2 **Palumbo G, Aust K. T**, *Structure-dependence of intergranular corrosion in high purity nickel*, Acta Metal Mater **38** (1990), DOI http://dx.doi.org/10.10162F0956-715128902990101-L.