Review of Multipass Extrusion of Ultra Low Carbon Steel: Mechanical properties

Abhishek Saini[1], Praveen Kumar[2] Ravi Kumar Bhatnagar[3]

(1) Assistant Professor, Department of Mechanical Engineering, Phonics Group of Institutions, Roorkee, Uttarakhand, India- 247667

(2) Assistant Professor, Department of Mechanical Engineering, Phonics Group of Institutions, Roorkee, Uttarakhand, India

(3) Assistant Professor, Department of Mechanical Engineering, Shobhit University, Gangoh, Saharanpur, Uttar Pradesh, India

Abhishek Saini (Corresponding Author)
E mail: abhimebit@gmail.com
Phone +91-9758058097

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ABSTRACT

Ultrafine grained microstructure was produced by multipass deformation using the extrusion method from carbon steels. The extrusions with lateral pressure were repeated up to 10 passes without any rotation. Each sample was uniformly deformed by the side-extrusion, and the equivalent strain was produced 1.145 after a single pass of the extrusion. After 10 passes of extrusion an ultrafine grained steel with a tensile strength of over 980MPa a grain size of 0.5pm x 0.2pm was developed for the ultra low carbon steel. The uniform elongation in tensile test for the steels after multipass extrusions was very small, but the cold formability was very good. By the heat treatment, the uniform elongation has been increased.

Key words- Multipass extrusion, low carbon steel, ultrafine grain, strength

1. INTRODUCTION:-

Material technology has been developed to realize good performance and high quality. However, recent social circumstances have brought about a new mission for material science, namely, harmony with our environment. In the field of structural materials, this mission is clearly to find a new process which produces materials such as eco-materials with high strength in order to reduce energy loss.

1.1 METHODS OF OBTAINING ULTRA FINE GRAIN STEEL:-

In order to obtain these high strength materials, severe plastic deformation processes such as ECAE (equal channel angular extrusion) [1-3] is used. In ECAE, pure shear deformation can be

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repeatedly imposed on a material so that intense plastic straining is produced in the material without any change in the cross section of work piece. For ECAE, it has been showed by many researchers that the grain size of the material is refined down to sub-micrometer order. Horita et al. have reported, in a series of papers [3], that the repeated subjection of aluminum and aluminum alloys to pure shear deformation by cold and warm ECAE led to ultrafine grain size, and that their strength increased. On the other hand, there have been few studies in which steels were repeatedly subjected to pure shear deformation by the ECAE process [1,6].

In this paper, in order to investigate the mechanical properties and the microstructure of steels subjected repeatedly to pure shear deformation, the ultralow-carbon steel is side-extruded with lateral pressure. After repetitive cold side extrusion, the stress-strain curve and the cold formability of the ultrafine grained steel are examined and the microstructures are analyzed by means of optical microscopy and a transmission electron microscope (TEM). Moreover, the properties of the ultrafine grained steel after heat treatment are examined.

2 EXPERIMENTAL PROCEDURES

2.1 Experimental apparatus

The experimental apparatus shown in Figure 1 is used for side extrusion with lateral pressure [7]. The four-pull rams can generate a force up to 160kN and travel a distance of up to 100mm with pressurized oil flowing through the servo valves which can be controlled manually or by a function generator with a maximum frequency of 100Hz or by a personal computer. The two columns and the crosshead in the middle are for supporting a manual hydraulic jack that holds down the cover plates of the fixture for the process with a force of up to 700kN.

The schematic representation of the fixture with the holding force is shown in Figure 2, where the retainer is displaced. The specimen is side-extruded between punches (A) and (B), while punches (C) and (D) are fixed. Punch (A), controlled by the function generator, moves at a constant speed and punch (B) generates a constant lateral pressure. The dimensions of the channels with a square cross section are 10mmx10mm and the inner surface is polished to a smooth finish. Generally, a specimen of almost the same cross section and lubricated with PTFE is placed into channel (A), and Figure 1.

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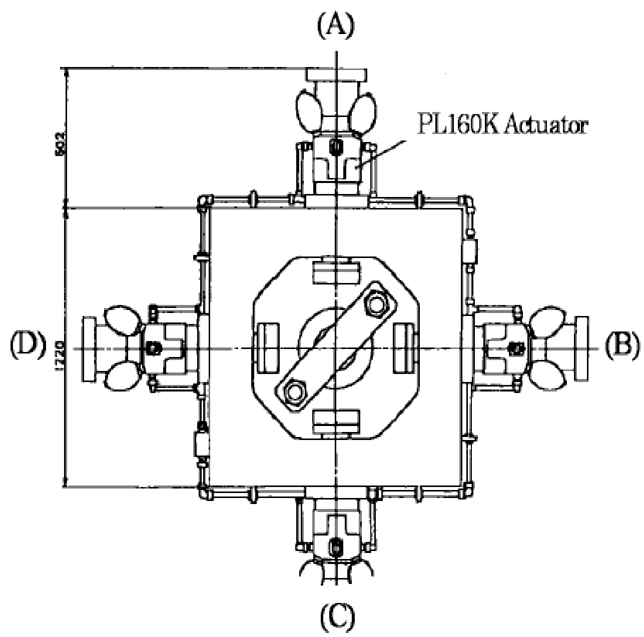

Figure 1: Schematic representation of testing machine

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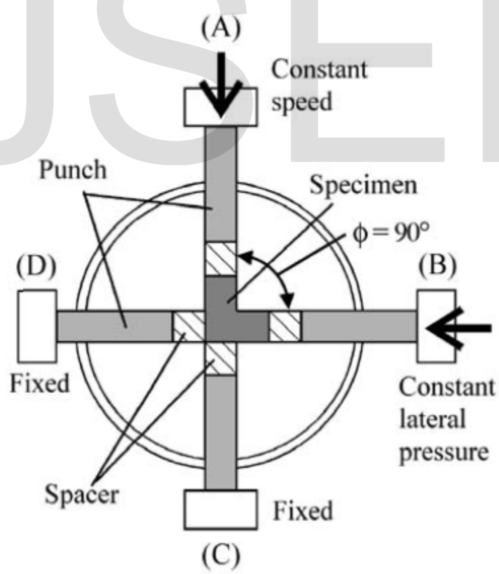

Figure 2: Schematic representation of the fixture with a specimen

punch (A) then extrudes it into channel (B). The specimen is side extruded through the shear deformation zone with ϕ which is channel angular and ψ due to the dead zone in the outer corner of the channel. The total strain [8] for one pass is

$$\varepsilon = \frac{1}{\sqrt{3}}\left\{2\cot\left(\frac{\phi}{2}+\frac{\psi}{2}\right)+\psi\operatorname{cosec}\left(\frac{\phi}{2}+\frac{\psi}{2}\right)\right\} \quad (1)$$

In this study, since the lateral pressure is applied to the specimen by punch (B), the specimen is deformed by pure shear deformation **so** that $\psi= 0$. Consequently, for the present experiment, it follows from equation (1) that $\epsilon=1.145$.

2.2 Experimental materials

The experiments were carried out using an ultralow-carbon steel (O.O015%C, O.O08%Si, 0.09%Mn,O.O06%P, 0.005%AI, 0.0017%Ti and balance Fe). The steels were received as a plate with a thickness of 22 mm after hot rolling. The initial grain size was approximately150pm and the Vickers hardness was HV99. For side extrusion, the specimens are machined in the rolling direction to the dimensions of 10mm **x** 10mm **x** 30mm.

2.3 Experimental procedures

In the repetitive side extrusion with lateral pressure, the shear strain exists throughout the side extruded specimen. In this study, the specimen is side extruded without rotation at each pass. This side extrusion process is called route A. For these repetitive side extrusions, the specimen orientation remains the same. Consequently, the distortion of the specimen is continuously increased with each successive pass. The total strain ϵ_n after n passes is 1.1%.

The experiments were carried out at a constant speed of 2mm/min at room temperature. PTFE spray film was used as a lubricant on both the specimen surface and the inner area of the die wall. In these experiments, a constant lateral pressure of 150MPa was applied to the specimen by punch (B). The specimens were side extruded up to a maximum of 10 passes.

After side extrusion, the tensile strength was measured and the microstructures were observed. For the tensile tests, the tensile specimens with a width of 4.5mm and a guage length of 5mm were machined from the side-extruded specimens after 1, 2, 5 and 10 passes. The tensile tests by means of the testing machine at a constant crosshead speed of 0.5mm/min. The optical microstructure observation was carried out using a specimen etched with 3% Nital, machined from the side-extruded rectangular specimen into a plate which is parallel to the top plane along the longitudinal axis of the specimen shown in Figure 5**.** The microstructures observed by transmission electron microscopy and the selected-area diffraction patterns were measured.

In order to examine the cold formability of the ultrafine grained steel, the side extruded specimen after 1, 2, 5 and 10 passes were rolled at room temperature. The specimens with a thickness of 10mm were rolled at a rolling speed of 2m/min without lubricants up to a total reduction in thickness of 95% by multiple passes. Moreover, the side-extruded specimens after 3, 5 and 10passes were annealed at a constant temperature of 600^0c changing the heat treatment time from 20s to 600s in air atmosphere. After the heat treatment, the hardness of specimens was measured by the Vickers hardness tester with a load of 5000g for a duration time of 15s and the stress-strain curves were obtained.

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Mechanical properties

Figure 3 shows the relationship between the nominal stress and the nominal strain of the as-received specimen and specimens after 1, 2, 5and 10 passes. The as-received specimen gives a stress-strain curve exhibiting normal strain hardening, while the specimen after side extrusions do not exhibit strain hardening; the stress for each specimen increases rapidly with increasing strain and reaches a maximum value at lower strain than that of as-received specimen. Figure 4 shows the relationship between the ultimate tensile strength and number of side-extrusion passes.

The tensile strength increases with increasing number of passes. It is increased by a factor of 2 after 1 pass in comparison with the as-received specimen and increases linearly with increasing number of passes up to 10 passes. The tensile strength is over 1000MPa after 10 passes and is increased by a factor of 3 in comparison with that of the as-received specimen. However, the total elongation showed a reduction from 65% of that of the as-received specimen to 15%. Generally, the increase of the tensile strength in cold metal forming occurs due to strain hardening, but it is anticipated that the increase of the tensile strength in the side-extruded specimen after 10passes occurs due to the formation of ultrafine grains.

3.2 Microstructure

The optical microstructure of the as-received specimen and the side-extruded specimens after 1, 5**,** and 10 passes is shown in Figure 5. The plates for the optical microstructure test were machined parallel to the top plane along the longitudinal axis. The initial microstructure of the as received ultra low carbon steel consists of 100% ferrite and the initial grain size is approximately15µm. It is found that a stronger filamentary microstructure is developed with increasing number of passes of the pure shear deformation. The microstructure after 1 pass, as shown in Figure 5(b), consists of a dark area characterized by the filamentary structure and a bright area characterized by the distortion of the ferrite grain. The microstructure after 5passes, as shown in Figure5(c), consists almost entirely of the filamentary structure (dark area) Beyond 5passes of side extrusion, a finer filamentary microstructure is developed with a greater number of passes. Figure 6(a) shows the TEM microstructure of the side-extruded specimens after 10 passes.

The SAD patterns at the center of the same area are also shown in Figure 6(b). The SAD patterns were measured with in a limited circular zone with a diameter of 1.35µm. From the TEM microstructure after 10 passes, it is evident that ultrafine grains with a length of 0.5pm and a width of 0.2pm are formed. Since the SAD pattern shows the appearance of rings, it is it is anticipated that the boundary angles of most of the ultrafine grains become high. The experimental data of the specimen after 10 passes is plotted in the Hall-Petch relationship of the yield stress against $d^{-1/2}$, as shown in Figure 7, where d is the measured grain size and the yield stresses are determined from the relationship between the stress and the strain shown in Figure 4**.** The grain size of the specimen after 10passes is 0.35pm that is the arithmetic mean of the length and the width of the ultrafine grain. In Figure 7, the experimental data for iron obtained by Takaki [9] is plotted. The results for these specimens show good agreement with the standard Hall-Petch relationship obtained by Takaki .

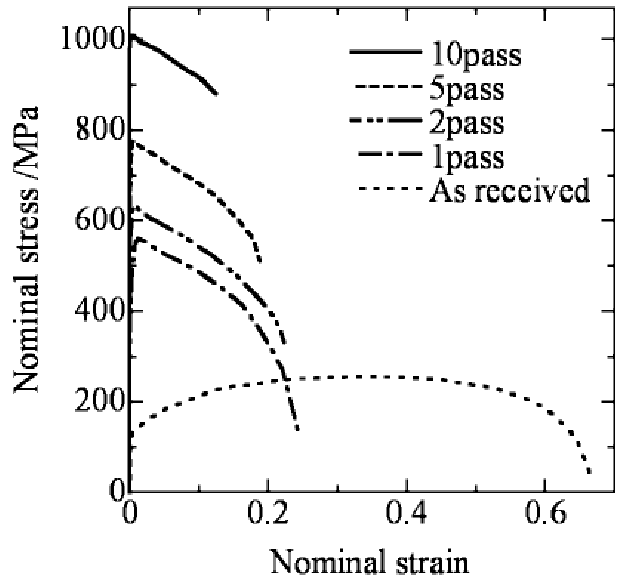

Figure 3: Stress-strain curves of side extruded ultralow-carbon steel specimens

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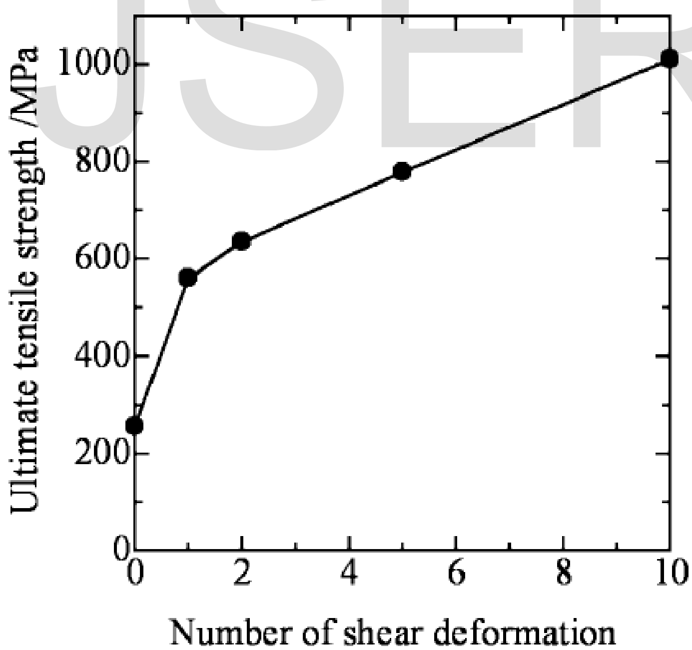

Figure 4: Relationship between ultimate tensile strength and number of shear deformation

3.3 Formability

The side extruded specimens with a thickness of 10mmafter 1, 2, 5and 10 passes were rolled up to total reduction in thickness of 95% by multiple passes of a reduction of about 5%per each pass at room temperature. All specimens after 1, 2, 5and 10 passes can be rolled up to 95% without fracture.

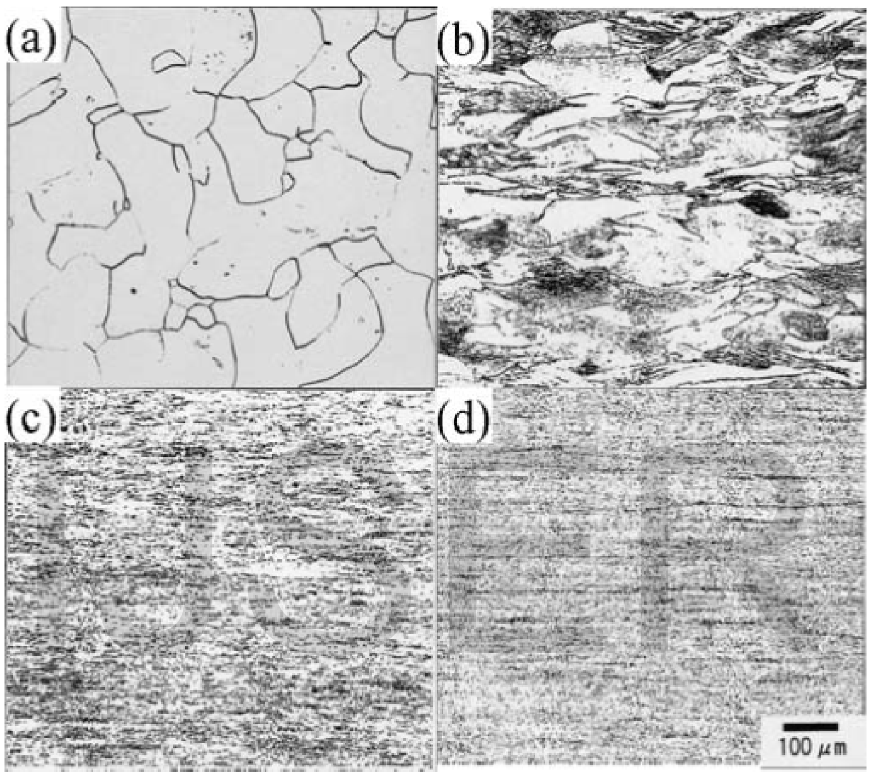

Figure 5: Optical micrographs of ultralow-carbon steel (a) as received, (b) 1 pass, (c) 5 passes and (d) 10 passes

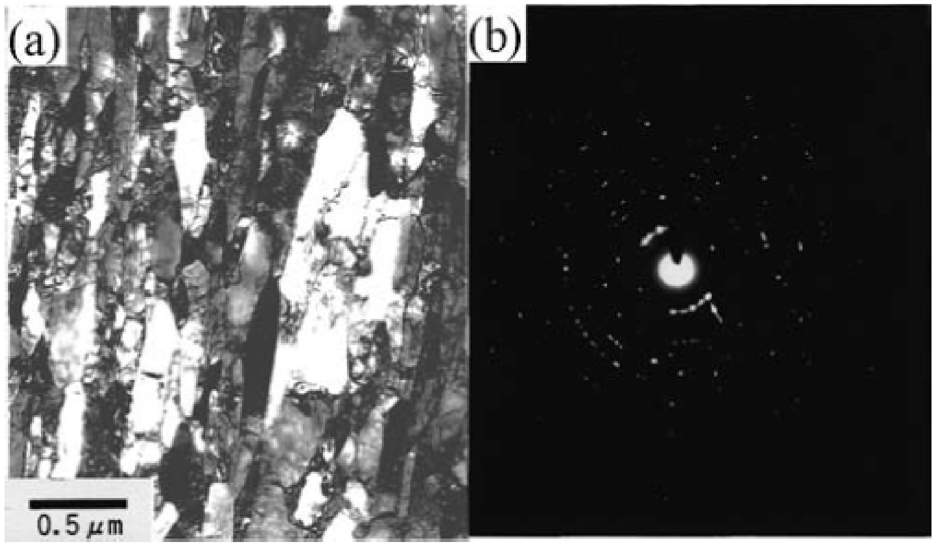

Figure 6: TEM micrograph of ultralow-carbon steel after 10passes: (a) bright image, (b) SAD pattern

3.4 Properties after heat treatment

After heat treatment of the specimen after 10 passes, the materials with the hardness of HV225, 215, 173 and 105were obtained. Figure 8 shows the relationship between nominal stress and nominal strain of the as-received material and materials after 10 passes. After heat treatment, the tensile strength becomes lower and total elongation increases with decreasing hardness. A uniform elongation can be observed on the material with Vickers hardness of 173 and 105. Figure 9 shows TEM micrographs of the microstructure in the side plane parallel to the extruded direction. From these micrographs, the grain size of the specimen with the hardness of HV220becomes lager a little compared with side extruded specimen. For the specimen with a hardness of HV176, grain growth can be observed. The microstructure becomes duplex grain structure with 1pm and smaller ingrain diameter. For the specimen with a hardness of HV105, a static recrystallization occurs and equivalent microstructures are obtained. From the results, it estimated that the presence of grains with approximately 1pm in diameter has a great influence for the uniform deformation.

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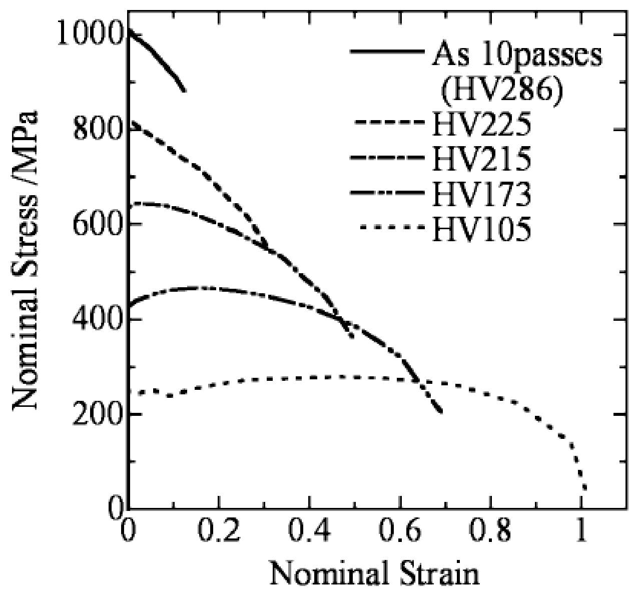

Figure 8: Stress-strain curves of side extruded specimens after heat treatment

The ultrafine grained metals produced by the repetitive side extrusion may be very effective as the material for the micro-forming process [l0,11] When the size of parts decreases in micro-forming, it is desired that the grain size of the material must become smaller in order to guarantee the strength.

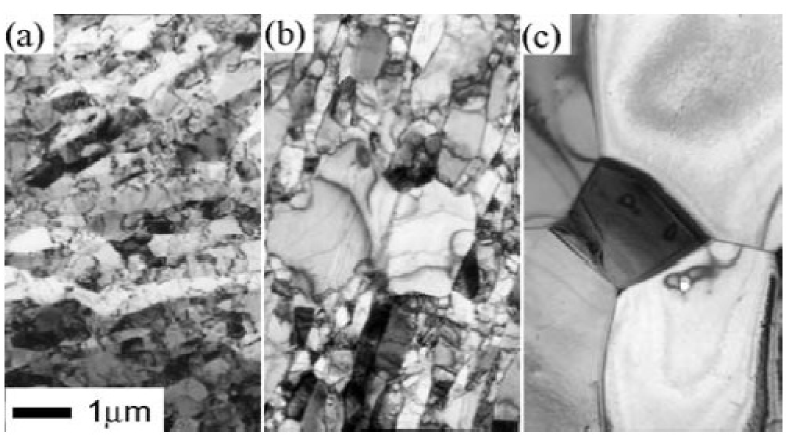

Figure 9: TEM micrographs of side extruded specimens after heat treatment : (a) HV220, (b) HV176 and (c) HV105

4. CONCLUSION:

The mechanical properties of ultralow-carbon steel with an initial grain size of 150pm on which pure shear deformation has been imposed repeatedly by side extrusion with lateral pressure are examined. The conclusions obtained are as follows:

(1) The tensile stress increased with increasing number of pass. It was increased by a factor of 3 after 10 passes of cold side extrusion and the value was 980MPa.

(2) The ultrafine-grained ultralow-carbon steel with a length of 0.5pm and a width of 0.2pm was developed after 10 passes.

(3) The specimen after 10 passes was rolled up to 95% without fracture at room temperature.

(4) For the specimen with the hardness with under HV 170of the heat treatment, a distinct uniform elongation was observed.

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