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TEXTURE FORMATION IN BULK IRON PROCESSED BY SIMPLE SHEAR

M.A. Gibbs[1], K.T. Hartwig[1], L.R. Cornwell[1] R.E. Goforth[1], and E.A. Payzant[2]
[1]Texas A&M University, Department of Mechanical Engineering, College Station,
Texas 77843-3123 [2]High Temperature Materials Laboratory, Oak Ridge National Laboratory,
Oak Ridge, Tenn. 37831-6064

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Introduction

The preferred orientation of grains in iron after conventional deformation by cold rolling or drawing is characterized as sheet or fiber texture (1–6) respectively. The main texture component in the rolling direction is [110](001). For the case of wire drawing, again, the [110] direction aligns with the wire axis.

A novel method of straining materials called equal channel angular extrusion (ECAE), has recently been developed (7). This new processing method has the capability of introducing large amounts of plastic strain into bulk material in a relatively uniform manner without a reduction in workpiece cross-section. The processing concept is elegant: press a block of solid material through a constant cross-section tunnel composed of two intersecting channels (8). The material undergoes simple shear in a thin zone at the crossing plane of the channels. Because workpiece dimensions are nearly the same before and after processing, multiple extrusions of the same workpiece in the same tooling are possible. By controlling workpiece orientation relative to the tooling crossing plane during multiple extrusion operations, different microstructures can be developed. For instance, ECAE has been successfully used to develop ultrafine equiaxed grains (9–11) and filamentary microstructures (12). An average grain size of less than 1μm is reported for iron ECAE processed to strains from 4 to 7 (13).

The purpose of the work reported here is to determine which kinds of texture are developed by three basic schemes of multipass ECAE. The schemes examined include what are termed route A, route B and route C. Route A maintains the same orientation of the shear plane and shear direction relative to the extrusion direction during all extrusions. The extrusion direction and the billet long axis are the same. The route A processing scheme leads to laminar microstructures similar to those developed by conventional rolling operations (12). The preferred orientation expected from multipass route A processing is "sheet texture." In fact, this is the texture that is seen to develop during route A extrusions.

Route B involves rotating the billet +90° about the extrusion direction before each even numbered extrusion and −90° before each odd numbered extrusion. The shear plane and shear direction alternate between two orientations separated by 90° around the billet long axis. The result of multiple extrusions is a fibrous microstructure similar to that developed by conventional drawing. By analogy with wire drawing, Route B processing is expected to produce a fiber-like texture. Because route B impresses shear strains at two specific locations (positioned 90° apart) around the extrusion direction, the texture developed is expected to be less uniformly symmetric around the long axis of the billet than that seen

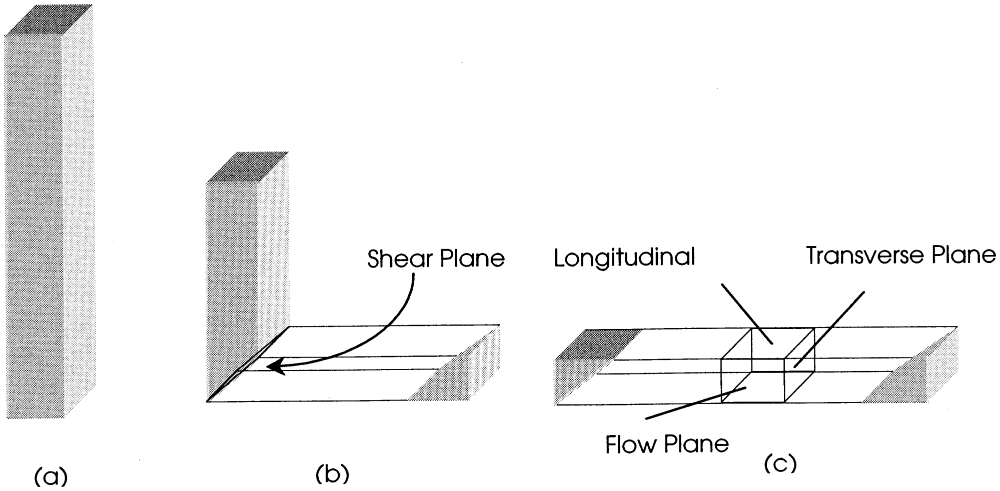

Figure 1. Illustration of workpiece geometry during equal channel angular extrusion through a 90° die: (a) initial position, (b) intermediate position (c) one pass complete. Flow (front face), longitudinal (top face), shear and transverse planes are shown. The shaded end regions are undeformed.

in cylindrical drawn products. Route B processing of iron is shown to develop texture similar to that in drawn iron bars.

Route C processing includes an even number of extrusion passes with a +180° or −180° rotation of the workpiece around the extrusion direction before each extrusion. The result is a shearing back and forth of the material such that after an even number of passes a material element (small volumetric region) is returned to its original shape. Even though the material element geometry is unchanged after an even number of extrusions, the material has experienced an equivalent strain of 1.17N where N is the number of extrusion passes (7). The texture expected after route C processing is one that will contain components of both shear and the original texture. Characteristics of a shear texture are seen after extrusion following route C.

Experimental

The pure iron used in this study was obtained as 31mm thick hot rolled plate from Magnetic International, Inc., a subsidiary of Inland Steel. The as-received material has nearly equiaxed grains with an average grain diameter of 130 μm. The nominal composition is 0.0025 weight percent (w/o) carbon, 0.009 w/o Si, 0.2 w/o Mn, 0.002% P, 0.001% S, 0.041% Al, 0.004% N, 0.0143% O with the balance iron. Bars for extrusion (billets) were machined transverse to the plate rolling direction to have nominal dimensions 25mm × 25mm × 150mm. Billets were extruded at room temperature with a velocity of 0.5mm/sec through tooling incorporating a 90° die angle. Processed billets were machined and sometimes rolled slightly between extrusions for multiple extrusion cases. Figure 1 illustrates the ECAE process for a 90° die angle.

Individual billets were processed through different sequences of extrusions including multiple passes via route A, B or C. A shorthand notation for ECAE processing history is written as the number (N) of extrusion passes followed by the route used (i.e. 4A refers to a billet given four passes using route A). Transverse, flow or longitudinal plane specimens of 6mm minimum thickness were cut with a diamond saw from the center regions of billets for x-ray analysis. The orientations of these planes are

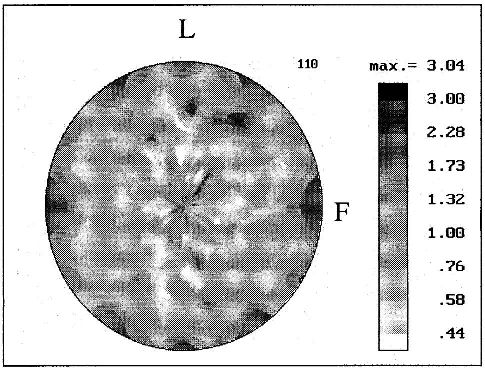

Figure 2. (110) pole figure from transverse plane of as-received pure iron. The flow plane and longitudinal plane locations are shown as F and L, respectively.

illustrated in Fig. 1. The surfaces examined by x-ray diffraction were polished with 0.5μm Al_20_3 to a metallographic finish. At least one unaltered billet surface remained as an edge on these specimens so that an accurate reference could be used for pole figure indexing.

The texture measurements were taken at the High Temperature Materials Laboratory (HTML) of Oak Ridge National Laboratory using a four stage PTS Goniometer with Mo K_α radiation. The surface planes examined for the route A, B and C processing cases were longitudinal, transverse and flow respectively. X-ray scans were acquired up to tilt angles of 75° for diffraction from the three planes conventionally used to map texture in BCC materials: [200], [110], [211]. Pole figures were constructed using popLA software (14). Completion of the pole figure range (75−90°), rotation to a conventional format and small corrections for specimen mounting misalignments were also accomplished with popLA.

Results

A [110] pole figure from the central transverse plane of a billet of as-received material is shown in Fig. 2. The scale bar to the right of the pole figure indicates relative intensity where 1.00 represents random orientation. The reader is cautioned when comparing pole figures because the scaling factors used for each pole figure are not necessarily the same as those used for others. Little texture is apparent for the as-received material. Complimentary [200] and [211] pole figures support this observation.

Fig. 3 presents the [110] pole figure from the flow plane of material extruded once. Fig. 4 shows the [110] pole figure from the flow plane of material extruded through four passes following route C. Fig. 5 presents the [200] pole figure from the longitudinal plane following a 2A schedule. [110] and [211] pole figures from the transverse plane are shown in Fig. 6 for material processed through 2B passes.

Discussion

Iron extruded once experiences a theoretical shear strain of 2.0 and exhibits a texture similar to material that has been twisted. The pole figure of Fig. 3 looks very similar to one on Armco iron reported by Backofen (16) for a torsion (shear) strain of 2.0. Similar pole figures characteristic of torsional texture have also been reported in copper (15) and 70–30 brass (16).

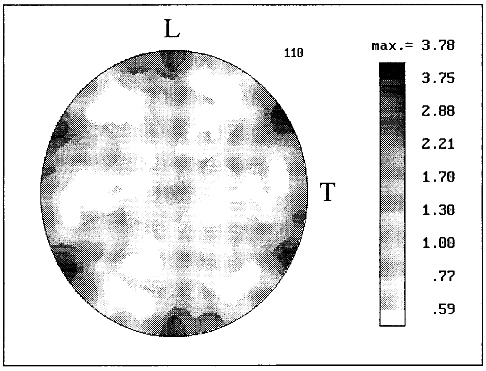

Figure 3. (110) pole figure from flow plane of pure iron extruded once. The longitudinal and transverse plane locations are shown as L and T, respectively.

For route C extrusions, which include only cases involving an even number of passes, the texture that develops (see Fig. 4) contains components of shear or torsion and the original texture. If plastic strain effects were perfectly reversible, one would expect the texture arising from route C to be identical to the original texture. But this is not observed. The difference between route C and the original texture must arise from plastic strain effect irreversibilities.

The pole figure shown in Fig. 5, which is for route A processing, is similar to those found in cold rolled iron (17) and cold rolled molybdenum(4). For these cases a sheet texture develops with {001}parallel to the rolling plane and <110>, parallel to the rolling direction.

Fig. 6 shows two pole figures for iron processed via route B. The corresponding texture appears similar to that seen in drawn BCC metals (4). It is referred to as a fiber texture with ⟨110⟩ aligned parallel to the wire axis or the extrusion axis for ECAE processed material. The ring formation seen in the (211) pole figure is characteristic of fiber textures where a particular crystallographic direction is parallel with the wire axis and other directions are distributed equally around the axial orientation giving cylindrical symmetry to the pole figure. The fact that route B gives a texture similar to drawn products is not unusual because conventionally extruded rods often have textures similar to drawn wire (4).

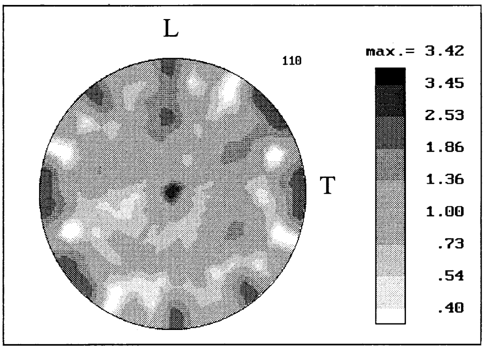

Figure 4. (110) pole figure from the flow plane of pure iron extruded through four passes following route C. L and T are longitudinal and transverse plane normal directions, respectively.

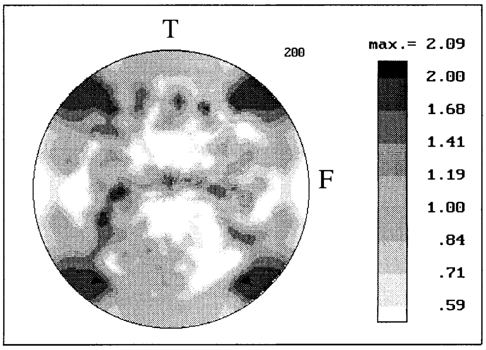

Figure 5. (200) pole figure from the longitudinal plane of pure iron extruded through two passes following route A. T and F are transverse and Flow plane normal directions, respectively.

Conclusions

Conventional sheet and fiber textures can be developed in bulk iron by using multipass ECAE processing. A shear texture results after a single extrusion. Multipass extrusions that return structural elements to their original shape after an even number of passes result in a texture that shows characteristics of both shear and the original texture.

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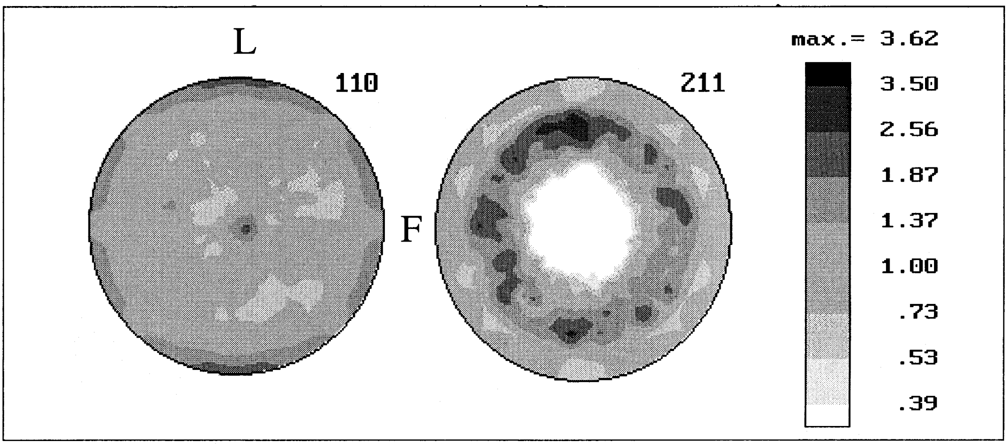

Figure 6. (110) and (211) pole figures from the transverse plane of pure iron extruded twice following route B. L and F are longitudinal and flow plane normal directions, respectively.

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