The Rolling Texture of 18%Ni-350 Maraging Steel

A. ul Haq and A.Q. Khan

Texture development in hot rolled sheet and hot forged tube of 18%Ni-350 maraging steel has been studied after various degrees of cold deformation and flow turning, respectively. Hot rolled sheet exhibited considerable mechanical anisotropy. Weak texture development was observed following flow turning compared to cold deformation. Above 80% deformation, an increase in work hardening was accompanied by an increase in the orientation density of the texture component (001)[110]. Deformation of 97% leads to the development of the texture component (111)[110], with the highest orientation density 10.3 times random and a constant orientation density of 9 times random along φ_1 at $\phi = 55°$ and $\varphi_2 = 45°$. This texture was correlated with the appearance of shear bands in the microstructure.

Keywords:
18%Ni-350 steel, maraging steel, rolling texture

1. Introduction

MARAGING steels are known for their excellent combination of strength and toughness.[1] Because of their very low strain-hardening coefficient, they are used in a flow turning process for making thin-walled tubes. Most of the published literature on these materials describes the influence of different heat treatments on the mechanical properties, kinetics of direct and reverse martensitic transformations, morphological features of martensite reaction products, etc.[2-8]

There has been little work on the formation of crystallographic textures, *i.e.*, nonrandom distribution of crystallite orientation in these steels. However, there is little doubt as to its importance, because it may be used to set the manufacturing parameters of the components. Furthermore, analysis of the formation of preferred orientations can frequently shed light on the mechanisms of the process responsible for texture formation. In particular, study of texture changes may provide important information on the mechanisms of plastic deformation, primary and secondary recrystallization, etc.

Rack and Kalish[9] studied the fatigue resistance of type 350 maraging steel after thermomechanical treatments and concluded that improvement in fatigue resistance exhibited no correlation with the differences in textures. Texture formation and aging behavior of cold rolled type 300 maraging steel was studied by Hosoya *et al.*[10] They concluded that (1,1,1)[*uvw*] orientations, which developed strongly during cold rolling, gradually changed into the near (–5,5,7) [1,1,0] and (–5,–5,4) [–1,–5,6] orientations, and the (0,0,1)[0,–1,0] orientation evolved with the progress of austenization. Brat[11] studied the effect of heat treatment on shear spun tube of type 250 maraging steel. They concluded that aging does not modify the original shear spun texture. However, an intermediate solution treatment stage between spinning and aging seems to partially relieve the effect of the deformation process.

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The aim of this investigation was to study the texture development caused by the cold rolling process in hot rolled sheet of type 18%Ni-350 maraging steel. Furthermore, the texture development that occurs during cold rolling and flow turning, respectively, is also compared.

2. Materials and Experimental Procedures

Annealed hot rolled 5-mm thick sheet of type 350 maraging steel, referred to as the as-received sample, were used for the study. The chemical composition is given in Table 1.

The orientation distribution in the as-received material was found to be fairly random, as was proved by texture analysis. Specimens 100 by 30 by 5 mm were cut from the central part of the plate and cold rolled at room temperature without lubrication. The mill used for rolling contained 180-mm-diameter rollers. The cumulative rolling reductions investigated were 0, 20, 40, 60, 70, 80, 90, and 97%. For comparison, forged tube of the same material, *i.e.*, 18%Ni-350 maraging steel, was also flow turned to 40 and 80% reduction.

Tensile tests were carried out on the as-received material (sheet) in three directions, *i.e.*, rolling, 45°, and transverse, using an Instron universal tensile machine. Vickers hardness of the as-received, cold rolled, and flow turned materials was measured using a load of 20 kg.

Optical metallography was performed for all rolling reductions on sections cut perpendicular to the rolling (R) and transverse (T) directions, respectively, and etched electrolytically by 10% chromic acid with few drops of sulfuric acid.[12]

Table 1 Chemical Composition of Sheet

Element	wt%
Carbon	0.003
Sulfur	0.0003
Phosphorus	0.0003
Nickel	18.0 ± 0.3
Cobalt	12.1 ± 0.2
Molybdenum	4.1 ± 0.1
Titanium	1.5 ± 0.1
Silicon	0.2 ± 0.1
Iron	bal

Table 2 Tensile Properties of As-Received Sheet

Direction	Tensile strength, N/mm^2	0.2% proof stress, N/mm^2	Elongation, %
Rolling	1200	880	14
45°	1150	840	15
Transverse	1275	890	12

Table 3 Vickers Hardness after Cold Rolling

Cold work, %	Hardness, HV
0	370
20	390
40	390
60	400
70	393
80	423
90	483
97	540

Table 4 Vickers Hardness after Flow Turning

Reduction in wall thickness, %	Hardness, HV
0	340
40	350
80	374

The 18%Ni-350 maraging steel is known to have only martensite present in the annealed condition.[1,12] Texture measurements using the Shulz method[13] were carried out for cold rolled sheet and flow turned tube, after various stages of deformation. Samples along the rolling direction were cut, and texture measurements were carried out on their etched central layers. Three incomplete pole figures—(1,1,0), (2,0,0), and (2,1,1)—were measured (maximum tilt angle 70°) using Co-Kα radiation. From these pole figures, the orientation distribution function (ODF) was calculated for only the cold rolled samples using a series expansion method up to $L = 22$ for the even part.[14] The orientation distribution function for flow-turned samples could not be calculated, because these samples have triclinic symmetry and the program could not accommodate the data.

3. Results and Discussion

The as-received material exhibited anisotropy in its properties, as determined by tensile tests in the three directions. Table 2 shows the tensile strength, 0.2% proof stress, and percent elongation measured in the rolling plane. Tensile strength and 0.2% proof stress are greater and elongation is less in the transverse direction. The results indicate that the material has considerable planar anisotropy.

The maraging steel studied consisted of either hot rolled 5-mm-thick sheet or 12-mm-thick tube forged at 900 °C in the austenitic state, which was partially recrystallized and transformed into martensite during cooling. Metallography indicated that there was no difference between the microstructure

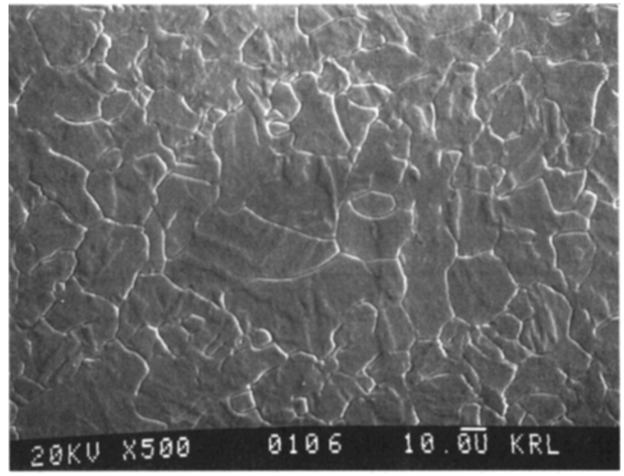


Fig. 1 SEM micrograph of hot rolled as-received sheet showing recrystallized grains.

of as-received, recrystallized hot rolled sheet, and recrystallized hot forged tube. Therefore, Fig. 1 shows the scanning electron microscopy (SEM) micrograph of the as-received sheet only. The material has a partially recrystallized grain structure.

Vickers hardness was measured after various amounts of cold reduction (Table 3) and flow turning (Table 4). Comparison of Tables 3 and 4 shows that the increase in Vickers hardness for the same percentage of deformation during cold reduction is much higher than for flow turning. However, deformation up to 70% does not lead to significant work hardening. This material is known to have a very high number of mobile dislocations in the lathe martensite,[8] which may cause low work hardening.[15] These results are in confirmation with the experimental literature.[2,4] This was also confirmed by texture measurements.

The measured (100) pole figures of 40 and 80% flow turned tube are compared with the relevant cold rolled sheet in Fig. 2(a) and 2(f). As mentioned earlier, the orientation distribution function for the flow-turned material could not be calculated due to the nonavailability of a computer program for triclinic sample geometry. Comparison of the pole figures for the cold rolled (Fig. 2a to 2c) and flow-turned material (Fig. 2d to 2f) indicates that the texture development in the flow-turned material is very weak compared to the cold rolled material.

The *r*-value (which is defined as the ratio of the width/thickness strain during tensile testing) for the 18%Ni-350 maraging steel has been reported[15] to range from 0.6 to 1.0. This value is low compared to that of a deep drawing mild steel, in which the *r*-value ranges from 1.2 to 1.5. It would appear then that pressing, stretch forming, and deep drawing are likely to be difficult when dealing with this steel, whereas spinning and flow forming should, according to theory, be the easier processes to adopt.

The cold rolled samples were etched and observed perpendicular to transverse direction, *i.e.*, RN sections in a scanning electron microscope, which revealed gradually increasing elongation of the former polygon grains with an increasing per-

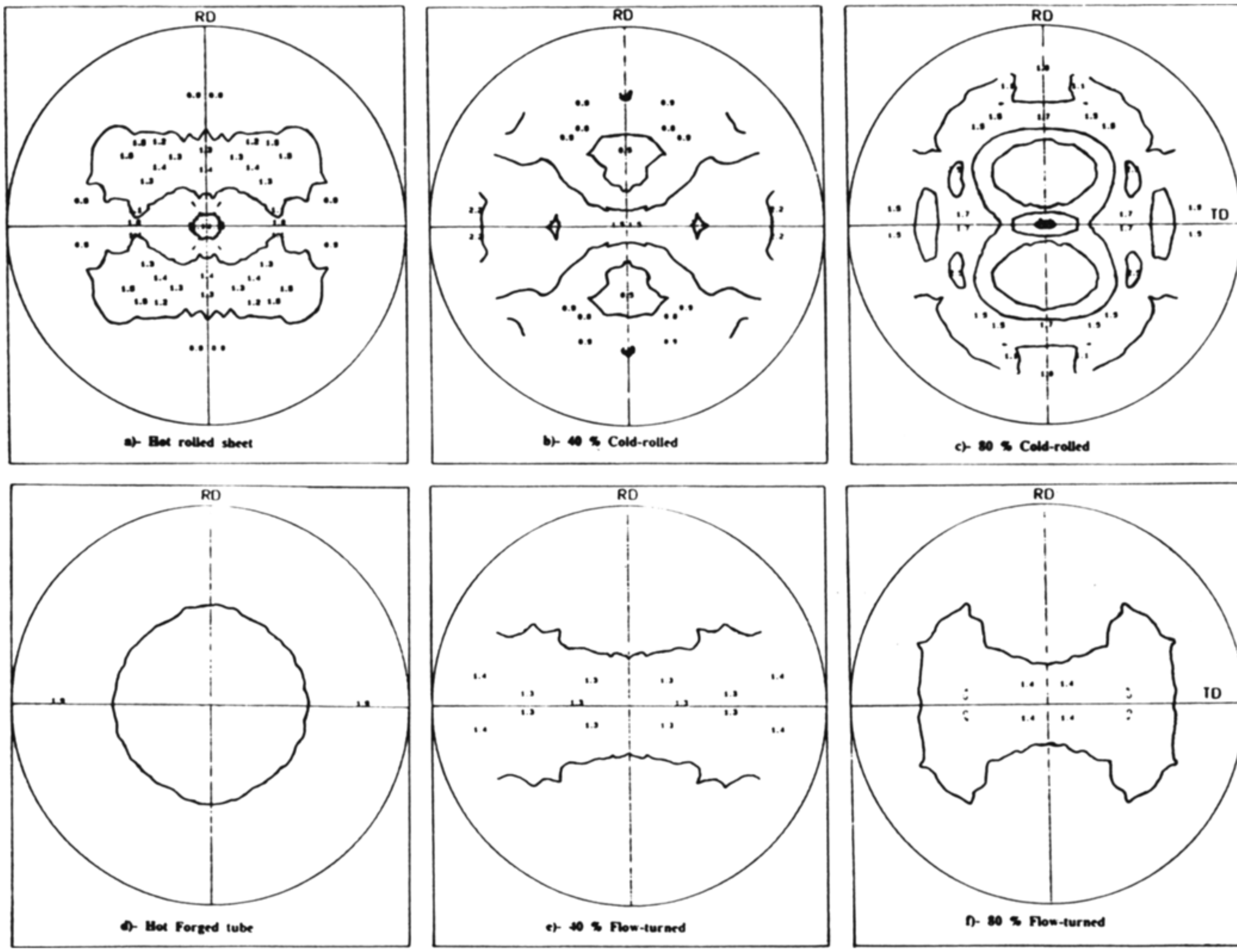


Fig. 2 Comparison of (100) pole figures of cold rolled and flow-turned material for the same percentage of deformation.

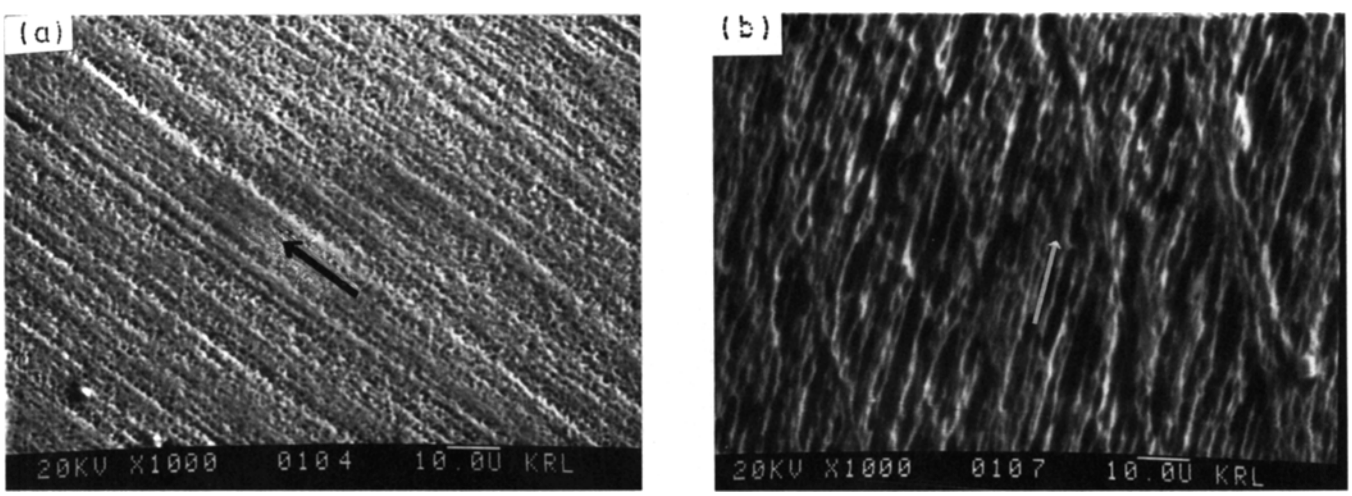


Fig. 3 SEM micrograph of RN section after **(a)** 70% and **(b)** 97% deformation. Etchant: 10% chromic acid plus few drops of sulfuric acid. Arrow parallel to rolling direction.

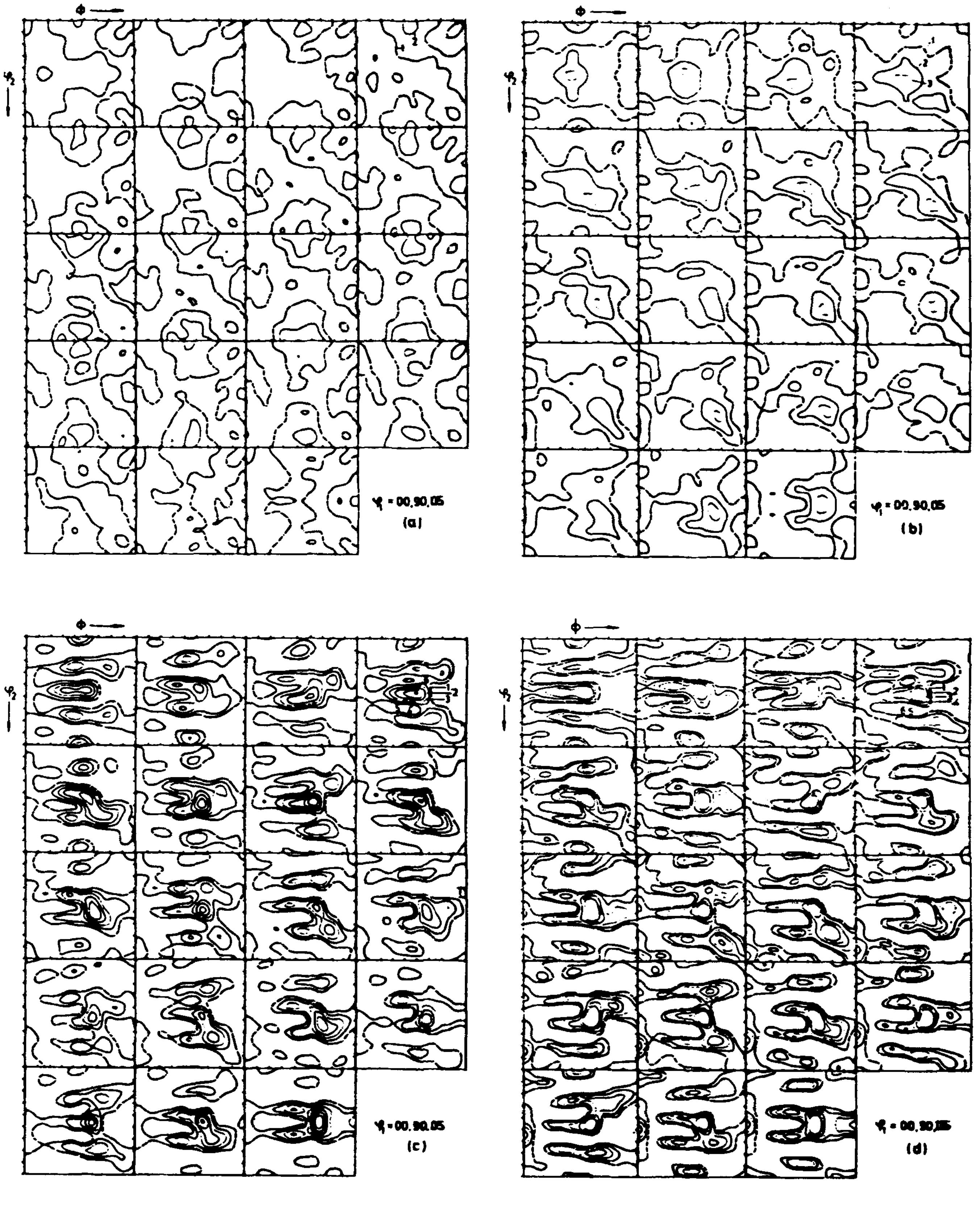
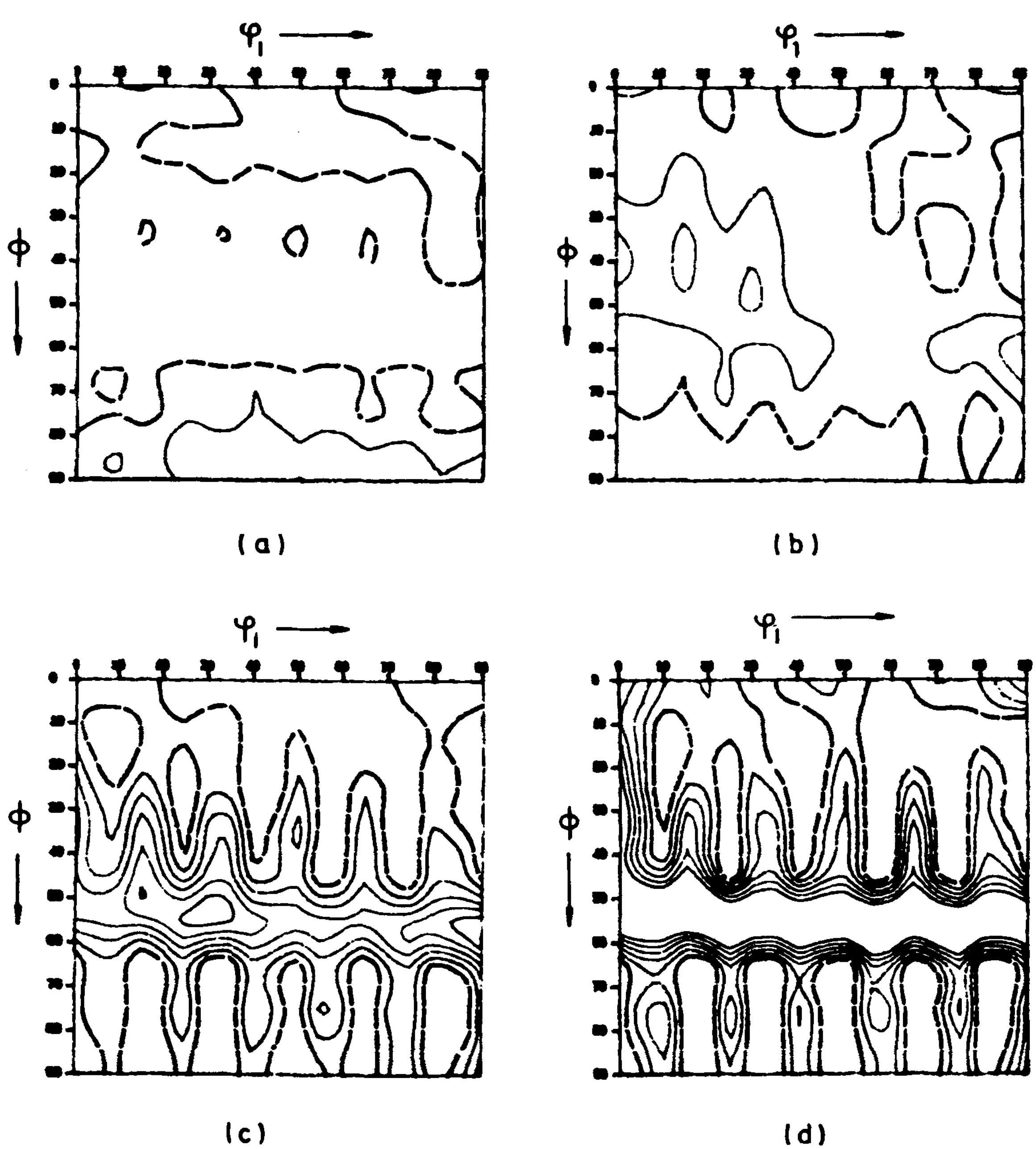


Fig. 4 Presentation of orientation distribution function in constant φ_1 section by isolines corresponding to multiples of random orientation density for **(a)** 0% deformation, **(b)** 60% deformation, **(c)** 70% deformation, and **(d)** 97% deformation.



(a) (b) (c) (d)

Fig. 5 Section φ_2 - 45° of the orientation distribution function of Fig. 4.

centage of cold reduction. Above 40% deformation, the former grains become thin, sheet-like bands that were parallel to the rolling direction (Fig. 3a). At the highest strain level, *i.e.*, 97% deformation, two sets of lines inclined at ± 30% to the rolling direction could be observed frequently in the RN section (Fig. 3b). This may correspond to the features commonly called shear bands, which often form in heavily rolled metals.

The cold reductions, on the basis of texture measurements and hardness values, were divided into three stages of deformation—low (up to 60% cold reduction), medium (70 to 90% cold reduction), and high (above 90% cold reduction). The three-dimensional orientation distribution function is presented in constant φ_1 sections. Four examples corresponding to the initial state and the low, medium, and high stages of deformation are given in Fig. 4(a) to 4(d). Figure 4(a) illustrates that, before cold rolling, the orientation distribution was almost random. The well-known orientation was observed at all three stages of deformation, although they were rather diffuse after 97% deformation.

However, the orientation distribution function for 60, 70, and 97% deformed samples indicates remarkable ideal texture components at (011)[100], with a constant orientation density of 2.3, 3.6, and 4.8 times random, respectively, whereas it was 1.8 times random in the as-received sample. Most of the prominent orientations of the bcc texture are contained in the φ_2 = 45° section, which is therefore often chosen as a concise al-

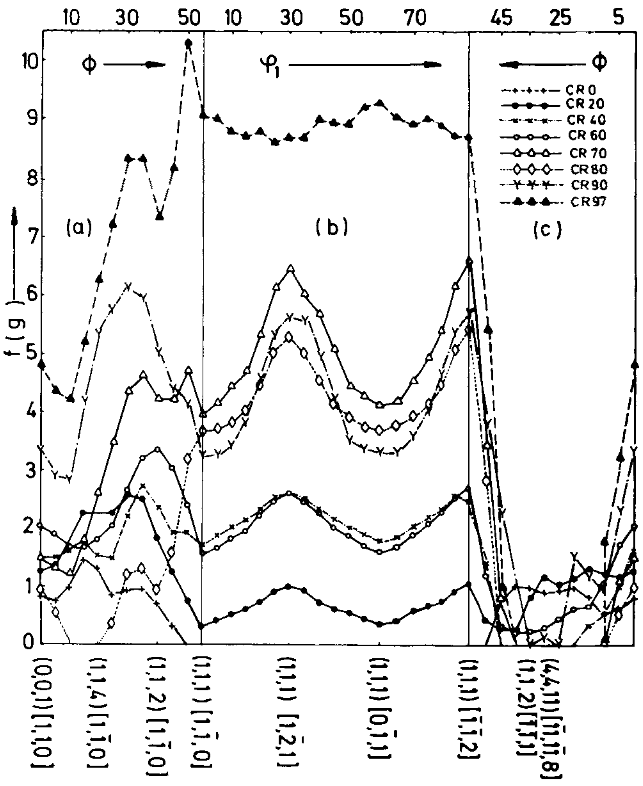


Fig. 6 Normalized orientation density along the linear section for the complete range of deformations studied.

though not complete representation. Figure 5 shows these sections of the above-mentioned four examples.

Figures 6(a) to 6(c) provide example of quantitative texture development. Here orientation densities along skeleton lines have been plotted. The texture of the bcc phase contains a strong fiber component with [110]/ND, which extends along the ϕ direction at $\varphi_1 = 0$ and $\varphi_2 = 45°$ (Fig. 6a). This component appears to increase as a function of cold reduction. This was not observed in the as-received material and has attained a value of 4.8 times random in 97% cold rolled sample in the (001)[110] orientation. A second fiber component may be best described as having a [110] direction 30° to ND in the ND-RD plane.[16,17] This component is clearly seen in the section $\varphi_2 = 45°$ (Fig. 6b). It contains the components (111)[112] and (211)[011].

Figure 6(a) shows that the texture component (001)[110] develops rapidly above 80% deformation and attains an orientation value of 3.4 and 4.8 times random for 90 and 97% deformation, respectively. As mentioned earlier, a rapid increase in hardness is also observed above 80% deformation. Thus, the texture component (001)[110] developed at high degrees of deformation may be responsible in this material for the increase in work hardening. Other texture components near (112)[110] do not reveal any specific trend as a function of cold reduction. Hence, their role could not be correlated with mechanical properties. However, 80% deformation leads to the development of a new texture component, (111)[110], with an orientation density of 3.6 times random, but texture component (112)[110] is absent in this case. Deformation of 97% also revealed a texture component near (111)[110], with the highest orientation density of the order of 10.3 times random. This may be correlated with the development of shear bands as observed in Fig. 3(b).

Figure 6(b) shows that the texture component (111)[121] has developed as a function of cold work, but its orientation density is approximately the same and on the order of 2 times random for the 0 to 40% and 5 times random for the 60 to 90% deformation. After 97% deformation, a constant orientation density of 9 times random is noted along φ_1 at $\phi = 55°$ and $\varphi_2 = 45°$ and no single texture component could be identified. Figure 6(c) shows diffuse peaks, and no texture component can be identified.

It may, thus, be concluded that texture development in 18%Ni-350 maraging steel is different from that in α-iron,[18] which is composed of two limited fiber axes centered about (111)[121] and (001)[110], respectively, with an angle of rotation of about 70°.[16] Up to 60% deformation, both components develop equally. At higher degrees of deformation, only the [110] fiber texture continues to develop. Furthermore, the results disagree with the work of Hosoya *et al.*,[10] who observed development of texture components (111)[112], (111)[110], (112)[110], and (100)[011] after 78% deformation in 18%Ni-300 maraging steel. The above-mentioned differences in texture development may be due to differences in the alloying elements in two materials. The current study used 18%Ni-350 maraging steel, whereas Hosoya *et al.*[10] used 18%Ni-300 maraging steel. Similarly, Dickson and Gray[19] noted rolling texture components (001)[110], (557)[110], and (111)[112] after 90% deformation in 18%Ni-300 maraging steel. These results agree with the current results, with the exception that the (337)[110] texture component was observed instead of (557)[110].

4. Conclusions

Hot rolled sheet and hot forged tube of 18%Ni-350 maraging steel have been subjected to cold reduction and flow forming, respectively, to study the texture development as a function of cold work. As-received hot rolled sheet exhibited considerable planar anisotropy. Measurement of Vickers hardness as a function of cold reduction or flow turning showed that work hardening is low up to 80% deformation. Work hardening is even lower, and weak texture development is observed after flow turning.

A rapid increase in texture component (001)[110] is observed above 80% deformation. This component appears to be responsible for the observed increase in work hardening. Deformation of 97% leads to the development of a texture component near (111)[110] with the highest orientation density equal to 10.3 times random, which may be correlated with the appearance of shear bands.

The texture component (111)[121] appears to have approximately the same orientation density for deformation in the range of 0 to 40% and 40 to 90%. However, 97% deformation has a constant orientation density of approximately 9 times random along φ_1 at $\phi = 55°$ and $\varphi_2 = 45°$.

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