

# THE REPRESENTATION OF TEXTURE IN COLD-ROLLED COPPER SHEET

## BY AN ADVANCED X-RAY DIFFRACTION TECHNIQUE

K. Kozaczek, C.O. Ruud, J.C. Conway Jr., and C.J. Yu

The Pennsylvania State University  
University Park, Pennsylvania 16802

### INTRODUCTION

The influence of texture on forming properties of metals has widely been recognized [1-4]. Preferred orientation of the crystallites (grains) in polycrystalline aggregates results in anisotropy of the mechanical properties. The desired degree of, or absence of, anisotropy depends on the particular process of forming, and any subsequent manufacturing process requires certain material properties for satisfactory performance. For example, the type of texture desired in deep drawing is quite different from the one necessary for simple stamping or multiaxial bending. Thus, in-process texture monitoring is receiving increased interest, both from manufacturers and researchers [4,5].

In the past texture has often been illustrated using pole figures. However, a more complete quantitative texture representation can be made in terms of an orientation distribution functions [6]. Both forementioned methods are tedious and restricted to laboratory applications. Often for the selection of plastic anisotropy a complete texture description is not necessary. It is sometimes sufficient to monitor the change in selected texture components as a rapid means of texture assessment to predict plastic deformation response.

An x-ray diffraction technique is described which allows the development of texture components to be monitored and provides supplementary information about the cold work and residual stresses in material. Both the cold work and residual stress state can also influence the formability of polycrystalline material.

### ADVANCED X-RAY DIFFRACTION TECHNIQUE

A fiber optic based x-ray diffraction (XRD) instrument [8] with a position-sensitive scintillation detector (PSSD) was used for the measurements described herein. X-ray diffraction in the high back reflection region was used for this investigation, i.e., between 60 and 80 degrees of Bragg angle. A miniature x-ray measuring head containing both x-ray tube and detectors assured easy maneuverability with respect to the specimen, which can be of arbitrary size and shape. Figure 1 shows the arrangement of single exposure technique of XRD stress measurement. The position, intensity and shape of two diffraction peaks for two angles can be registered simultaneously.  $\Psi$  ( ) is the angle between normal to the crystallographic plane and normal to the specimen surface. Dedicated software allows the analysis of the following:

- Peak Intensity. Peak intensity for a selected crystallographic plane measured in the orientation space represented by the polar coordinates (Fig. 2) is proportional to the volume of crystallites suitably oriented for diffraction.
- Peak Breadth. Full width at half maximum (FWHM) can be related to grain size and microstrains which are manifest by broadening of diffraction line [10].
- Peak Shift. The change in interplanar spacing due to elastic strain, caused by stress, can be calculated from the change in peak position (Bragg's equation) [11].

An example of XRD used for materials characterization is stress measurement. The feasibility of on-line XRD edge stress measurement on copper strip moving at 375 ft/min was demonstrated recently [9].

In order to provide good peak intensity, and comparison with previously reported pole figures and ODF's for copper, [7, 12] the (222) crystallographic plane was selected as the diffraction plane.

## EXPERIMENTAL PROCEDURE

### Tailored Samples

The samples were 0.01 x 6 x 12 inches in size. There were two sets with different grain size: 14  $\mu$  and 19  $\mu$ m. Each set consisted of four samples, one sheet with "random texture" and 15%, 45%, and 75% cold rolled sheets.

### Measurement

A full wave rectified x-ray power supply and an iron target x-ray tube was used with the PSSD system for measurement. The monochromatic iron K-alpha

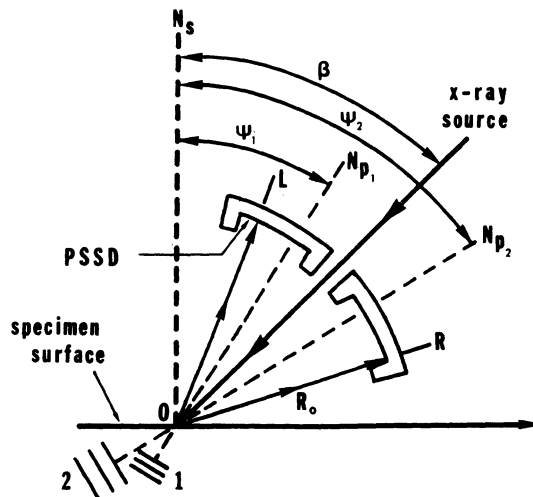


Fig. 1. Single exposure technique. The angles  $\psi_1$  and  $\psi_2$  indicate the tilt angle of the normals of crystallographic planes 1 and 2 to the specimen surface.

radiation penetrated the copper specimen sufficiently to provide measurement about  $12\ \mu\text{m}$  deep which was comparable with grain size. For (222) crystallographic plane the diffraction angle was  $2\theta = 146.4^\circ$ . In order to eliminate the errors due to fluctuation of measured parameters all data was normalized against copper powder. Successive measurements were taken for four selected  $\psi$  angles:  $\psi = 0^\circ, 44^\circ, -22^\circ,$  and  $22^\circ$ , in the range  $0^\circ$  to  $90^\circ$  for  $\phi$  angle as measured from rolling direction (Fig. 2). The measurements were taken at three points on each specimen. In order to prove the assumption that for thin copper sheets the surface texture and inside texture are the same, two specimens (15% and 75% cold rolled) were electropolished to half thickness and the measurement procedure was repeated.

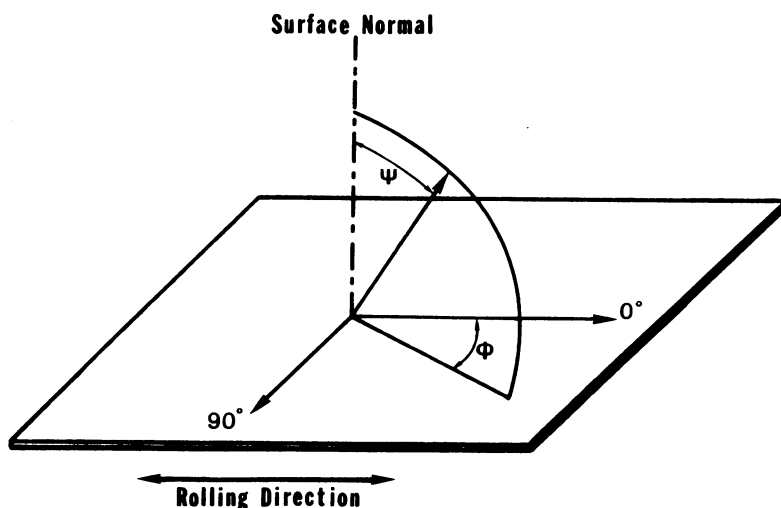


Fig. 2. Definition of the reference directions  $\psi$  and  $\phi$

## EXPERIMENTAL RESULTS AND DISCUSSION

### Peak intensity as a Texture Indicator

Plots of normalized peak intensity for two  $\psi$  angles are presented in Figs. 3 and 4. Different character of curves for  $\psi = 22$  and  $\psi = -22$  indicates the lack of grain orientation symmetry across the transverse to the rolling direction. The texture in the rolling direction shows the predominance of "brass" and "S" type components whereas texture in reverse direction seems to consist of "copper type" component mainly. This fact is especially noticeable for higher reduction (75%). With increasing strain, the slope of intensity curve versus  $\phi$  ( $\phi$ ) angle also increases.

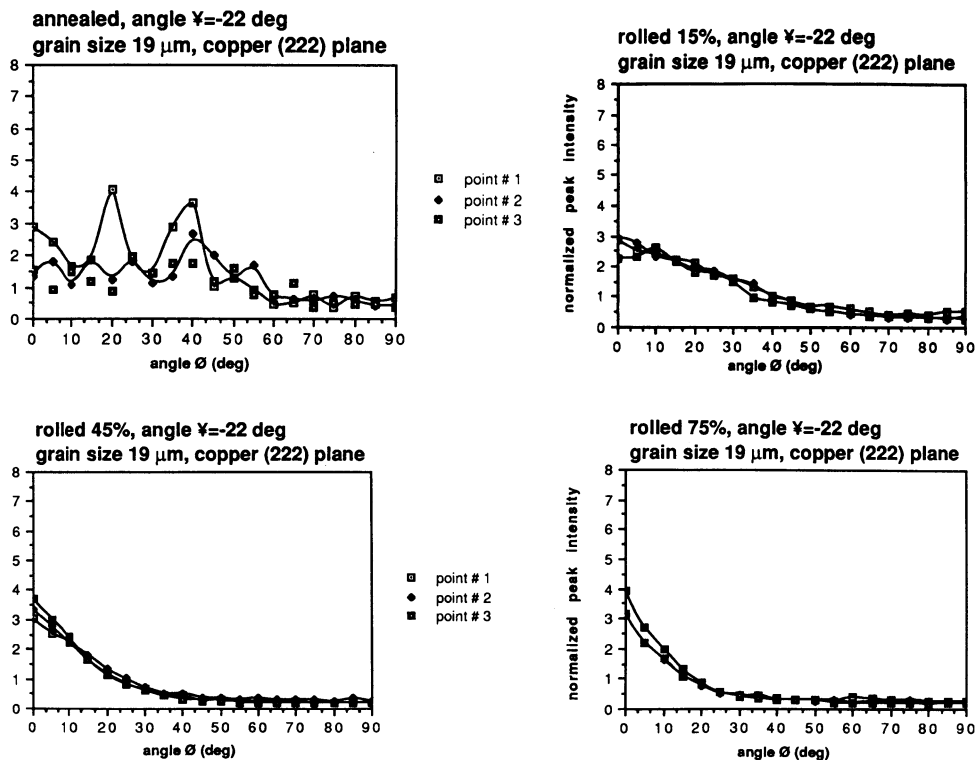


Fig. 3. Normalized peak intensity for  $\psi = -22^\circ$

The texture asymmetry derives from the fact that specimens were passed through the rolls in the same direction in successive passes. The inside texture measured on half thickness electropolished samples is represented in Fig. 5. The character of curves is the same as for surface texture.

#### Peak Breadth

Plastic deformation of a metal causes the lattice planes to be distorted in such a way that the spacing of any particular plane varies from one grain to another, or even within a grain itself [11]. This is due to stress inhomogeneity within and between grains and subgrains. This nonuniform microstrain causes the broadening of diffraction lines. Some of the results of peak breadth measurement are shown in Fig. 6.

There is no microstrain induced peak broadening in  $\psi = 22$  and  $\psi = -22$  directions for any level of reduction. The higher values and scatter of normalized peak breadth in regions  $\phi > 60^\circ$  for  $\psi = 22^\circ$  stem from the fact that in these ranges peak intensity is very low and determination of peak breadth is difficult. The lack of microstrain in  $\psi = 22$  and  $\psi = -22$  can be explained in terms of deformation mechanisms in copper. In the cold reduction levels measured (0-75% reduction) all the deformation modes occur on (111) plane. Therefore, since this is a plane of easy slip, strain incompatibility on these planes is very unlikely and microstrains are not observed.

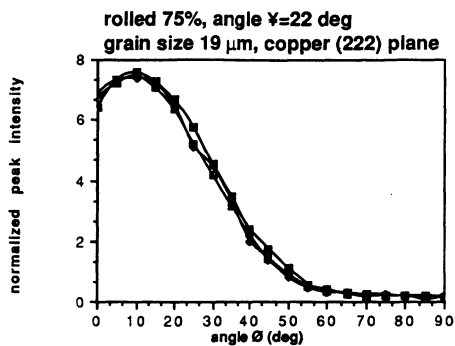
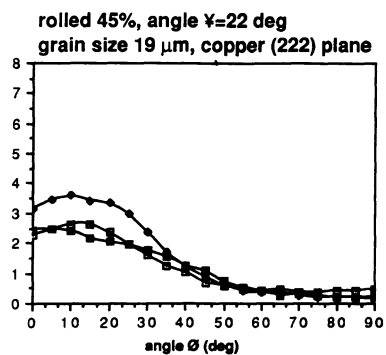
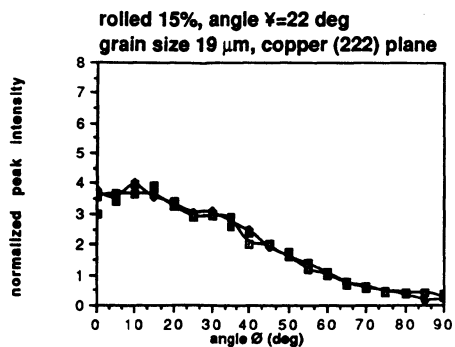
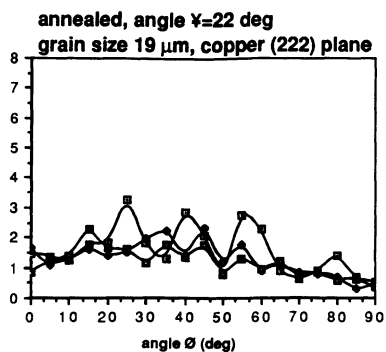


Fig. 4. Normalized peak intensity for  $\psi = +22^\circ$ .

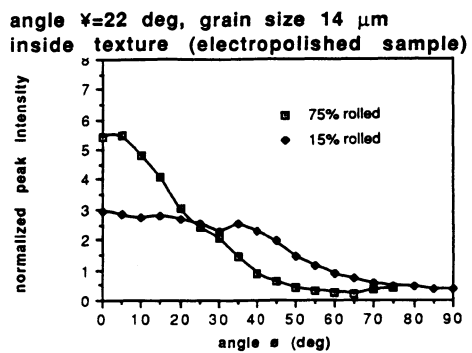
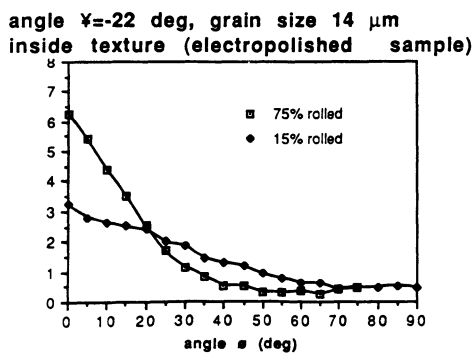


Fig. 5. Normalized peak intensity for electropolished samples.

## Macrostress

The single exposure technique for XRD stress measurement was used in order to measure the change in spacing between (222) crystallographic planes at various  $\psi$  angles. The results are presented in Fig. 7. There is a noticeable lack of strain symmetry across the transverse direction; the planes oriented towards rolling direction are subjected to tensile stresses and the planes in opposite direction are under compression.

## Ultrasonic Measurement

Additionally, the measurements of velocity of Leaky Lamb acoustic waves were conducted on these same tailored copper sheet specimens. The angular variation of ultrasonic velocity was measured in the same  $\psi$  angles and analyzed in terms of deformation mechanisms and ODF's. The results are presented elsewhere in this conference [14].

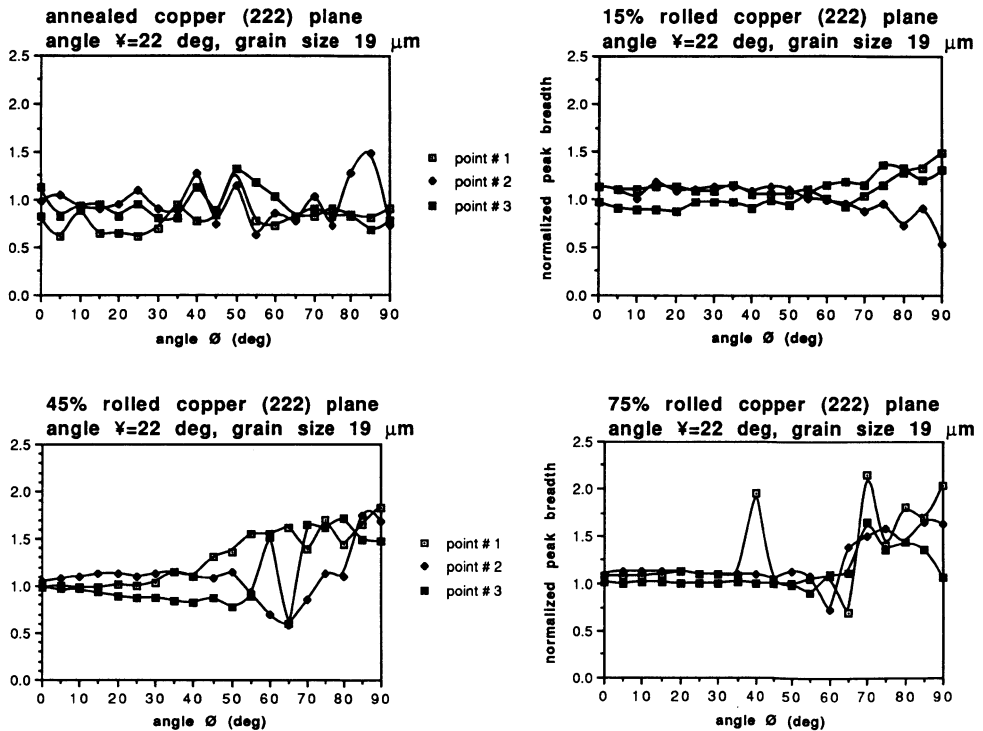


Fig. 6. Normalized peak breadth (FWHM) for  $\psi = 22^\circ$ .

## CONCLUSIONS

X-ray diffraction patterns representative of the texture were obtained in time frames of less than one minute. Macrostrain, represented by changes in interplanar spacing and microstrain, characterized by peak breadth were assessed as a function of the angular position of (222) crystallographic

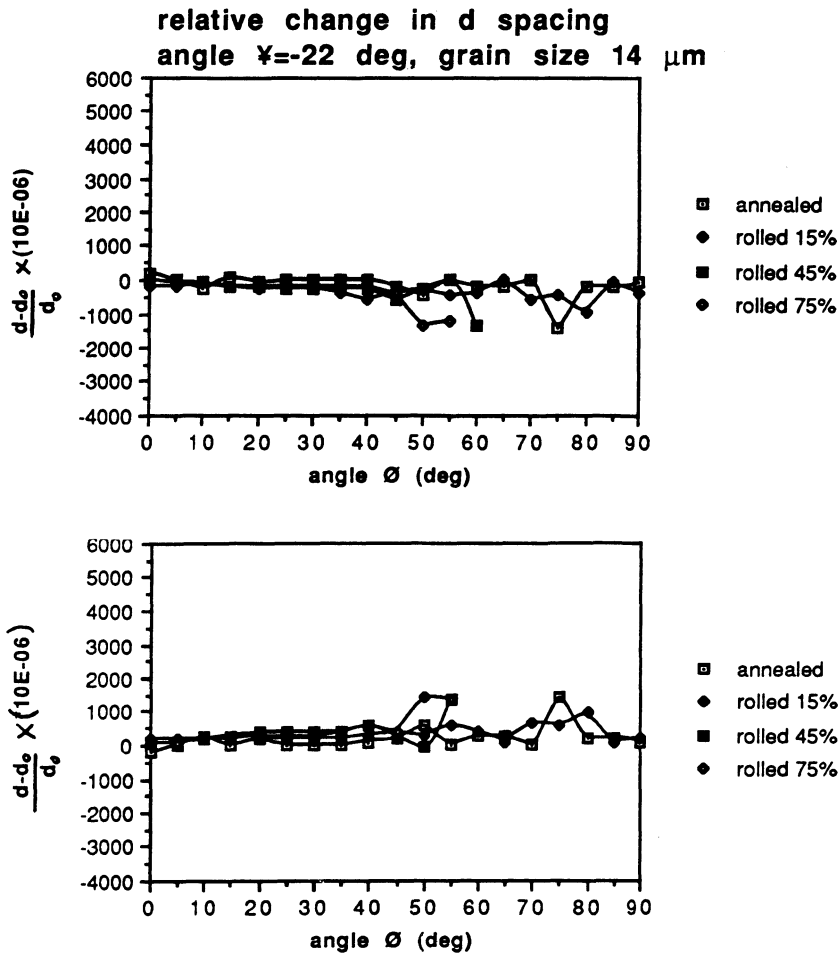


Fig. 7. Relative change in interplanar spacing for  $\psi = -22^\circ$  and  $\psi = 22^\circ$ .

plane. Orientation and distribution of crystallites were characterized by peak intensity as measured in polar coordinates. The analysis of XRD data lead to the following conclusions:

- The nondestructive x-ray diffraction intensity measurement correlates well with previously reported texture studies for cold-rolled copper sheet.
- X-ray diffraction measurements provide a means of monitoring texture from surface readings on thin cold-rolled copper sheet.
- In agreement with theoretical predictions the x-ray diffraction readings showed no indication of microstrain on (111) type crystallographic planes.
- The XRD technique indicated a lack of symmetry across the transverse direction as predicted in literature and this lack of symmetry caused the expansion of the lattice for those planes oriented towards rolling direction and a compression for those planes in opposite direction.

## ACKNOWLEDGEMENTS

The research was supported by NSF under the contract under DMC-8615863.

## REFERENCES

1. "Textures in Non-Ferrous Metals and Alloys," ed. H.D. Merchant and J.D. Morris, The Metallurgical Society (1985).
2. N. Kanetake et al., "Calculations from Texture of Earing in Deep Drawing for f.c.c. Metal Sheets," *Int. J. Mech. Sci.*, Vol. 25, No. 5, pp. 337-345 (1983).
3. Y. Kwang, J.G. Morris, "The effect of Structure on the Mechanical Behaviour and Stretch Formability of Constitutionally Dynamic 3000 Series Aluminum Alloys, *Mat. Sci. and Eng.*, 77, 58-74 (1986).
4. W.G. Frike, J.T. Ioannov, "A practical Texture Measurement Instrument," ICOTOM8, ed. by J.S. Kallend and G. Gottstein, The Metallurgical Society, pp. 257-262 (1988).
5. H.J. Kopineck, H. Otten, "Texture Analyzer for On-Line  $r_m$ -Value Estimation," *Textures and Microstructures*, Vol. 7, pp. 97-113 (1987).
6. H.J. Bunge, "Texture Analysis in Materials Science," (1982).
7. J. Hirsch, K. Lucke, "Mechanism of Deformation and Development of Rolling Textures in Polycrystalline f.c.c. Metals," *Acta Metal.*, Vol. 36, No. 11, pp. 2863-2927 (1988).
8. C.O. Ruud, "Position Sensitive Detector Improves X-Ray Powder Diffraction," *Industrial Research and Development* pp. 84-87, Jan. (1983).
9. C.O. Ruud, Private communication (1989).
10. R. Delhez, Th.M. De Keijser, E.J. Mittemeijer, "Role of X-ray Diffraction Analysis in Surface Engineering; Investigation of Microstructure of Nitrided Iron and Sheets," *Surface Engineering*, Vol. 3, No. 4, pp. 331-342 (1987).
11. B.D. Cullity, "Elements of X-ray Diffraction," Addison-Wesley Publishing Company, Inc. (1978).
12. J.S. Kallend, G.J. Davies, "The Development of Texture in Copper and Copper-Zinc Alloys," *Texture*, Vol. 1, pp. 51-69 (1972).
13. C.O. Ruud, J.C. Conway, K. Kozaczek, "Development of a System for In-Process Characterization of Properties and Forming Characteristics of Copper Alloy Strip," *Advances in Manufacturing Systems and Integration and Processes*, 15th Conf. on Prol. Res. and Tech., SME, Dearborn, MI, pp. 329-332 (1989).
14. C.J. Yu, J.C. Conway, C.O. Ruud, K. Kozaczek, "Ultrasonic Monitoring of Texture in Cold-Rolled Copper Sheets," published in these proceedings.