ISSN 2176-5480

22nd International Congress of Mechanical Engineering (COBEM 2013)
November 3-7, 2013, Ribeirão Preto, SP, Brazil

EFFECT OF COLD ROLLING ON THE EARING FORMATION DURING DEEP DRAWING OF THE ASTM C22000 COPPER ALLOY

Renato Altobelli Antunes
Mariana Maia Chams Eddine
Universidade Federal do ABC (UFABC), Centro de Engenharia, Modelagem e Ciências Sociais Aplicadas (CECS), R. Santa Adélia 166, CEP: 09210-170, Santo André - SP
renato.antunes@ufabc.edu.br; mariana.eddine@paranapanema.com.br

Nelson Batista de Lima
IPEN/CNEN-SP, Av. Prof. Lineu Prestes, 2242, Cidade Universitária, CEP: 05508-000, São Paulo – SP
nblima@ipen.br

Abstract. *The cartridge case containing the explosive and primer powder for ammunition is made of a cup obtained by deep drawing. In this process a disk is fixed and a punch rises to prolong the cup's wall. The process is repeated until the wall is sufficiently thin and elongated. Copper alloys offer the best compromise among the materials for such applications, with excellent deep drawability, moderate re-formability, resistance to cracking and suitable tensile strength. Depending on the thickness reduction by cold rolling (%red), the anisotropy resultant from the process can reduce or even impede successful deep drawing of the product. This study aimed at investigating the relationship between the thickness reduction by cold rolling and the earing behavior during deep drawing of the ASTM C22000 alloy. Different specimens of this alloy were tested with regard to Swift cupping test and x-ray diffraction (for obtaining orientation distribution functions). The results showed that earing was more intense as the thickness reduction by cold rolling increased. Moreover, the Copper texture was favored as the thickness reduction increased and this led to the formation of four-fold ears ooriented at 45º in relation to the rolling direction.*

Keywords: *ASTM C22000, earing, deep drawing, cold rolling*

1. INTRODUCTION

Deep drawing is traditionally employed to deform metal sheets in order to obtain cups with specific shapes designed for engineering applications (Boljanovic, 2004). The manufacturing of cartridge cases made of brasses is an important application of this process (Higgins, 2010). During the process a blank is clamped against a die by a blankholder. The drawing operation is carried out by a punch moving against the die, thus forming the metallic cup (Chen et al., 2006). Earing has been recognized as a major concern during deep drawing of metals due to the increasing generation of scrap and the development of heterogeneous properties along the walls of the cup (Zhou et al., 1998). The phenomenon has been described based on a crystallographic approach in an attempt to predict the earing behavior of different engineering alloys (Oluwole et al., 2010). In this regard, texture evolution during forming operations of metallic materials lead to anisotropic plastic flow properties and, in turn, to earing formation during deep drawing. Typical deformation textures of face centered cubic (FCC) metals have been described in the literature. Common deformation texture components are Copper $\{112\}\langle 11\bar{1}\rangle$, Brass $\{110\}\langle 112\rangle$, R-cube $\{001\}\langle 110\rangle$ and S $\{123\}\langle 6\bar{3}\bar{4}\rangle$ which are reported to contribute to 45º earing (related to the rolling direction) (Sowerby et al., 1980). It is also known that the crystallographic texture can be modified depending on heat treatment, mechanical processing, rolling strain, strain rate and temperature (Souza et al., 2012).

In this work the relationship between plastic deformation by cold rolling and the earing behavior of the ASTM C22000 alloy has been investigated. Cold rolled sheets of this alloy were submitted to deep drawing in the Swift cupping test. Deformation texture components of the cold rolled sheets were evaluated by means of X-ray diffraction (XRD) measurements across the thickness of the sheet samples. The observed earing behavior was correlated with the crystallographic texture determined XRD.

2. EXPERIMENTAL DETAILS

2.1 Material

The material used in this work was the copper alloy designated as C22000 whose chemical composition is shown in Table 1. The material was kindly provided by Eluma - Paranapanema S.A. in the form of annealed sheets with a thickness of 1.83 mm.

ISSN 2176-5480

Table 1. Chemical composition of the ASTM C22000 sheet samples used in this work.

Element	Cu	Zn	Fe	Others
Mass (%)	89.75	10.22	0.0031	0.0269

2.2 Preparation and characterization of the sheet samples

The as-received sheet samples were cold rolled in an electric twin-roll mill G3 150M, obtaining thickness reductions of 40%, 64% and 89%. Next, the cold-rolled sheets were annealed in a muffle furnace (Fornitec) at 550 ºC for 3 h. Following annealing, the samples were etched in a 15%v H_2SO_4 solution at 50 ºC for 2 minutes in order to remove the surface oxides formed during annealing. After thorough washing by distilled water and drying in hot air the samples were submitted to deep drawing using the Swift cupping test. The cupping tests were performed in an Erichsen machine model 134 with a blankholder force of 10 kN and a drawing speed of 5 $mm.s^{-1}$.

After deep drawing, the sheet samples were evaluated to verify the earing formation. Thus, the height of the ears formed after the Swift test were measured using a digital caliper gauge. The earing value (E) was calculated using the following equation where h_{min} is the height at the valley and h_i is the height of the earing peak:

$$E = \left(\frac{h_i - h_{min}}{h_i} \right) .100 \qquad (1)$$

The crystallographic texture was determined using X-ray diffraction (XRD) with Cu K radiation (40 kV, 30 mA), 5 º angular pass and counting time of 4 s. Pole figures of the (111), (200), (220) and (311) planes of the copper alloy were determined using an horizontal goniometer (Rigaku). Orientation distribution functions (ODFs) were obtained using a home-made program developed at IPEN/CNEN-SP.

3. RESULTS AND DISCUSSION

3.1 Swift cupping test

The sheet samples submitted to the Swift test were inspected after deep drawing in order to determine the earing formation. Three different samples were testes. Photographs of representative deep drawn cups are shown in Figure 1 for samples with different thickness reductions by cold rolling.

Figure 1. Deep drawn cups of the C22000 alloy. The thickness reduction by cold rolling of the original blank used for the cupping test is indicated in the photographs.

It is obvious upon visually inspecting the cups shown in Fig. 1 that earing formation was enhanced as the thickness reduction increased. Figure 2 shows the earing profiles of the drawn cups with respect to the rolling direction. The height values correspond to the average values of three different samples. The samples exhibited four ears at 45º to the rolling direction. In order to give a more quantitative analysis of this situation, the earing percentage of each sample has been determined according to the procedure described in section 2.2. The values of the earing percentage calculated

ISSN 2176-5480

according to equation 1 are plotted as a function of the thickness reduction in Fig. 3. The earing value increased with increasing rolling reduction. This behavior has been observed for FCC metal sheets submitted to deep drawing (Li et al., 2010).

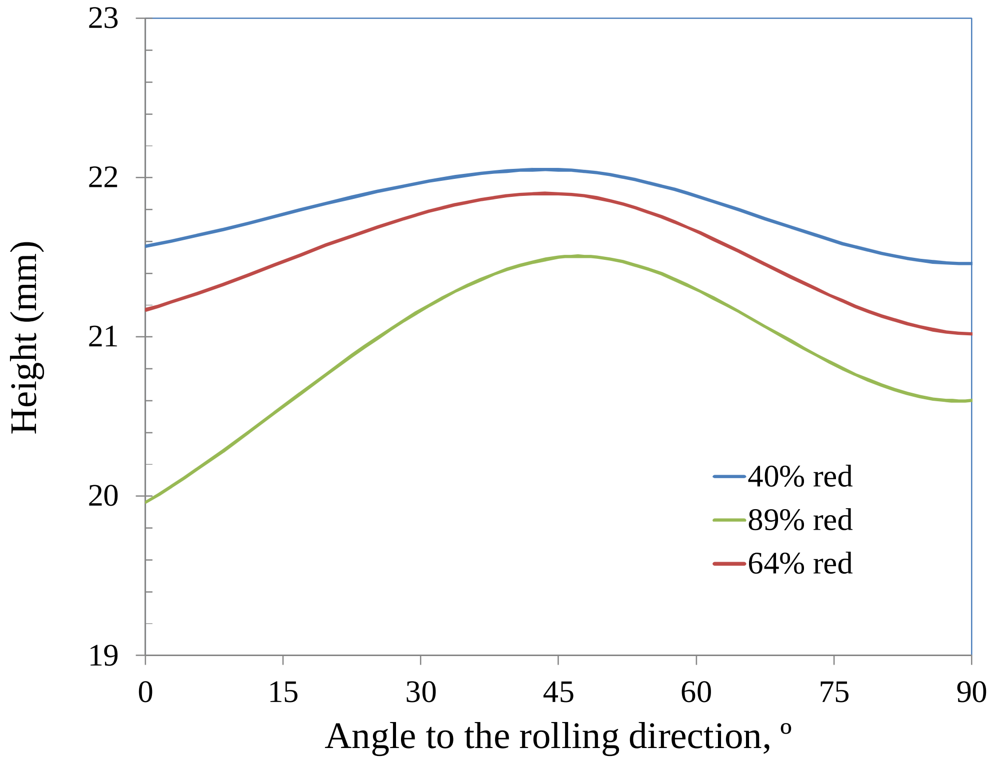


Figure 2. Earing profiles of the drawn cups with respect to the rolling direction.

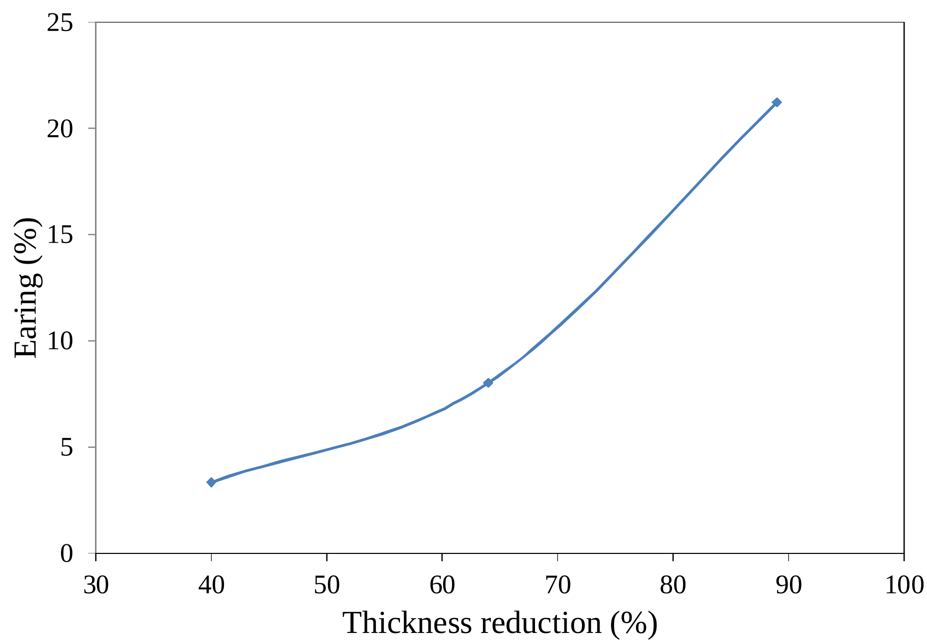
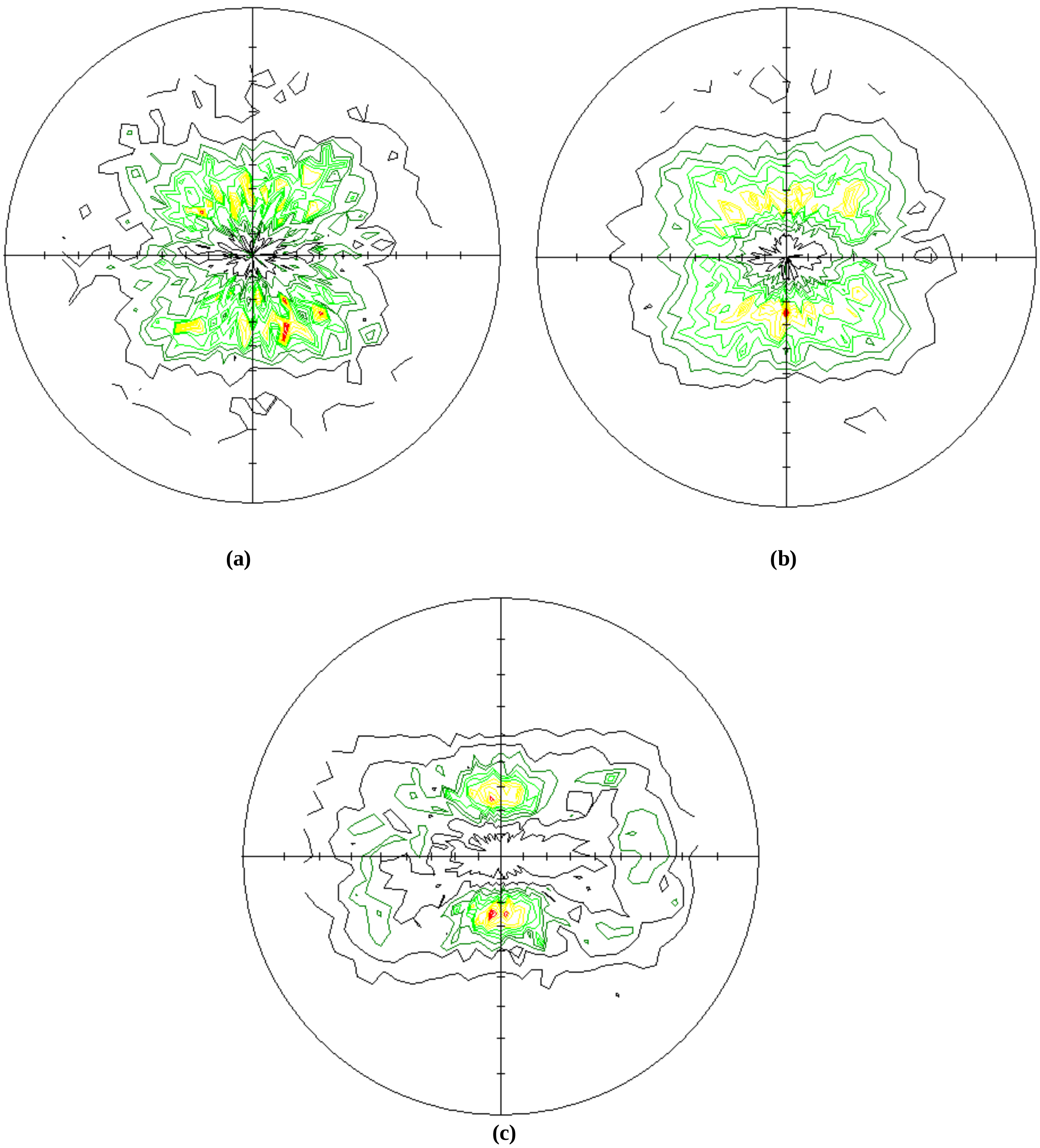


Figure 3. Earing percentage of the cups shown in Figure 1 plotted as a function of the thickness reduction.

3.2 Texture evolution

ISSN 2176-5480

Figure 4 presents the (111) pole figures of the ASTM C22000 alloy with different thickness reductions. It is clear that the texture of the drawn sheets has been altered as the thickness reduction increased. The most intense lines become more concentrated in specific regions of the pole figure as the cold working increased. Bunge (1982) stated that if the crystal grains are randomly distributed, the iso-intensity lines present a homogeneous distribution. If, instead, the material is textured, then the lines agglomerate around the preferential orientations, leaving other regions of the pole figures relatively desert.



(a) **(b)** **(c)**

Figure 4. (111) pole figures of the ASTM C22000 alloy with different thickness reductions: a) 45%; b) 64% and c) 89%.

ISSN 2176-5480

The three-dimensional orientation distribution functions (ODFs) f(g) were computed, where the orientations g are expressed in form of a triple of Euler angles ($_1$, , $_2$) according to Bunge's notation (Bunge, 1982). In this work, the ODFs are represented by plotting iso-intensity lines in two characteristic sections with $_2$ = 0º and $_2$ = 45º through the Euler orientation space which contain the most part of the typical FCC orientation crystallographic planes (Viana and Paula, 2003). The ODFs are shown in Fig. 5 for the ASTM C22000 alloy with different thickness reductions. The most important texture components are indicated in the figure.

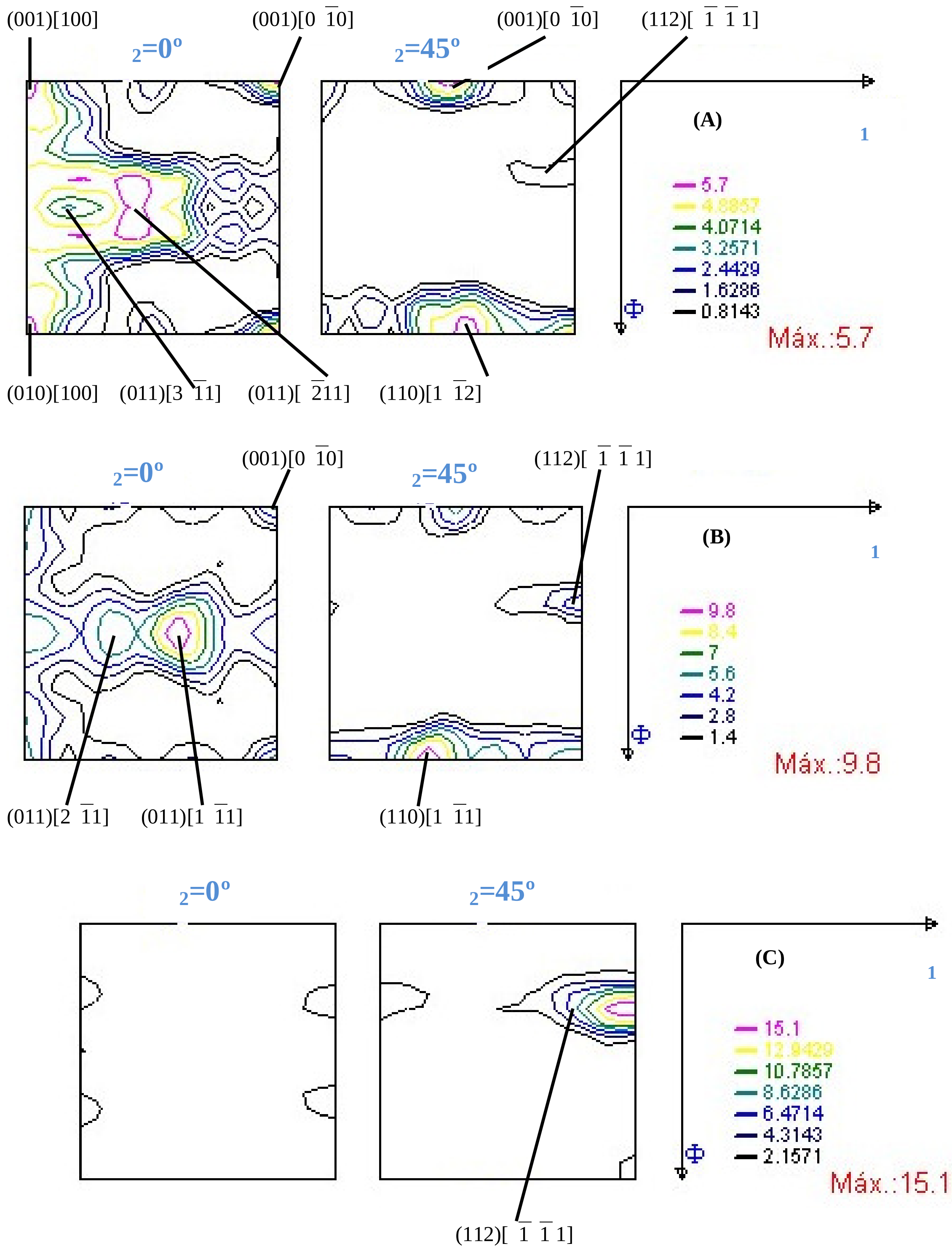


Figure 5. ODFs of the cold rolled samples with different thickness reductions: a) 45%; b) 64% and c) 89%..

The ODF of the sample with 45% thickness reduction presented the two dominant texture components: Brass ({110}<112>) and Cube ({001}<100>). The Copper texture ({112}<111>) is also observed but with a lower intensity. Yet, other components such as the $(011)[3\bar{1}1]$ orientation are also present at intermediate intensities. This result indicates that the 45% sample presents more randomly distributed orientations which would lead to the formation of ears with a relatively low height. In fact, this behavior was observed for the sheets submitted to the Swift cupping test as shown in section 3.1.

The sample with 64% thickness reduction presented a different texture profile. The evolution of the rolling texture was observed as the relative intensity of the Brass component decreased whereas the Copper component became more intense. The strongest texture component was observed for the orientation $(110)[1\bar{1}1]$. Thus, the anisotropic character of the sheet sample was accentuated by cold rolling. This behavior had a direct consequence on the earing formation. As seen in Fig. 3 the sample with 64% thickness reduction presented more profound ears due to the increased plastic strain imposed by cold rolling.

This trend was confirmed for the sample with 89% thickness reduction. The observed texture component was mainly represented by the Copper texture whereas the other components were significantly weakened and disappeared. The Copper texture was enhanced for increasing cold rolling, leading to a strong anisotropic character of the metallic sheet. This, in turn, intensified the earing formation as seen in Fig. 1.

The textures observed for the ASTM C22000 alloy are typical of cold rolled FCC metals (Engler, 2012). It can be inferred that the Copper texture favored the earing formation due to the more anisotropic character of the sheet samples in which this component was the most intense. From a practical engineering standpoint this result evidences that the deep drawing operation of the ASTM C22000 can be tailored to avoid earing by properly controlling the initial deformation state of the blanks that will be processed. Texture measurements by XRD are a powerful tool to identify the most critical aspects of earing formation in the ASTM C22000.

4. CONCLUSIONS

The earing behavior of ASTM C22000 alloy sheets was studied as a function of the thickness reduction produced by cold rolling. The earing profile was shown to be dependent on the thickness reduction. After the Swift cupping test, more profound ears formed as the thickness reduction increased. Typically, four ears were formed at 45º to the rolling direction. Crystallographic texture measurements by X-ray diffraction indicated that the anisotropic character of the cold rolled sheets was accentuated as the thickness reduction increased. As a consequence, earing formation was intensified. Deep drawing of cold rolled ASTM C22000 alloy sheets should be properly designed to avoid excessive earing formation based on the identification of specific cold rolling and annealing conditions that would favor the anisotropic character of the cold worked sheets. X-ray diffraction is a powerful technique to support and guide this operation.

5. ACKNOWLEDGEMENTS

To Eluma - Paranapanema S.A. for kindly providing the ASTM C22000 alloy used in this work.

6. REFERENCES

Boljanovic, V. 2004. ***Sheet metal forming processes and die design***. Industrial Press,1st ed., New York, USA.

Bunge, H. J. 1982. ***Texture analysis in materials science***. Londres, Butterworths.

Chen, C.-Y, Kuo, J.-C., Chen, H.-L. and Hwang, W.-S. 2006. "Experimental investigation on earing behavior of aluminum/copper bimetal sheet". *Materials Transactions*, Vol. 47, p. 2434.

Engler, O. 2012. "Control of texture and earing in aluminium alloy AA 3105 sheet for packaging applications". *Materials Science and Engineering A*, Vol. 538, p. 69.

Higgins, R.A. 2010. *Materials for engineers and technicians*. Taylor and Francis, 5th edition, Oxford, United Kingdom.

Li, J., Liu, W.C., Yuan, H. and Gao, Y.K. 2010. "Comparison of earing behavior between continuous cast and direct chill cast AA 5182 aluminum alloys during cold rolling and annealing". *Journal of Materials Processing and Technology*, Vol 210, p. 2007.

Oluwole, O.O., Anyaeche, C.O., Faola, O.V. 2010. "Effect of draw ratio and sheet thickness on earing and drawability of Al 1200 cups". *Journal of Minerals & Materials Characterization and Engineering*, Vol. 9, p. 461.

Souza, F.M., Plaut, R.L., Lima, N.B., Fernandes, R.C., Padilha, A.F. 2012. "Recrystallization and crystallographic texture in AA4006 aluminum alloy sheets produced by twin roll caster and direct chill processes". *Metallurgy and Materials*, Vol. 65, p. 363.

Sowerby, R., Viana, Da C. Viana, C.S., Davies, G.J. 1980. "The influence of texture on the mechanical response of commercial purity copper sheet in some simple forming processes". Materials Science and Engineering, Vol. 46, 23.

Viana, C.S.C. and Paula, A.S. 2003. *Texturas de deformação*. In: Sandim, H.R.Z. et al.(Editores) – Textura e Relações de Orientação. 2ª edição, EPUSP-IPEN-IPT, São Paulo.

ISSN 2176-5480

Zhou, Y., Jonas, J.J., Savoie, J., Makinde, A., MacEwen, S.R. 1998. "Effect of texture on earing in FCC metals: Finite element simulations". *International Journal of Plasticity*, Vol. 14, p. 117.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.