

Earing Characteristics of Cold-Rolled and Temper Annealed Aluminium 1200

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Abstract: Earing characteristics of deep-drawn cold-rolled and temper-annealed Aluminium 1200 was studied at high deformation levels of 75, 85 and 90% cold rolling. The relationship of earing with varying degrees of cold roll was studied and the effect of different annealing temperatures on earing. Hardness, ductility and strength variations with earing were also studied. Earing was observed to show no definite behavioural pattern with increasing degree of cold-roll. With increasing anneal temperature, earing was found to increase first and then fall making a steep drop to smallest earing at an anneal-temperature peculiar to the degree of cold roll after which it increases again with increasing anneal-temperature. The relationship of earing to hardness, ductility and strength properties were observed to follow the same pattern. Hardness, ductility and strength properties of cold-rolled and temper-annealed Aluminium 1200 at lowest earing did not necessarily correspond to the materials lowest hardness, highest ductility or lowest strength respectively and were found to vary for varying degrees of cold-roll.

Key words: Earing characteristics, cold-rolling, temper-annealing, Aluminium 1200

INTRODUCTION

Aluminium 1200 is the grade of Aluminium used for holloware (Aluminium Association, 1999). When cold-rolled, aluminium or its alloys are recrystallised by annealing, new grains form with orientations that differ from those present in the cold-rolled condition (Plomear, 1981). Preferred orientation is much reduced but seldom eliminated.

Preferred orientation in the plane of sheets that are associated with textures may cause a problem known as Earing. Earing is wasteful of material because of larger blank than necessary must be used in deep drawing hollow-ware production. Moreover, it may lead to the production problems due to difficulties in ejecting products after a pressing operation. Four ears usually form because of non-uniform plastic deformation along the rim of deep drawn products (Fig. 1). If there is a desirable balance between the rolling texture and the annealing texture however, eight small ears could be formed or none at all (Fig. 2 and 3). Because of this possibility of annealing to produce a texture which could minimize or eliminate earing, the careful control of annealing schedules is said to minimize earing (Baker, 1977; Ricks, 1999).



Fig. 1: Cups Deep-drawn from 90% cold-worked Aluminium 1200 Annealed at 400°C for 3 and 4 h (left to right) showing five ears formed at the rims 60/33 die used

The aim of this study is to study the earing characteristics of Aluminium 1200 with increasing cold

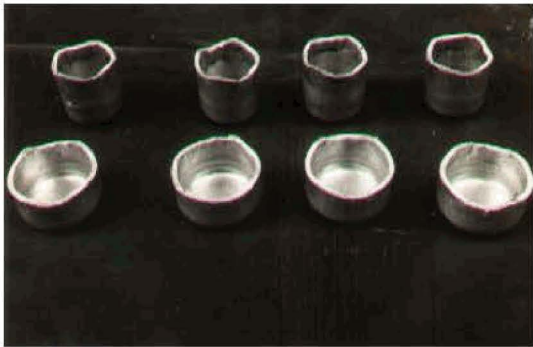


Fig. 2: Three sets of cups showing eight small ears formed at the rims. Each set (left to right) was deep-drawn from 90% cold-rolled Aluminium 1200 sheet and annealed at 460°C for 2, 3 and 4 h, respectively



Fig. 3: One set of cups showing no earing at the rims. The set was deep drawn from 90% cold-rolled Aluminium 1200 sheet annealed at 460°C for 4 h, respectively

rolling and different anneal temperatures. The tensile strength and elongation were also measured as well as the hardness of the materials in relation to earing. The study is performed at high deformation levels at which cold rolling is carried out for this sheet production with hollo-ware production as end- products.

MATERIALS AND METHODS

Starting materials were Aluminium 1200 as cast in the form of sheets of different thicknesses: 8 and 6 mm obtained from Aluminium Rolling Mills, Ota, Nigeria. The chemical composition is shown in the Table 1.

The starting materials were cold rolled to three different thicknesses of 2 mm (starting gauge 8 mm), 0.9 and 0.6 mm (starting gauge 6 mm) representing 75, 85 and 90% cold- reduction, respectively.

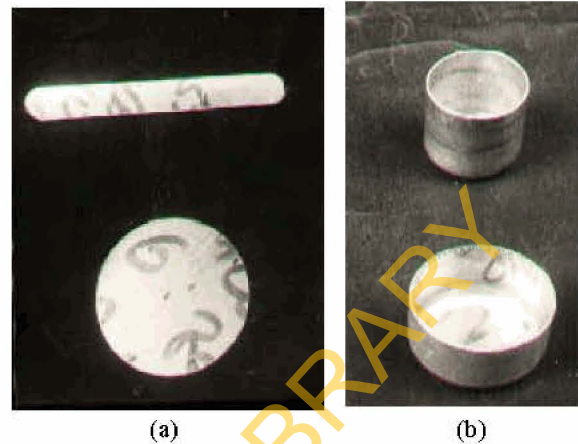


Fig. 4: Test specimens, (a) Tensile test specimen ASTM E8-65T standard, (b) Deep-drawn specimen from 60 mm blanking die

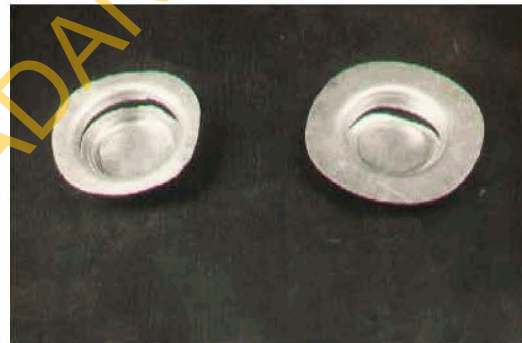


Fig. 5: Broken cup due to low ductility of materials on the left is material deformed 80%, Annealed at 300°C for $2\frac{1}{2}$ h. 60/33 die used on the right is material deformed 90%, annealed at 400°C for 2 h. 65/33 deep drawing die used

Table 1: Chemical composition (Wt. %) of Aluminium 1200

Fe	Si	Mg	Mn	Al
0.53	0.225	0.025	0.025	Balance

Seven anneal temperatures were selected: 225, 250, 275, 300, 400 and 460°C (Devgun, 1981). At each temperature and % cold roll, anneal times of 1, 2, 2.5, 3 and 3.5 h were used (Ivarsson, 1981). Heraus Industrial muffle furnace was used for annealing and cooling was done in air (Baker, 1977). This study was carried out in the materials laboratories of University of Lagos, Akoka, Obafemi Awolowo University, Ile-Ife and Tower Aluminium Rolling Mills, Ota Nigeria in the late 90's.

Tensile specimens: Conformed to ASTM E8-65T standards (50×12 mm) (Fig. 4a). Tests were carried out on Monsanto Tensometre on each sample in a direction perpendicular to rolling direction since the

(Ultimate Tensile Strength) UTS and elongation in this direction are limiting values for deep drawing (Devgun, 1981).

Deep-draw specimens: Deep-Drawing test specimen were 60 mm circle blanks (Fig. 4b), from the annealed materials and tests were carried out on a laboratory Erichsen deep-drawing equipment with dies of 60/33 mm (Fig. 5).

Reproducibility of results: For reproducibility of results, tests were performed on identically treated specimens and the standard deviation obtained for Ultimate Tensile Strength (UTS), percentage elongation (EL %) and deep-draw tests averages. Standard deviation of 2.26 N mm^{-2} was obtained for UTS, 0.58% for percentage elongation and 0.58 mm for deep draw.

Comparison of Monsanto UTS values with results obtainable on the Avery Tensometer was also done using a strain rate of 0.4 KN mm^{-1} . Conversion factors are

$$\begin{aligned} \text{UTS (AVERY)} &= 1.50 \text{ UTS (Monsanto)} \\ \% \text{ EL (AVERY)} &= 0.88 \% \text{ EL (Monsanto)} \end{aligned}$$

RESULTS AND DISCUSSION

Table 2-4 show data on earing characteristics of Aluminium 1200 with varying degree of cold roll and temper-annealing. Table 5 results have been compressed from Table 2-4 and these show the averaged values of earing, hardness, elongation and ultimate tensile strength for varying degree of cold roll and anneal temperature. Results from these data are represented in Fig. 6-10 and these will be used for the proceeding discussions.

Figure 6a-c shows that for increasing degrees of cold-rolling, earing does not exhibit any particular trend of being higher or lower for a higher degree of cold-roll. Figure 6d shows that at 300°C anneal, earing is lowest for 75% cold roll Aluminium 1200 while earing is higher for 85 and 90% cold-rolled Aluminium 1200. At 350°C anneal, earing starts to increase again for 75% cold-rolled Aluminium 1200 and still high for 85 and 95% cold-rolled Aluminium 1200.

At 400°C, earing falls dramatically to its lowest for 85% cold-rolled Aluminium 1200 and starts to fall for 90% cold-rolled Aluminium 1200. At 460°C, temper-annealing, earing is lowest for 90% cold-rolled Aluminium 1200.

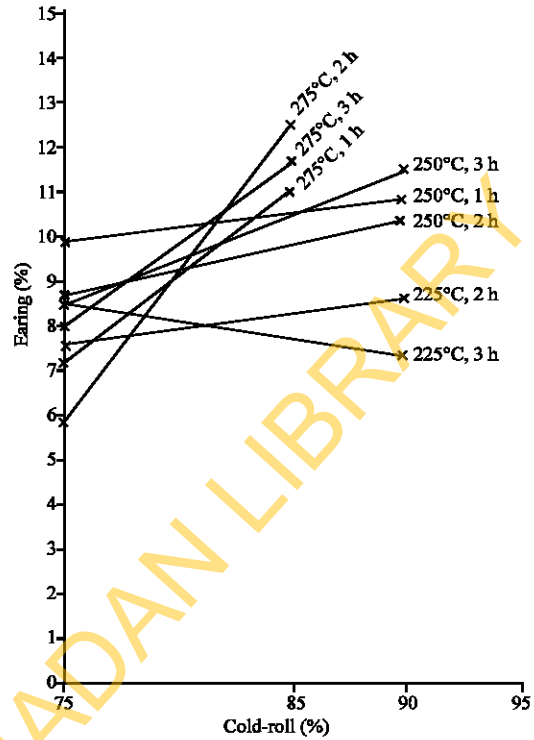


Fig. 6a: Earing (%) versus cold-roll (%) curves for cold-roll and temper-annealed Aluminium 1200 at annealing temperatures 225, 250 and 275°C

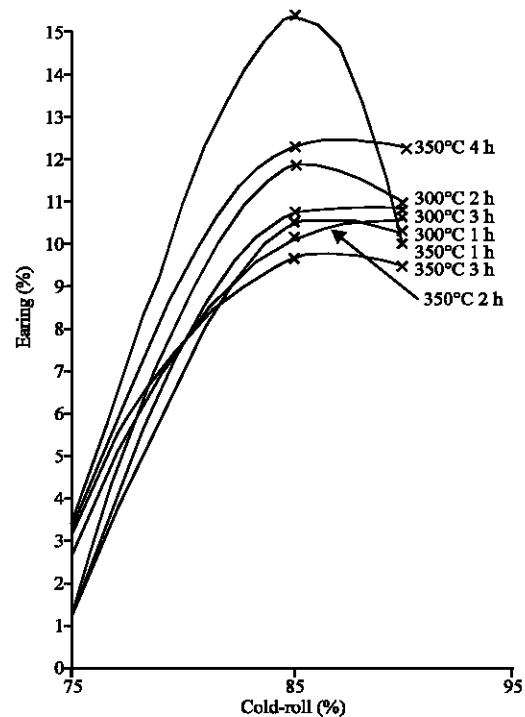


Fig. 6b: Earing (%) versus cold-roll (%) curves for cold-rolled and temper-annealed Aluminium 1200 at annealing temperatures 300 and 350°C

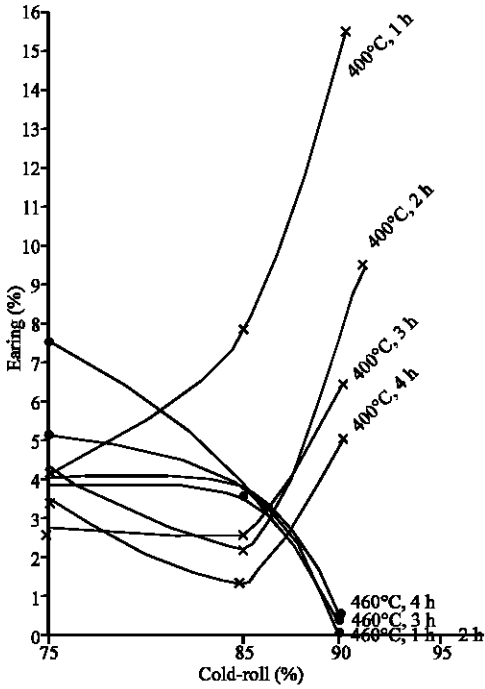


Fig. 6c: Earing (%) versus cold-rolled (%) curves for cold-roll and temper-annealed Aluminium 1200 at annealing temperatures 400 and 460°C

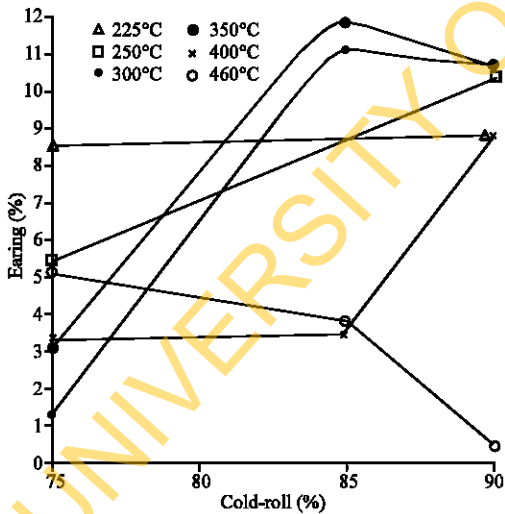


Fig. 6d: Compressed (%) earring versus (%) cold-roll curves for cold-rolled and temper-annealed Aluminium 1200

Figure 7 shows that there is an initial trend of increasing earring with increasing anneal-temperature and a steep drop to smallest earring at anneal temperature peculiar to the degree of cold-roll and then an

Table 2: Results data on earring characteristics at 75% cold-roll with varying annealing temperatures and holding time

Cold -roll (%)	TEMP (°C)	Annealing time (h)	UTS (N mm ⁻²)	*Hardness (Webster)	Elongation (%)	Earring (%)
75	225	1.0	202.1	10 (67)	4	Broken ⁺
		2.5	198.7	10 (67)	6	7.4
		2.0	195.4	10 (67)	5	Broken
		3.0	194.2	9 (63)	5	8.4
	250	3.5	195.0	9 (63)	6	10.4
		1.0	199.2	10 (67)	4	9.9
		2.0	193.7	9 (63)	6	8.6
		2.5	135.6	9 (63)	7	9.7
	275	3.0	187.5	8 (58)	6	8.4
		3.5	185.4	8 (58)	5	8.4 ⁺
		1.0	196.2	10 (67)	4	7.1
		2.0	160.4	10 (67)	6	5.8
300	2.5	170.0	7 (55)	6	7.9	
	3.0	160.7	7 (55)	8	7.9	
	3.5	152.1	6 (50)	10	7.0	
	1.0	153.3	8 (58)	11	1.3	
350	2.0	127.3	5 (50)	14	1.3	
	3.0	116.7	4 (43)	16	1.3	
	4.0	111.7	4 (43)	11	1.3	
	1.0	133.3	5 (50)	40	3.27	
400	2.0	89.2	0 (24)	42	2.78	
	3.0	88.5	0 (24)	40	3.2	
	4.0	89.6	0 (24)	36	3.2	
	1.0	90.4	0 (24)	40	4.3	
460	2.0	88.7	0 (24)	38	4.3 ⁺	
	3.0	89.6	0 (24)	34	2.6	
	4.0	89.6	0 (24)	36	3.4	
	1.0	93.7	0 (24)	36	4.07	
	2.0	85.4	0 (24)	41	7.52	
		89.6	0 (24)	3	4.2	

Rockwell E. Hardness readings in brackets ⁺ Interpolated results

Table 3: Earring characteristics at 85% cold-roll with varying anneal temperature and holding time

Cold -roll (%)	Annealing Temp (°C)	Annealing Time (h)	UTS (N mm ⁻²)	*Hardness (Webster)	Elongation (%)	Earring (%)
85	275	1.0	222.2	10(67.0)	2	10.95
		2.5	217.0	19(67.0)	3	12.48
		2.0	206.5	9(63)	3	10.52
		3.0	208.3	10(67.0)	3	11.48
		3.5	208.7	10(67.0)	3	10.41
	300	1.0	199.1	10(67.0)	3	10.46
		2.0	196.3	10(67.0)	4	11.87
		2.5	190.7	9(24)	4	11.60
		3.0	186.1	9(63)	5	10.71
	350	3.5	185.2	8(58)	4	10.64
		1.0	175.9	7(55)	4	15.4
		2.0	162	6(50)	8	10.2
400	3.0	148.1	5.5(47.5)	12	9.7	
	4.0	143.5	3(37.5)	12	12.3	
	1.0	131.9	6(50)	18	7.8	
	2.0	82.4	0(24)	34	2.2	
460	3.0	81.5	0(24)	23	2.5	
	4.0	80.6	0(24)	29	1.3	
	1.0	81.5	0(24)	32	3.5	
	2.0	86.1	0(24)	27	3.9	
	3.0	83.3	0(24)	29	3.9	
		80.6	0(24)	28	3.9	

ascend again with increasing anneal-temperature. From all Fig. 6-10, it could be seen that at 300°C, earring is

Table 4: Results data on earing characteristics at 90% cold-roll with varying annealing temperature and holding time

Cold -roll (%)	Annealing temp (°C)	Annealing time (h)	UTS (N mm ⁻²)	*Hardness (webster)	Elon Gation (%)	Earing (%)
90	225	1.0	254.2	11(70.5)	5	10.3
		2.0	143.1	12(75)	4	8.4
		3.0	250	11(70.5)	2	7.1
		4.0	250	11(70.5)	4	9.3
	250	1.0	236.1	11(70.5)	4	10.7
		2.0	150	11(70.5)	3	10.2
		3.0	252.6	11(70.5)	3	11.3
		4.0	230	11(70.5)	2	9.5
	300	1.0	248.6	11(70.5)	2	9.5
		2.0	243.1	10(67.0)	2	10.9
		3.0	238.1	10(67.0)	2	10.9*
		4.0	229.2	9(63)	2	10.7*
350	1.0	233.3	10(67.0)	3	10.10*	
	2.0	213.9	10(67.0)	3	10.65	
	3.0	206.9	9(63)	3	9.54	
	4.0	197.9	8(58)	4	12.3	
400	1.0	194.4	8(58)	4	15.5	
	2.0	177.8	7(55)	28	9.5	
	3.0	118.1	0(24)	24	5.3	
	4.0	116.1	0(24)	18	4.98	
460	1.0	122.2	0(24)	19	0.02	
	2.0	120.0	0(24)	22	0.72	
	3.0	118.1	0(24)	24	0.30	
	4.0	115.3	0(24)	24	0.39	

*Rockwell E. Hardness readings in brackets, + Interpolated result.

Table 5: Compressed data of earing characteristics with varying degrees of cold-rolling and temper - annealing

Cold -roll (%)	Anneal Temp (°C)	UTS (average) (%)	*Hardness (Webster)	Elongation (%) (average)	Earing (%) (average)
75	225	197.1	9.6(65)	5.2	8.6
	250	191.1	8.8(61)	5.6	9.1
	275	143.5	8.0(58)	6.8	7.1
	300	127.2	4.75(44)	13.7	1.3
	350	100.2	1.25(30)	33.3	3.1
	400	89.6	0.00(24)	37.0	3.4
	460	88.2	0.00(24)	38.0	5.2
85	275	211.7	9.8(67)	3.0	11.2
	300	191.5	9.2(64)	4.0	11.1
	350	157.4	5.5(47)	9.0	11.9
	400	94.1	1.50(28)	27.3	3.5
90	460	82.9	0.22(24)	28.9	3.8
	225	249.3	11.3(71.5)	3.8	8.8
	250	243.7	11.0(70.5)	3.5	10.4
	300	239.8	10.0(67.0)	2.0	10.6
	350	213.0	9.3(64.5)	3.3	10.6
	400	152.1	3.80(40.0)	18.5	8.8
460	118.5	0.00(24.0)	22.3	0.4	

*Rockwell E. Hardness readings in brackets

lowest (1.3%) for 75% cold-rolled Aluminium 1200. For 85% cold-rolled Aluminium 1200, earing is smallest averaging 3.5% at 400°C and 2 h anneal time. At this temperature, earing has started to fall for 90% cold-roll Aluminium 1200 but it actually hits its minimum earing at 460°C and 1 h anneal time dropping at 0.02% earing. It is also observable from Fig. 7 that increased anneal-temperature is needed to bring about least earing with increasing degree of cold-rolled Aluminium 1200.

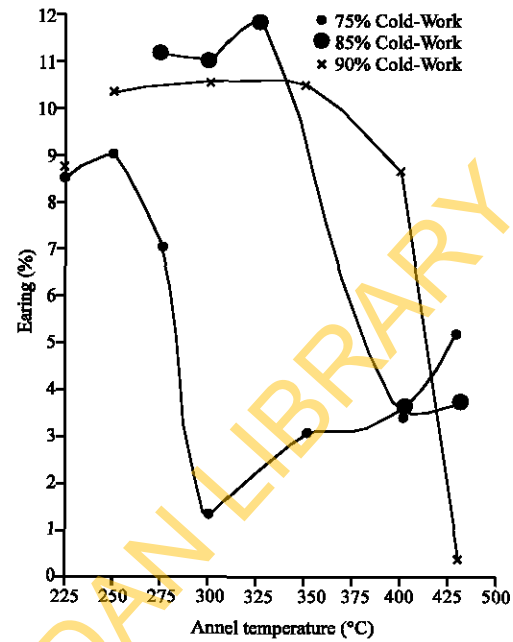


Fig. 7: Earing % versus anneal-temperature (°C) curves for cold-rolled and temper-annealed Aluminium 1200

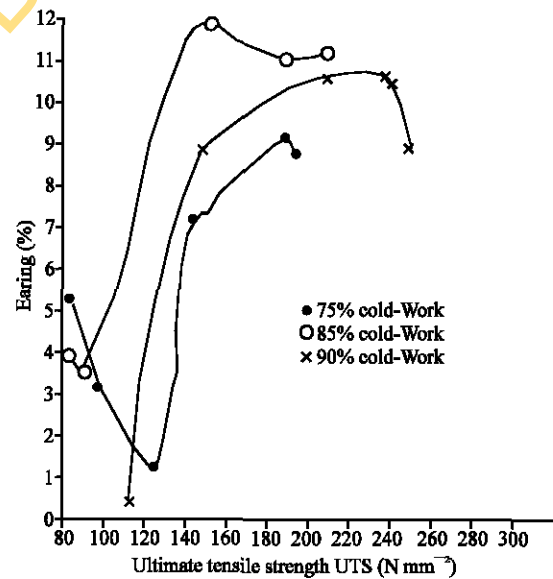


Fig. 8: Earing % versus ultimate tensile strength (UTS) curves for cold-rolled and temper-annealed Aluminium 1200

From Fig. 7, it is observed that earing increases again after hitting its minimum if the anneal temperature is increased. In Fig. 8-10, it could be seen a regular pattern of relationship between earing and the parameters-hardness, ductility and ultimate tensile strength. Hardness, ductility and ultimate tensile strength

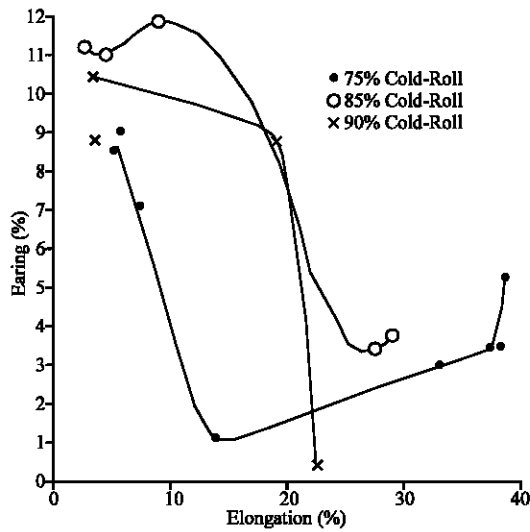


Fig. 9: Earing % versus elongation % curves for cold-rolled and temper-annealed Aluminium 1200

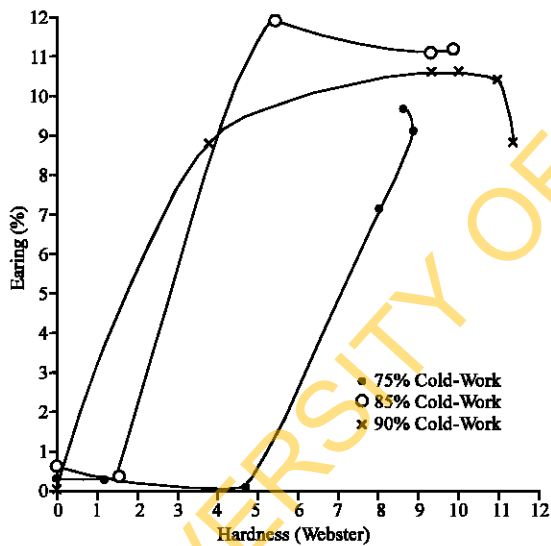


Fig. 10: Earing % versus hardness curves for cold-rolled and temper-annealed Aluminium 1200

are seen to be not necessarily at the lowest, highest and lowest values respectively when cold-rolled tempered annealed Aluminium 1200 exhibits lowest (minimum) earing. Thus, these three properties at minimum earing vary for varying degrees of cold-rolled Aluminium 1200.

CONCLUSIONS

- Earing in cold-rolled Aluminium 1200 generally initially increases with anneal-temperature after

which it drops to minimum at anneal-temperature unique to the particular degree of cold-rolling. For a 75% cold rolled Aluminium 1200, this is found to be 300°C, 1-4 h anneal time. For a 85% cold rolled Aluminium 1200, this is found to be 400°C, 2-4 h anneal time and for a 90% cold rolled Aluminium 1200, this is found to be 460°C, 1-4 h anneal time.

- Earing in Aluminium 1200 increases again with increasing anneal-temperature after this unique temperature at which earing is minimal.
- It can therefore be stated that for cold-rolled Aluminium 1200, earing increases with increasing anneal temperature after which it begins to drop to its minimum at a temperature of anneal unique to the particular degree of cold-rolling.
- Hours of anneal do not seem to make any big difference in earing until the right anneal-temperature unique to the particular degree of cold-rolling is reached.
- The minimal earing for the degrees of cold-rolling does not necessarily corresponds to the state of full softening as seen in Table 2 for 75% cold-rolled Aluminium 1200. Hence, the state of minimal earing does not necessarily correspond to the state of highest ductility or lowest ultimate tensile strength (also noticeable from Table 2) whereas, it corresponds to the state of highest ductility for 95% cold-rolling. This implies that experiments must be carried out for specific degrees of cold-rolled Aluminium 1200 to determine the state of minimum earing for deep-drawn hollowares production. This however, has to be determined in conjunction with strength and ductility values so as to have good ductility- strength ratios with minimal earing. An example is 75% cold-rolled Aluminium 1200 despite lowest earing at 300°C, 2-4 h anneal: 350°C, 2-4 h would be the best annealing temperature to produce best ductility-strength ratio with tolerably low percent earing.

ACKNOWLEDGEMENTS

The Management of Tower Aluminium Rolling Mills, Ota, Ogun state Nigeria is greatly acknowledged for the provision of laboratory facilities and materials.

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