JOURNAL OF ENGINEERING RESEARCH VOL. JER–1 NO. 1 APRIL 1989

EFFECTS OF TEMPER ANNEALING TEMPERATURES AND TIMES ON THE MECHANICAL PROPERTIES OF COLD-WORKED ALUMINIUM 1200

– D. A. Aderibigbe +, and O. O. Sowole ++

ABSTRACT

Experiments have been conducted to develop temper-annealing schedule for continuously cast and cold-worked aluminium 1200. By using the method of graphical combination of the results of tensile and deep-drawn tests, it is shown that a cost-effective temper-annealing schedule that would impart improved mechanical properties (compared with full annealing at 460°C for 6 hours) can be developed for Al-1200.

For optimum combination of desired properties during deep-drawing, the 75% cold-worked material should be temper-annealed at 380°C for 3 hours; the 85% cold-worked material should be temper-annealed at 400°C for 2 hours while the 90% cold-worked Al-1200 should be temper-annealed at 460°C for 3 hours.

1. INTRODUCTION

In the forming of metal sheets by various stamping procedures, the tensile strength, yield strength and formability of the materials used are amongst the most important characteristics [1] to be considered in the design and processing of various alloys. The materials used are expected to initially possess sufficient ductility to deform without necking or cracking. This requirement is generally fulfilled by materials in the annealed condition although with the attendant result of low strength for the formed part.

One possible way of achieving higher ductibility for a given strength level is by temper annealing (or partial annealing) as demonstrated by Devgun et al [2] in their study on Commercially Pure Alluminium 1100. Here, Devgun et al explored the possible range of mechanical properties obtainable in commercially pure aluminium 1100 by partial annealing and attempted to construct a model of the process in order to optimize the system. While their regression equation for the model predicted satisfactorily, the ultimate tensile strength in both longitudinal and transverse directions, it is observed that the prediction is not satisfactory for yield stress and percent elongation. Also, there was no comparison of the relative improvement in the mechanical properties of temper annealed aluminium 1100 with that of fully-annealed aluminium 1100.

Another thermomechanical process for improving the strength of commercially pure aluminium is called temper rolling. In this case, the fully annealed material is plastically deformed in contrast to temper-annealing where a heavily cold-worked material is either recovery-annealed or partially recrystallized. Farge and Williams [3] have demonstrated that the ductility of the temper-annealed material is always superior to that obtained by temper rolling at all strength levels in 70/30 brass.

The present work is based upon the effort made at improving the mechanical properties of commercially pure aluminium 1200 by temper

---

+Faulty of Engineering, University of Lagos, Lagos Nigeria.
++Aluminium Rolling Mills, Otta, Nigeria.

annealing at the Aluminium Rolling Mills (ARM), Otta in Ogun State of Nigeria. Previously, the practice was full-annealing of continuously cast but cold-worked aluminium 1200 at 460°C for 6 hours. This resulted in a rather low strength of deep-drawn hollowares. The primary objectives was do develop an appropriate temper-annealing schedule which would improve the strength of deep-drawn aluminium 1200 without impairing ductility.

2. EXPERIMENTAL DETAILS

2.1 Material

Continuous cast Aluminium 1200 sheets obtained from ARM and with thicknesses of 8mm and 6mm were used as the starting materials. The average chemical analysis of the material is shown in Table 1.

2.2 Specimen Preparation

The Aluminium 1200 sheets were cold-rolled to three different thicknesses of 2mm (from guage 8mm), 0.9mm and 0.6mm (from guage 6mm), to obtain 75%, 85% and 90% cold-reduction respectively. The 75% cold-worked sheet (i.e. 2mm thick) is the minimum degree of cold-work given to any material at ARM. And, it is known [4] that a high degree of cold-work reduction is necessary to produce a fine grain structure needed to achieve good deep-drawing characteristics. The aluminium sheets were then blanked into 60mm diameter circles to produce the required specimens for subsequent tests.

Seven annealing temperatures of 225°C, 250°C, 275°C, 300°C, 350°C, 400°C and 460°C were selected. At each temperature and for ezch percentage cold-reduction, annealing times of 1,2,2½,3 and 4 hours were used. At the end of the pre-determined time, samples were taken out of the muffle furnace and allowed to cool in air.

2.3 Tensile Testing

After annealing, the specimens for the tensile tests were cut into strips of 50mm x 12mm in accordance with the specification of ASTM E8-65T. Tensile tests were carried out on an Avery Universal Testing Machine on each of the samples in a direction perpendicular to the direction of rolling. The strain rate was 0.04 per minute. For each sample the Ultimate Tensile Strength (UTS) and the percentage elongation at fracture (E1.%) were calculated from the stress-strain curve. In order to test for the reproducibility of the results, three identically treated specimens were tested and the results showed that the maximum deviation from the mean observation was less than 1% for UTS.

2.4 Deep-Drawing Test (or Cup-Test)

The use of tensile-tests alone does not surface in drawing up and annealing schedule because a given strength level in a commercially pure aluminium material may be achieved by different combinations of process variables [2] — lower temperature and percent elongation require longer annealing times while at higher temperatures relatively shorter times may be used. Also, the preferred orientations in the plane of aluminium sheet as a result of deformation textures [4,5] may cause earing problems which are not desirable during the fabrication of hollowares. The 60mm diameter (and occasionally 65mm diameter) specimens were subjected to deep-drawing tests after appropriate annealing, using an Erichsen deep-drawing equipment. The cup-tests on this equipment simulate the earing behaviour of the annealed materials before actual industrial drawing to form hollowares.

TABLE 1 (a)
CHEMICAL ANALYSIS OF ALUMINIUM 1200

F_e	S_i	M_g	M_n	Al
0.53	0.225	0.025	0.025	Balance

TABLE 1 (b)

MECHANICAL PROPERTIES OF FULLY-ANNEALED
75% COLD-ROLLWED ALUMINIUM 1200 AT 460°C FOR 6 HOURS

Ultimate Tensile Stre

Ultimate Tensile Strength	—	86N/mm^2
Percent Elongation	—	39%
Percent Earing	—	4.8%

From the cup-tests, the percent earings of the specimens can be determined. The tests performed on three identical specimens annealed under the same conditions showed that the maximum deviation from the mean reading of the cup-tests was less than 0.5%

2.5 Hardness Test

Using a Webster hardness equipment, the hardness of the temper-annealed specimen was determined in Rockwell, E. hardness test.

3. RESULTS AND DISCUSSION

3.1 Tensile-Tests

Figure 1 shows the plot of Ultimate Tensile Strength (UTS) and percent elongation as a function of annealing time at different temperatures for the 75% cold-rolled aluminium 1200 sheet. In general, at annealing temperatures lower than 350°C, the UTS decreases with increasing annealing times while the corresponding percent elongation at fracture increases with increasing annealing time. However, at temperatures beyond 350°C, the UTS was observed to have decreased to about one-half the value at 225°C while the corresponding percent elongation had undergone almost an eight-fold increase (relative to that at 225°C) with increasing annealing times. In particular, after annealing times of over two hours, it appears that there is no significant difference in the values of these properties (as they are asymptotic with annealing time) at temperatures greater than 300°C. These observations are in agreement with those of Devgun et all [2] on aluminium 1100 who concluded that at high temperatures, the annealing process is very rapid.

Figure 2 shows the plot of hardness as a function of percent reduction in thickness (degree of cold-work) after annealing for 3 hours at 300°C, 400°C and 460°C. In this case, the higher the deformation (i.e. percent reduction the higher the hardness at temperatures of 300°C and 350°C. However, there was no significant change with deformation in the hardness values of the material at 400°C and 460°C. This type of behaviour could be attributed to the fact that the deformed structure is unstable thermodynamically [5] at the lower temperatures during the period of annealing. It appears that even when a stable deformation texture 'mix' is attained at high degree of cold working (i.e. greater than 70%) as pointed out by Blade [6], a relatively high temperature is required for a given period of annealing to impart a relatively low dislocation density with approximately equilibrium concentration of vacancies on the material. At such temperatures, it is feasible to envisage that the effect of strain hardening may be at its lowest as demonstrated for the graphs at 400°C of figure 2.

3.2 Cup-Tests

A typical result of the cup-tests along with the corresponding tensile-tests for 75% cold-worked aluminium 1200 sheet is shown in Table 2. In the column on percent earings, it can be seen that the earing is biggest at the lowest temperature of anneal (i.e. 225°C) and, in general, decreases until it reaches its lowest value at 300°C, thereafter, it rises again. This type of behaviour on the development of "ears" during deep-drawing is similar to that observed by Basset and Bradley [8] on Cupronickel sheet.

Table 2 also shows that for the A1 1200, a combination of strain hardening and partial annealing could be used to produce the H26, H24 and H22 series of tempers which represent three-quarter hard, half-hard and quarter hard conditions respectively. This observation is in agreement with the views of Anderson [10] in respect of the strain-hardened tempers of the non-heat-treatable allows.

At high temperatures, the earing was observed to be more random with increasing time of annealing. A similar observation was made by Sheppard and Zaidi [4] who reported that the earing was more random when larger subgrain sizes were produced (i.e. at higher temperatures) and varied linearly with subgrain size as the temperature of processing is reduced in AL-2Mg sheet. They attributed this effect to the ease of recovery processes occuring at different temperatures.

Figure 3 illustrates the development of 'ears' during deep-drawing of 90% cold-worked aluminium 1200 sheet annealed at 460°C for 1,2,3 and 4 hours. Of interest is the relative decrease in the number of ears with increasing annealing time at this temperature. This observation could be attributed [5,9] to the tendency to achieve a desirable balance between rolling texture and annealing (or cube) texture in the Aluminium 1200.

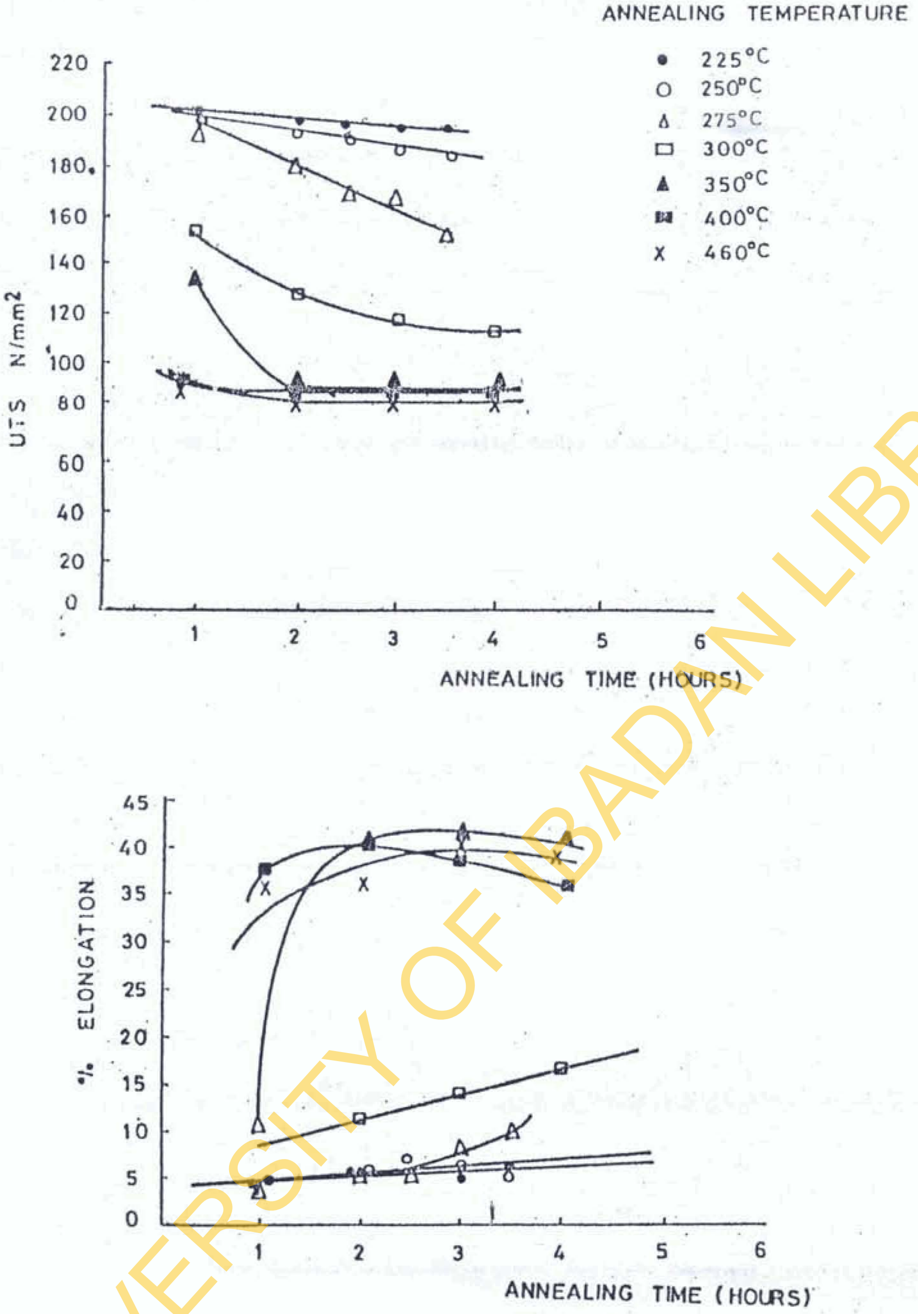
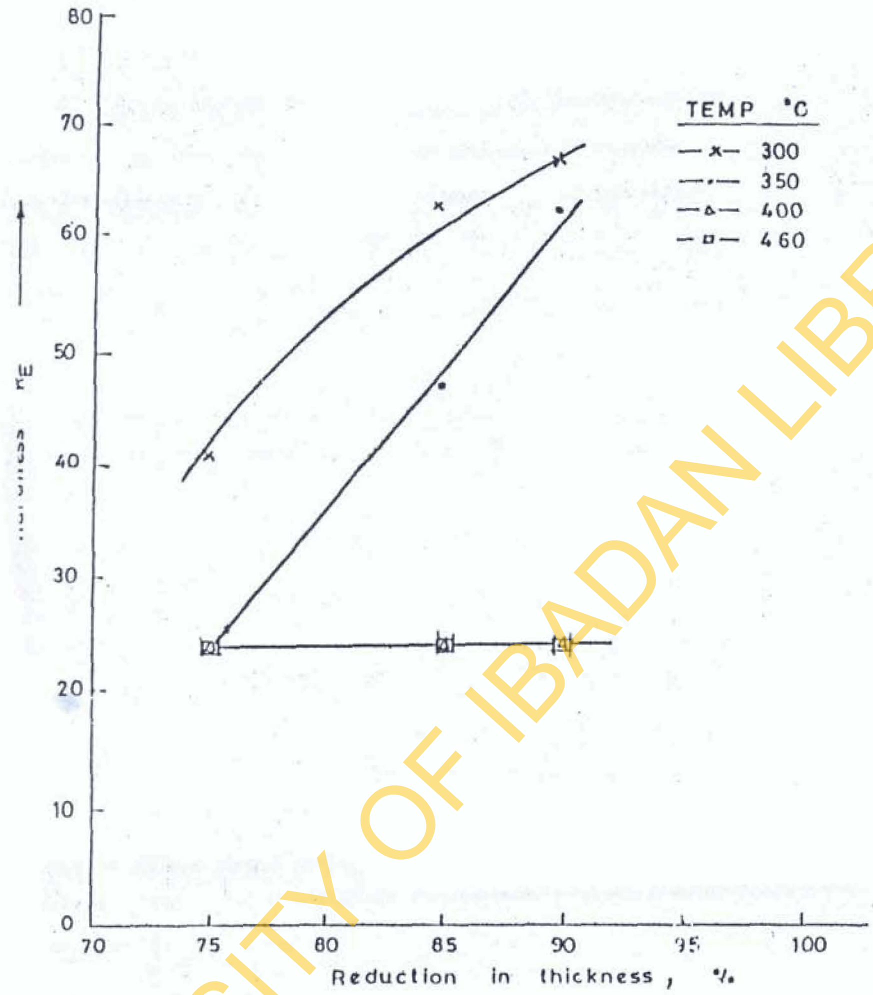


Fig. 1 a&b: Plot of ultimate tensile strength and percent elongation as a function of annealing time at different temperatures for 75% cold-rolled aluminium 1200.



2: Plot of hardness as a function of percent reduction in thickness, (cold-work) of A1-1200 after annealing for 3 hours at 300°C, 350°C and 460°C.

ANNEALING		UTS Nmm^{-2}	Temper Designation	Hardness (R_E)	Elongation (%)	ASTM Grain Size No.	Draw Ratio i.e. blank Ø / punch Ø	Earing (%)
Temp. (°C)	Time (HRS.)							
225	1.0	202.1	H26	66.5	4	5	60/33	-
	2.0	198.7	H26	66.5	6	6	60/33	7.4
	2.5	195.4	H26	66.5	5	6	60/33	-
	3.0	194.2	H26	62.5	5	7	60/33	8.4
	3.5	195.0	H26	62.5	6	8	60/33	10.1
250	1.0	199.2	H26	62.5	4	6	60/33	9.9
	2.0	193.7	H26	62.5	6	6	60/33	8.6
	2.5	189.6	H26	62.5	7	7	60/33	9.7
	3.0	187.5	H26	58.0	6	7	60/33	8.4
	3.5	185.4	H26	58.0	5	8	60/33	-
275	1.0	196.2	H26	66.5	4	6	60/33	7.1
	2.0	180.4	H26	66.5	6	7	60/33	5.8
	2.5	170.0	H26	54.0	6	7	60/33	7.9
	3.0	168.7	H26	54.0	8	8	60/33	7.9
	3.5	152.1	H24	50.0	10	8	60/33	7.0
300	1.0	153.3	H24	50.0	10	Fine	60/33	1.3
	2.0	127.1	H22	45.5	11	"	60/33	1.3
	3.0	116.7	H22	41.0	14	"	60/33	1.3
	4.0	111.7	H22	41.0	16	"	60/33	1.3
350	1.0	133.3	H22	45.5	11	"	60/33	3.3
	2.0	89.2	0	24.0	40	"	60/33	2.8
	3.0	88.5	0	24.0	42	"	60/33	3.2
	4.0	89.6	0	24.0	40	"	60/33	3.2
400	1.0	90.4	0	24.0	36	"	60/33	4.3
	2.0	88.7	0	24.0	40	"	60/33	2.6
	3.0	89.6	0	24.0	38	"	60/33	3.4
	4.0	89.6	0	24.0	34	"	60/33	-
460	1.0	93.7	0	24.0	36	"	60/33	4.1
	2.0	85.4	0	24.0	36	"	60/33	7.5
	3.0	82.2	0	24.0	41	"	60/33	5.1
	4.0	81.5	0	24.0	39	"	60/33	4.2

TABLE 2: RESULTS OF TENSILE TESTING AND DEE-DRAWING OF 75% COLD-WORKED ALUMINIUM 1200

3.3 Metallographic Examination

The results of the metallographic examination of the specimens (Figs. 4a & 4b) revealed that the aluminium 1200 is characterised by a fairly pure aluminium matrix with insoluble constituent particles of impurity elements (possibly those of silicon and Iron) dotted all over the matrix. In addition, the rolling direction was easily discernable from the preferred orientation of the impurity particles.

3.4 Annealing Schedule

In order to draw up the annealing schedule, at a given degree of cold-work, the results of the tensile and cup-tests at different annealing temperatures and time have to be combined to evolve the optimal processing conditions. Figure 5 is a typical graphical illustration of the investigated properties of aluminium 1200 as a function of cold-work and annealing. The annealing data are for 75% reduction in thickness by rolling at room temperature and 3-hour annealing time. For a given degree of cold work and annealing time, the criterion for the selection of the optimal annealing temperature is considered to be that which minimizes the percent earing and the ultimate tensile strength while maximizing the percent elongation at fracture. Under these conditions, the annealing temperature of 380°C would provide a UTS of 90N/mm^2 with percentage earing of 2.6%, and a percentage elongation at fracture of 40% to the material. The corresponding results for a fully annealed, 75% cold-rolled A I-1200 at 460°C for 6 hours (as practised at ARM) are UTS, 86N/mm^2, percentage elongation of 39%, and earing of 4.8%. Thus, some improvements in mechanical properties of A I-1200 sheets can be achieved at ARM by temper-annealing instead of full annealing. If one takes into account the cost-savings in energy that would result from the shorter annealing time and temperature without compromising the mechanical properties of the material, then temper-annealing can be considered to be a cost-effective process for working A I-1200 sheets.

Plots similar to those in Figure 5 can be made for other degrees of cold-working of the material to establish the appropriate temper annealing schedule for an optimal combination of strength and ductility for the deep drawn material. A summary of the appropriate annealing schedule for the different levels of cold-working in this investigation is shown in Table 3.

CONCLUSIONS

On the basis of the results of this investigation on the mechanical properties of continuously cast and cold-worked aluminium 1200 that was temper annealed, the following conclusions can be made:

(b) Through the use of graphical combination of data on mechanical properties, annealing temperatures and time, it is possible 'to select an appropriate temper-annealing schedule that would impart improved strength, minimize earing, and provide acceptable ductility to A I-1200 sheets at different levels of cold-work used in deep-drawing of hollow-wares, and result in significant energy savings.

(c) For optimum combination of desired properties, the 75% cold-worked material should be temper-annealed at 380°C for 3 hours; the 85% cold-worked material should be temper-annealed at 400°C for 2 hours while the 90% cold worked. A I-1200 sheets should be temper-annealed at 460°C for 3 hours.

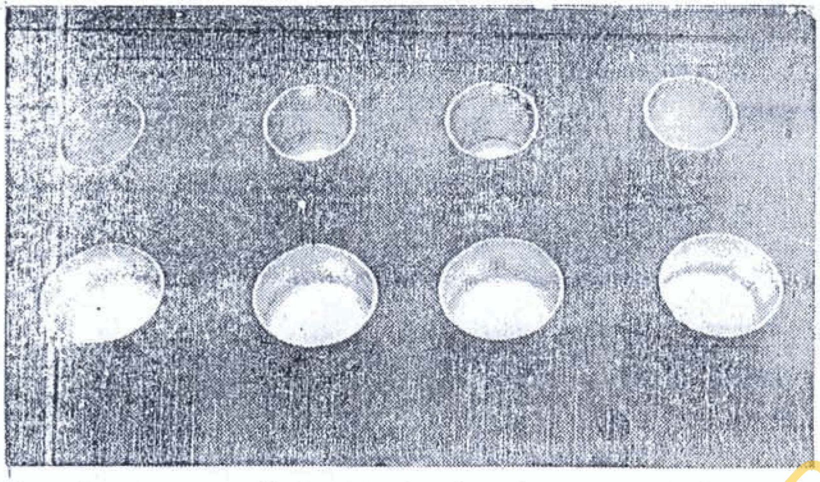


Fig. 3: Development of 'ears' during deep-drawing of 90% Cold-worked Al-1200 sheet annealed at 460°C for (from left to right) 1,2,3 and 4 hours. The draw-ratio for the top set is 60/33 while it is 65/33 for the bottom set.

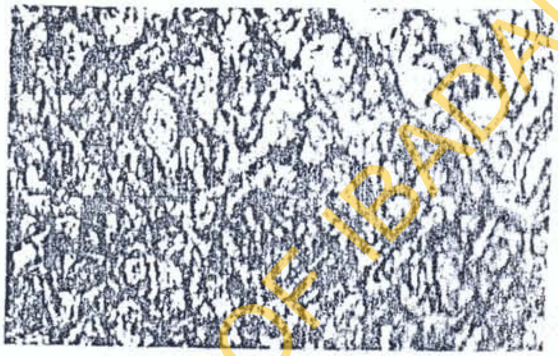


Fig. 4a: As Cast Structure of Al-1200 showing Large Undefined Grains.

Fig. 4b: Phomicrograph of 75% Cold-rolled and Unannealed Structure showing impurities and directionality of rolling texture 100X.

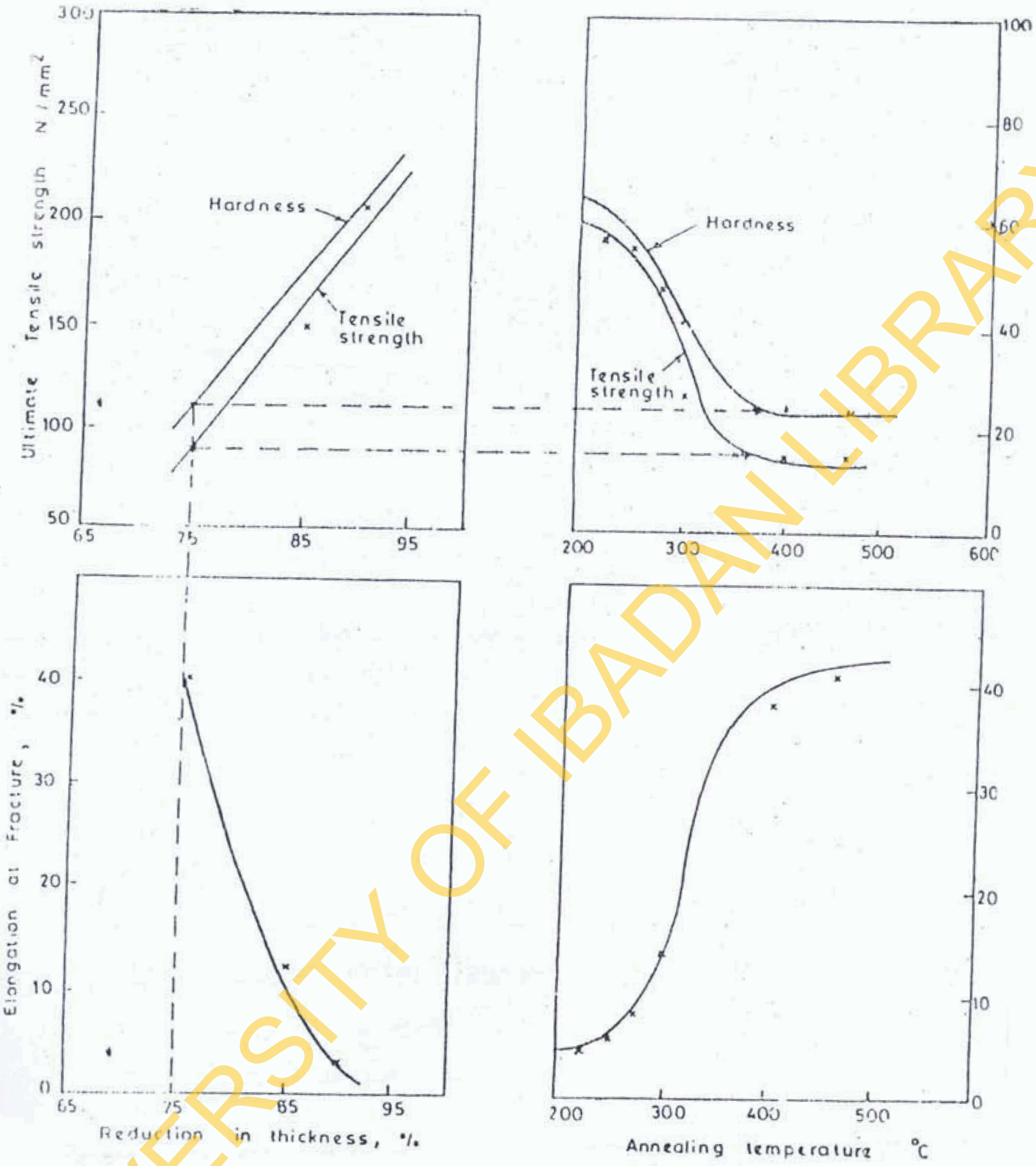


Fig. 5: Properties of Al -1200 as a function of Cold Work and annealing. Annealing data are for 75% reduction in thickn.ss by rolling at room temperature and 3-hour annealing time.

TABLE 3: SUMMARY OF OPTIMAL TEMPER-ANNEALING SCHEDULE FOR 75%, 85% and 90% COLD-WORKED ALUMINIUM 1200

Degree of Cold-Working (%)	Optimal Annealing Temperature and Time		Expected UTS (N/mm^2)	UTS Improvement over full-Annealing (N/mm^2)	Expected Elongation (%)	Elongation Improvement over full-Annealing (%)
	(°C)	(HRS)				
75	380	3	90.0	4.0	40	1.0
85	400	2	82.4	3.1	34	4.3
95	460	3	118.1	27.5	24	None

REFERENCES

[1] K.R. Van Horn (ed.): "Aluminium – Vol. III, Fabrication and Finishing", Ch. 6: 1967 American Society for Metals.

[2] M.S. Devgun, L.L. Andressen and J.G. Castillo: Light Metal Age, 1981, February, P. 13.

[3] J.C. Farge & W.M. William: Canadian Metallurgical Quarterly, 1971, 20(4) 309.

[4] T. Sheppard & M.A. Zaidi: Metals Technology, 1982, 9, 308.

[5] I.J. Polmear: "Light Alloys-Metallurgy of the Light Metals", 67; 1981, London, Edward AArnold.

[6] C.R. Brooks: "Heat Treatment Structure and properties of Non-Ferrous Alloys", 21; 1982, American Society for Metals.

[7] J.C. Blade: J. Inst. Met., 1961–62, 90, P. 374.

[8] W.H. Basset & J.C. Bradley: Trans. AIME, 1933, 104, p. 181

[9] K. R. Van Horn (ed.): Aluminium – Vol. I, Properties, Physical Metallurgy and Phase Diagrams, p. 85; 1967 American Society for Metals.

[10] W.A. Anderson: "Work Hardening, Recovery, Recrystallization and Grain Growth" in Aluminium Vol. I – Properties, Phhysical Metallurgy and Phase Diagrams, ed. by K.R. Van Horn, ASM (1967) p. 79.

ACKNOWLEDGEMENT

The authors wish to scknowledge the partial funding of the work reported here by the Management of Tower Aluminium Nigeria Limited.