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CORRELATION BETWEEN SHEET METAL TEXTURE AND DRAWABILITY FOR ALPHA BRASS

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INTRODUCTION

Since the work of Lankford, et al [1] and Whitely, [2] R has been considered the primary materials variable controlling, by "texture strengthening", [2, 3] the deep drawability of sheet metal. Extensive research in the ferrous metals industry recently summarized by Blickwede [4] has demonstrated the direct correlation between high R and good drawability. While factors other than texture strengthening were shown to influence forming characteristics, the overwhelming statistical trends revealed in Blickwede's compilation single out R as the principal materials variable in predicting deep-drawing behaviour of ferrous-alloy sheet.

A similar body of knowledge does not exist for the nonferrous metals. Both positive correlation between R and formability as well as exceptions to this relationship have been reported in the literature [5, 6, 7]. The paucity of published data of this kind does not permit a statistical analysis to identify a clear pattern of behaviour. The authors attempted, therefore, to examine the correlation of changes of R with changes in the formability of α-brass under very restricted conditions wherein R was varied and the tensile properties and grain size held constant.

EXPERIMENTAL MATERIAL AND PROCEDURES

A lot of alloy 260 (29.45% Zn, major impurities 0.011% P, 0.22% Fe, 0.01% Ni, 0.005% Ag, balance copper) was obtained as commercially-produced, hot-rolled plate at 9.1 mm gauge. Cold rolling and annealing were carried out in the laboratory to obtain the desired variations of R at 0.76 mm gauge.

ASTM standard sheet tensile specimens were cut at 0°, 45°, and 90° to the rolling directions. Whilely's [8] nomograph and the relation:

$$R = \frac{\ln (w_o/w_f)}{\ln(l_f w_f/l_o w_o)} \qquad (1)$$

were used to calculate R values in the 0°, 45° and 90° directions. The subscripts o and f refer to the original and final measured dimensions of width, w, and gauge length, l. The R values thus determined at 0°, 45° and 90° to the rolling direction were used to calculate R by the relationship:

$$R = (R_{0°} + 2R_{45°} + R_{90°})/4 . \qquad (2)$$

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Final dimensions were measured at approximately 20% elongation (R values were determined to be independent of strain between 15 and 25% elongation and independent of temperature to 150°C). Elongation was measured to within 0.1%, and w_o and w_f were measured at the same point along the gauge length to ± 0.127 mm. According to Duncan, [9] this leads to an error of about 0.03 in R. Duplicate tensile tests were conducted, and when R differed by more than 0.09, additional tests were run.

The criterion for drawability, Limiting Draw Ratio (LDR), was determined by measuring the ratio of the blank diameter at which 50% of the blanks draw to the punch diameter. Tooling (33.0 mm diameter punch and 35% die clearance), hold-down pressure (3318 N), draw speed (38 mm/min.) and lubricant (Cindol No. 4669) were held constant for all tests. A Tinius Olsen Ductomatic machine was used for these tests. With at least six blanks tested at each blank diameter (1.57 mm diameter increments), differences in LDR greater than 0.015 could be attributed to differences in materials characteristics.

EXPERIMENTAL RESULTS AND DISCUSSION

Table 1 lists the mechanical property data and grain sizes for material conditions where only $\bar{R}$ was varied and all other materials factors remained essentially constant. LDR and $\bar{R}$ values are listed in Table 2, and LDR versus $\bar{R}$ is plotted in Figure 1. The increase in LDR with increasing $\bar{R}$ for each set of experiments is evident. It can be seen that increasing $\bar{R}$ improves drawability over a wide range of grain sizes, elongations, strengths, and n values.

The dashed lines in Figure 1 represent a plot of a theoretical relationship between LDR and $\bar{R}$: [2, 10]

$$\ln\ (\mathrm{LDR}) = \left(\frac{1}{1+\eta}\right) \left(\frac{1+\bar{R}}{2}\right)^{1/2} \qquad (3)$$

the quantity η is an empirical friction factor in this expression and takes on values between 0.2 and 0.3. The slope of the experimental and theoretical plots of LDR versus $\bar{R}$ are in reasonable agreement when $\bar{R}$ is the only factor varying. Hosford suggests that agreement can be improved by accounting for planar anisotropy [11]. For experimental conditions where no attempt was made to isolate $\bar{R}$ as the only variable, large discrepancies between the theoretical and experimental slopes were noted. Similar discrepancies have been reported elsewhere [12].

It should be emphasized that for substantially different materials characteristics it cannot be assumed that a direct correlation between $\bar{R}$ and LDR exists. In fact, the partially recrystallized metal of experiments Cc shows an LDR of 2.22 at an $\bar{R}$ level of 0.92 in contrast to B and D which have higher $\bar{R}$ but lower LDR. This implies that other variables, aside from $\bar{R}$, exert an influence on the drawability of brass sheet.

The higher drawability of partially recrystallized metal compared to fully-annealed metal at the same $\bar{R}$ value points out the error of the commonly-held notion that the highest deep drawability is achieved with fully-softened metal. Aside from the few examples illustrated here, numerous instances, particularly in deep drawing aluminum alloys, can be found to show that fully-softened material is not always superior to partially-recrystallized or even cold-worked material.

CONCLUSIONS

1. Increasing the $\bar{R}$ values of alpha brass sheet increases the Limiting Draw Ratio (LDR) under conditions where $\bar{R}$ is the only materials factor which varies.

2. The magnitude of the increases in drawability correlate with theoretically derived LDR versus $\bar{R}$ relationships.

3. Under conditions where other materials factors were varied along with $\bar{R}$ correlations between $\bar{R}$ and LDR were less reliable.

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REFERENCES

1. LANKFORD, W. T., SNYDER, S. C. and BAUSCHER, J. A., "New Criteria for Predicting the Press Performance of Deep Drawing Steels", Trans. ASM, 42, 1950, 1197.
2. WHITELY, R. L., "The Importance of Directionality in Drawing Quality Sheet Steel", Trans. ASM, 52, 1960, 154.
3. BACKOFEN, W. A., HOSFORD, W. F., Jr. and BURKE, J. J., "Texture Hardening", Trans. ASM, 55, 1962, 267.
4. BLICKWEDE, D. J., "New Knowledge About Sheet Steel", Metals Progress, 96, December, 1969, 64.
5. WRIGHT, J. C., "Relationship Between Mechanical Properties, Deep Drawability, and Stretch Formability for Some Nonferrous Sheet Materials", Sheet Metal Industry, 39, 1962, 887.
6. WARWICK, J. O. and ALEXANDER, J. M., "Prediction of the Limiting Draw Ratio from the Stress/Strain Curve", J. Inst. of Metals, 91, 1962-63, 1.
7. WILSON, D. V., "Plastic Anisotropy in Sheet Metals", J. Inst. of Metals", 94, 1966, 84.
8. WHITELY, R. L., "Correlation of Deep Drawing Press Performance with Tensile Properties", ASTM Publication STP 390.
9. DUNCAN, J. L., GONI, F. and JOHNSON, W., "Measurement of Normal Plastic Anisotropy in Sheet Metal", J. Aust. Inst. of Metals, 12, 1967, 127.
10. HOLCOMB, R. T. and BACKOFEN, W. A., "Anisotropy for Drawability Control by Plane-Strain Compression Testing", Sheet Metal Ind., 1966, 479.
11. HOSFORD, W. F., "Cold Formability", Third Int. Congress on the Strength of Metals and Alloys, Cambridge, England, August, 1973.
12. LAWLEY, A., LAFFERTY, S. P. and SCHMIDT, F. E., "Aspects of the Structure-Drawability Relationship in Alpha Brass", Drexel University, Philadelphia, Pennsylvania 19104, presented at the Annual Meeting of the BDDRG, University of Swansea, Wales, April, 1971.

Table 1 Mechanical Properties and Grain Size for Material Processed to Vary R

Ident. Code	0.2% YS, MPa	UTS, MPa	n	Grain Size, mm	Elong., %	$\overline{R}$
A	100	337	0.45-0.50	0.06	62	0.93
a	100	333	0.45-0.50	0.06	63	1.10
B	75	316	0.45-0.50	0.14	63	0.97
b	78	330	0.45-0.50	0.13	61	1.12
C	357	431	0.30-0.35	PR*	38	0.84
c	381	441	0.30-0.35	PR*	38	0.92
D	79	331	0.45-0.50	0.11	61	0.98
d	90	345	0.45-0.50	0.08	63	1.17

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*PR = partially recrystallized.

Table 2 Comparison of LDR and $\overline{R}$ Values

IDENT	$\overline{R}$	LDR
A	0.93	2.17
a	1.10	2.24
B	0.97	2.18
b	1.12	2.24
C	0.84	2.17
c	0.92	2.22
D	0.98	2.17
d	1.17	2.24

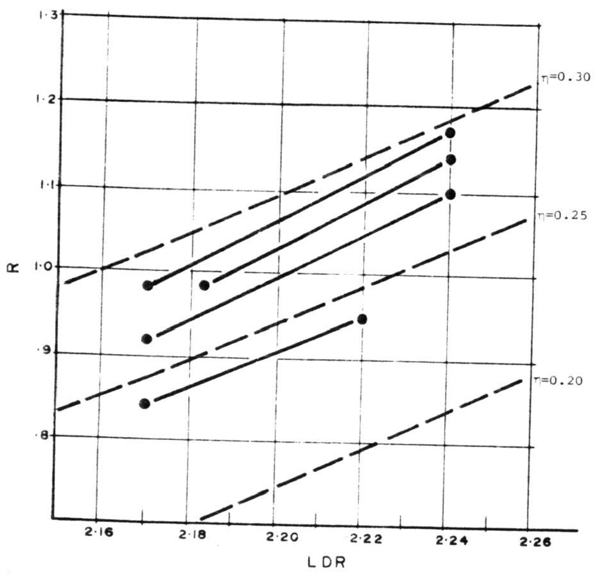

Figure 1 Solid Lines Represent $\overline{R}$ versus LDR for Conditions where only $\overline{R}$ was Varied and other Materials Factors Remained Essentially Constant. Dashed Lines are Explained in the Text