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EFFECT OF DIE-TEMPERATURE ON AGE HARDENING CHARACTERISTICS OF ALUMINUM COPPER AND ALUMINUM COPPER MAGNESIUM ALLOYS

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EFFECT OF DIE-TEMPERATURE ON AGE-HARDENING CHARACTERISTICS OF ALUMINIUM-COPPER AND ALUMINIUM-COPPER-MAGNESIUM ALLOYS

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ABSTRACT

During permanent mold casting, die temperature exerts significant effects on the characteristics of age-hardenable aluminium alloys. In this paper the authors have presented the results of their experimental work relating to the effects of die temperature on the hardness values of 1" x 1" x 6" square section bars cast in permanent mold and subsequently aged for various lengths of time. The alloys used in this study were:

i. Al - 4.5% Cu.
ii. Al - 4.5 % Cu. - 0.5 % Mg and
iii. Al - 4.5 % Cu. - 1.0 % Mg.

It was observed that with the rising temperatures of the die the aging response of the bars improved resulting in greater hardness. The results of this study were successfully employed to improve the mechanical properties of some commercial engineering components in an economical manner without using expensive heat-treatment equipment and complex procedures.

INTRODUCTION

Ever-since its discovery age-hardening has proved to be one of the most useful and fascinating areas of investigation for the metallurgists. The age-hardening treatment is mainly utilized for hardening and strengthening non-ferrous alloys. The treatment essentially consists of the following two steps:

SOLUTION TREATMENT

Solution treatment consists of forming supersaturated solution of one constituent in another by sudden quenching of the homogenous solid solution from a higher temperature. The necessary condition for this treatment is that the solute metal should have a decreasing

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solubility in the solvent metal with decreasing temperatures. Copper in aluminium with minor amounts of magnesium offers one typical example of such cases. In this study no separate solution treatment was proposed and the chilling effect of the die during casting was made use of to meet the necessary conditions for solution treatment.

AGING OR PRECIPITATION TREATMENT

The alloy after solution treatment is super saturated and is in an unstable state. The excess solute tends to precipitate out of the solution. The speed at which precipitation occurs varies with aging temperature. The precipitation of the second phase is responsible for rise in hardness and strength of the alloy. Those alloys in which precipitation takes place at room temperature, over a period of time, are known as natural aging alloys. Most alloys, however, require re-heating to elevated temperatures for certain length of time to develop their full strength. The treatment is then known as artificial aging. However, these alloys also age to a limited extent at room temperature. The rate and extent of strengthening depends upon the composition of the alloy.

Addition of magnesium in small amounts to 4.5% Cu-Al alloys results in lowering of temperature required for precipitation treatment to the extent that precipitation treatment is accomplished at room temperature.

In the family of Al-Cu-Mg alloys, favourable results of aging are evident at room temperature within a few days. During present experimentation it was assumed with a reasonable degree of certainty that sudden cooling of these alloys in metallic dies offers cooling rates high enough to eliminate the need of separate post casting solution treatment of components even more. All that is required is to cast the components in metallic dies, take them out and then cool them in water and let them stay at atmospheric temperature for a few days to gain desired rise in hardness and strength.

EXPERIMENTAL PROCEDURE

Calculated amounts of electrolytic copper and master alloys (10% Mg-Al) were added to aluminium for the preparation of 4.5% Cu-Al, 0.5% Mg - 4.5% Cu - Al and 1% Mg - 4.5% Cu - Al alloys. These alloys were melted in graphite crucible and were cast in a permanent mold into 6.00" long bars of 1" x 1" cross-sectional area. The arrangement for measuring

die-temperature is shown in Figure 1. The specimens removed from the hot die were directly quenched in water.

RESULTS AND DISCUSSION

The effects of die temperature on the aging response of permanent mold cast 4.5% Cu - Al, 0.5% Mg - 4.5% Cu - Al and 1% Mg - 4.5% Cu - Al alloys were studied. It was observed that the specimens cast in cold die had lower initial hardness and poor aging response compared to those cast in hot die. Tables 1, 2 and 3 and the corresponding curves (Fig. 2 & 3) show the improvement in initial hardness and aging response of various alloys with the increase of die temperature.

Table-1: Hardness values of age hardened 4.5% Cu-Al alloy cast at various die temperatures in permanent molds

Sample No.	Die Temp. °C	Hardness (Brinell)					
		At the time of casting	After 12 hours	After 24 hours	After 48 hours	After 72 hours	After 120 hours
1	25	34	36	38	39	40	41
2	100	36	38	41	42	43	45
3	160	58	61	64	65	65	66
4	200	62	65	68	68	69	70
5	220	64	68	70	71	71	72
6	225	64	68	70	72	72	73

Table-2: Hardness values of age hardened 0.5% Mg – 4.5% Cu-Al alloy cast at various die temperatures in permanent molds

Sample No.	Die Temp. °C	Hardness (Brinell)					
		At the time of casting	After 12 hours	After 24 hours	After 48 hours	After 72 hours	After 120 hours
1	25	52	56	60	63	63	65
2	68	59	64	69	72	73	75
3	100	59	64	69	73	75	77
4	135	64	69	74	77	81	84
5	190	70	75	82	89	94	99
6	200	70	75	83	89	95	99

Table-3: Hardness values of age hardened 1.0% Mg – 4.5% Cu-Al alloy cast at various die temperatures in permanent molds

Sample No.	Die Temp. °C	Hardness (Brinell)					
		At the time of casting	After 12 hours	After 24 hours	After 48 hours	After 72 hours	After 120 hours
1	25	55	60	63	67	70	71
2	68	69	75	80	83	85	87
3	100	73	80	87	91	93	94
4	140	78	85	94	96	99	100
5.	160	80	88	95	98	100	102
6.	175	86	96	100	102	104	104
7	200	96	109	119	122	124	124
8	210	96	109	119	122	124	124

The peculiar rise in the hardness and the improved aging response of samples with rise of die-temperature were interesting features of the experimental work. Higher die temperatures are supposed to result in slower cooling rates, thereby interrupting the solution treatment (a pre-requisite for age-hardening). One explanation that may be possible to this peculiar rise of hardness is that complete dissolution of copper in aluminium would result in low hardness due to the absence of Cu Al_2 precipitates emerging out of the solid solution. In cold die the temperature gradient is sharp allowing no time for hard θ–phase to precipitate out. However, with rise of die temperature milder temperature gradients are introduced resulting in slower cooling rates which bring about favourable structural changes in the alloy at the atomic level to facilitate an easier nucleation of the hard θ-phase ($CuAl_2$ ppt) possibly by reducing the interfacial energy between matrix and the precipitates. The nucleating sites so formed exhibit a stronger tendency of further growth during subsequent aging treatment.

It is obvious that at higher die temperatures faster diffusion and segregation of copper and magnesium atoms takes place during aging resulting in the formation of $CuAl_2$, $Al_5Cu_2Mg_2$ and other complex phases.

It, however, seems pertinent to verify this explanation through electron microscopy and X-ray diffraction which may possibly reveal further details of the mechanism responsible for the rise in hardness of the specimens with the rise in the die-temperatures.

CONCLUSIONS

1. It is possible to eliminate the solution treatment to be performed on some age-hardenable Al-Cu-Mg alloys by casting them in metallic dies. This saves the cost of expensive heat-treatment furnaces and energy consumed.
2. A careful selection of the composition of the alloy can allow favourable aging response at room temperature. This eliminates the need for precipitation treatment at higher temperature and further simplifies the process as well as reduces the cost of production.
3. During the gravity die casting of Al-Cu and Al-Cu-Mg alloys rising temperatures of the die improve the hardness and aging response. A control of the die-temperature can, therefore, result in desirable hardness in the components subjected to aging after removal from die.

REFERENCES

1. R.B. Nicholson, G. Tohomas, and J. Nutting, "J. Inst. Met"., Volume 87, Aug. 1959, p 492.
2. Miss J.M. Silcok,. "J. Inst. Met.", Volume 89, Feb. 1961, p 203.
3. John B. Newkrik' "ASM Transactions Quarterly", Volume 61, June 1968, p367.
4. Rhines & H.H. Johnson, "Scripta Metallurgica",Volume 11, Feb 1977, p 155.
5. J.W. Martin, "Precipitation Hardening", Pergamon Press London, 1968.

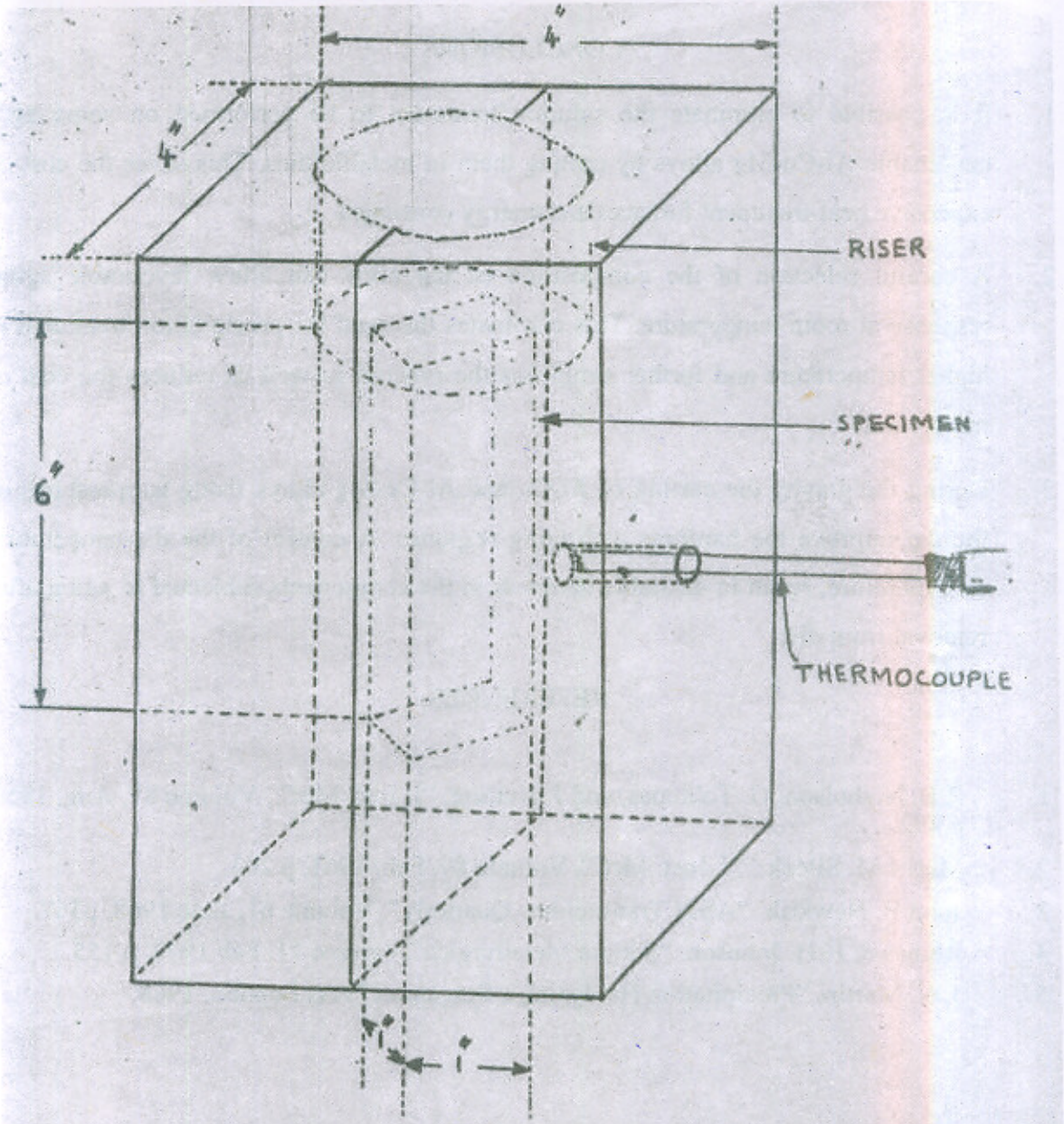


Figure 1: Die Mold and Thermocouple For Casting Samples.

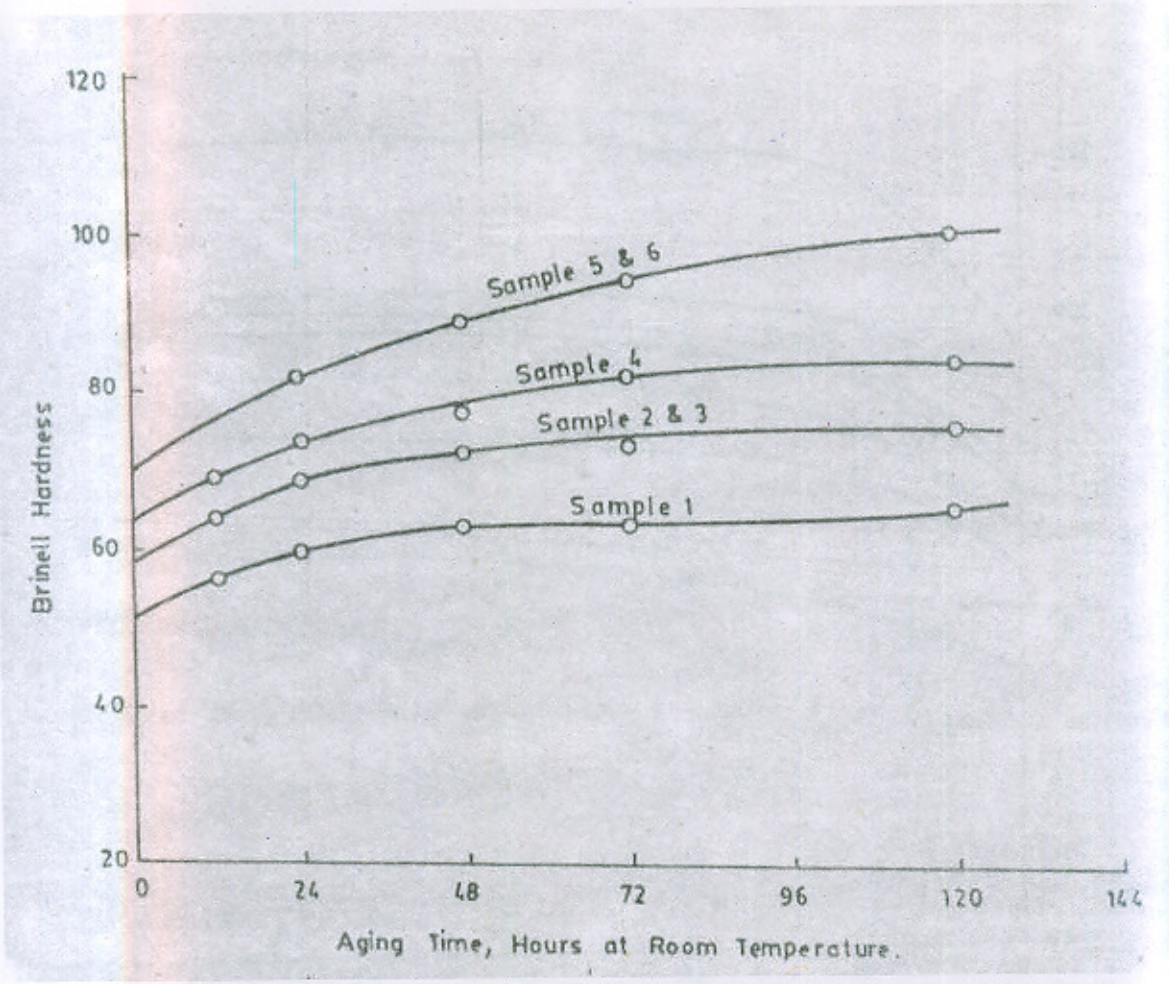


Figure 2: Age Hardening Curves, at Room Temperature, of Permanent Mold Cast 0.5 % Mg – 4.5 % Cu – Al Alloy Cast at Various Die Temperatures.

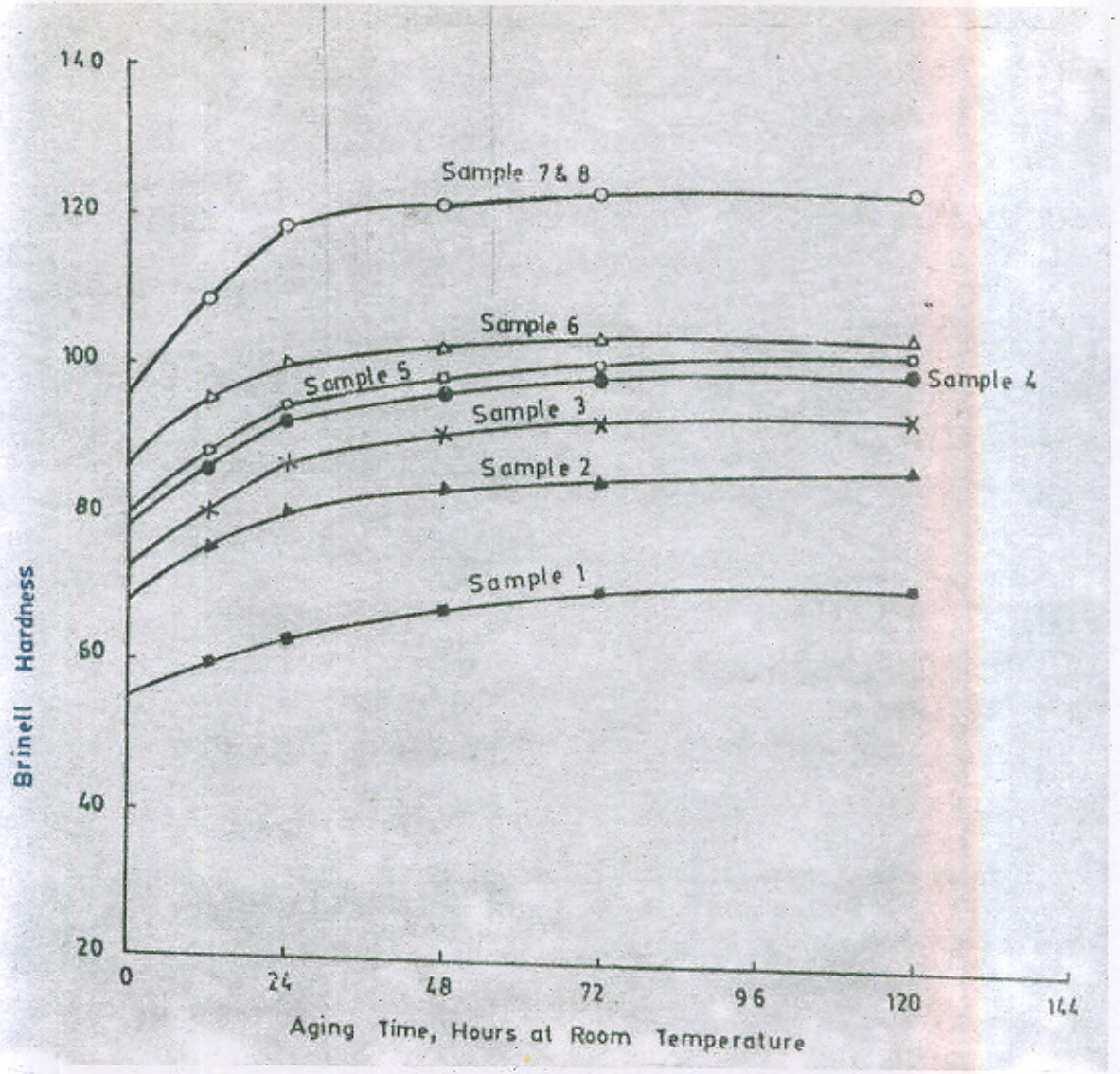


Figure 3: Age Hardening Curves, at Room Temperature, of Permanent Mold Cast 1.0 % Mg – 4.5 % Cu – Al Alloy Cast at Various Die Temperatures.