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EFFECTS OF COOLING RATE ON THE FORMATION OF KAPPA PHASE IN THE Cu-Al-Ni-Fe-Mn SYSTEM (*)

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Aluminium bronzes of the complex type produced by the addition of Fe, Ni and Mn in amounts of the order of 5 %, 5 % and 1 % respectively, with Al close to 10 % find widespread use as naval propeller material and in other marine applications. Their excellent properties are attributed to the transformation of the high temperature beta phase to an additional phase termed kappa in the alpha matrix. As the mode of formation of the kappa phase is reported to be influenced by the cooling rate, which in turn affects the mechanical properties and corrosion resistance of the alloy, an attempt has been made to study the effects of cooling rates on the types, sizes, shapes, hardness and composition of the kappa phase using metallographic techniques and electron microprobe analysis.

EXPERIMENTS:

Test bars of 10/5/5/1 composition were sand-cast conforming to ASTM and BS Specification with a view to reproduce standard mechanical properties and to obtain the related structural characteristics. The alloy way prepared from virgin metals and preingoted which was subsequently remelted with charcoal cover followed by final flushing with nitrogen for about 2-3 minutes. The metal was poured at 1250°C.

The same composition was selected for cooling rate studies where melting was done in an industion heating coil, using graphite crucible. Preheated charcoal was used as a cover during melting, followed by stirring a small quantity of fluoride flux for scavenging the metal and final degassing with nitrogen. The The whole melting operation was carried out as rapidly as possible. For obtaining different cooling rates, a metal mold preheated to different predetermined temperatures, viz. 1000°C, 900°C, 800°C, 700°C and 600°C was used for pouring the metal.

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RESULTS:

The chemical composition and mechanical properties of the sand cast test pieces were determined and metallographic studies and microprobe analysis were carried out.

The chemical composition conformed more or less to the 10/5/5/1 grade. The tensile strength and elongation values obtained were as high as 43 tons per square inch and 18 % respectively, with hardness in the order of 150 BHN. The samples in the unetched condition contained plenty of gray coloured kappa phase of varying shape and size as well as finely divided kappa, and also several rosettes (star-like) of the same, in an alpha matrix. On etching, however, the star-like phase and a few fine globular particles turned dark, while the coarse and fine kappa are as showed no change in colour. Besides, lamellar eutectoid areas corresponding to alpha plus kappa were also present. The gray kappa areas, however, turned dark on prolonged etching. The microhardness of the alpha phase was around 166 VPN; that of coarse gray kappa 306 VPN; fine kappa 256 VPN; and dark etching kappa 193 VPN. Electron microprobe analysis showing the phase compositions is given below:

Element	Percentage in matrix	Percentage in coarse gray kappa (of size 20 microns & above)	Percentage in fine kappa (of appx. 10 microns & below)	Percentage in dark etching rosettes(of size appx.5 micron).
Cu	81.0	11.5	10.6	40.0
Al	9.4	8.5	7.5	14.5
Ni	3.8	8.0	4.9	7.9
Fe	3.2	71.5	72.5	35.1
Mn	1.8	1.8	2.4	2.2
Si	Trace	1.0	2.3	1.0

DISCUSSIONS:

Complex nickel aluminium bronze is difficult to cast in view of its certain inherent characteristics and compositional fluctuations. The melting and casting technique adopted here in producing the same cast test pieces have yielded satisfactory results particularly in respect of composition and strength values.

Photomicrographs indicate that the kappa phase is highly sensitive to fluctuations in cooling rate. A relatively uniform distribution of kappa in an alpha matrix with areas of eutectoid has been observed in the sample subjected to slowest cooling rate. It has also been found that the slowest cooling rate contributed to the precipitation of most of kappa phase in massive and coarse form, whereas the precipitation of finely divided kappa has been favoured by fast cooling rate, the precipitation of intermediate sizes of kappa being influenced by the intermediary cooling rates. Even though the differences between successive cooling rates are not significant as for example, with mold temperature 1000°C to 900°C, or 700°C to 600°C, the observations on relative distribution of precipitates resulting from the two extreme cooling rates confirm the general trends.

In general, three forms of precipitates have been found to occur, viz. coarse kappa, fine kappa and dark-etching rosettes, distributed in a matrix of alpha. Fine and rosette like precipitates are usually difficult to be distinguished in the unetched condition. On etching, however, most of the rosettes turned dark, while fine kappa remained unaffected. This differential etching can be attributed to the basic difference in the phase composition with consequent difference in microhardness. Both coarse and fine gray kappa precipitates have been found to be essentially iron base, having approximately similar composition and comparable microhardness. This suggests that coarse and fine gray kappa are essentially the same phase, their morphology being controlled by cooling rate, other factors such as composition etc. remaining the same. The alpha phase was not found to be sensitive to cooling rate effects. Although the dark etching rosettes offered difficulty in their identification as having rosette-shape, they could, however, be identified as such at high magnification (1800 x).

The dark etching rosette may perhaps be identifiable with a so-called delta phase reported in 9-10 % aluminium group of alloys by earlier workers.

CONCLUSIONS :

1. The formation of kappa phase in nickel aluminium bronzes of 10/5/5/1 type, is influenced by the cooling rate.

2. Slower cooling rates favour massive formation of gray kappa, and faster cooling rates, fine gray kappa.

3. A dark-etching, rosette-shaped precipitate x has been found to occur under the conditions studied, having a distinctly different composition and hardness from that of fine and coarse gray kappa.

4. Both the coarse and fine kappa precipitates are found to be essentially iron base having comparable hardness.