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PHYSICAL METALLURGY OF ALUMINIUM ALLOYS (*)

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Aluminium is a soft and weak metal and is strengthened by alloying with suitable elements. The elements which are added to aluminium in appreciable quantities to increase its strength are limited to only four elements namely magnesium, silicon, copper and zinc. These may be added singly or in combination. It will be seen that the alloying elements magnesium and silicon belong to aluminium period itself while the copper and zinc metals belong to the copper period in the periodic table. Out of these four elements magnesium has bigger atomic diameter (3.1906 Å) than aluminium (d = 2.857 Å), while silicon, copper and zinc have smaller diameters, 2.345 Å, 2.551 Å and 2.659° respectively. These values are within 15% of the aluminium diameter values. Therefore these alloying elements arefavourably placed for-forming. Substitutional solid solutions with aluminium.

Magnesium, copper and zinc also form compounds with aluminium which have bearing on their hardening behaviour. The compounds in case of Mg and Cu are Mg_2Al_3 and $Cu\ Al_2$ respectively. The compound formation is disputed in case of zinc but there are indications that a metastable phase of F.C.C. lattice, does form during the ageing of aluminium zinc alloys. When these alloying elements are present in combination more stable binary arternary compounds may form. For example when magnesium-silicon are present together, they may give rise to a stable compound $Mg_2\ Si$ in addition to the compounds discussed above.

The solubility of these alloying elements decreases with decrease of temperature but it is possible to retain them in solution on fast quenching. Due to differences in solubility at room and high temperatures the solute atoms try to precipitate out.

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The precipitation in the aluminium alloys is generally not a straight forward step but involves a series of structural changes. These changes have been identified as rejection of solute atoms on preferred planes to form zones, the zones giving rise to metastable and stable phases. At the interface of the zones and metastable phases the lattice is appreciably strained and therefore hardened. The maximum strengthening effect depends upon the size and distribution of zones or metastable phases which in turn are determined by the concentration of alloying elements and time and temperature of ageing.

During room temperature or early stages of ageing at intermediate temperatures (130 - 180°C) zones are the first structures which are formed. The formation of zones proceedes with velocities 10^{7} times. The self diffusion rate of the solute atoms. To resolve this difference, it has been proposed that quenched alloys are assirted in the transport of solute atoms to form zones by the quenched in excess vacancies, the concentration of which depends greatly upon the solute atom dia meter, quenching speeds, specimen size, quenching bath temperature, solution temperature employed and reversion treatment.

Small amount of impurities present may profoundly alter the course of hardening. Metals like Cd, Sn, In and Ag present upto 0.1% can completely suppress room temperature ageing while accelerate high temperature ageing by a factor of 3 to 8. These first effect eliminates the necessity of storing the specimen, at low temperatures to minimise room temperature ageing for fabrication work, the second effect shortens the ageing time. Other beneficial effects of these impurities are that they suppress discontinuous precipitation in favour of general precipitation and thus improve their stress corrosion properties. Small quantities of metal like chromium, and manganese are added to Al-Zn-Mg alloys from this point of view. Manganese also affects recrystallization temperature of the aluminium alloys in which it is present as a small quantity. Na, S, P etc present in small quantities to Al-Si casting, alloys refines the primary and secondary silicon and thus enhance their mechanical strength. Titanium is universally used as a grain refiner. Small amount of Be addition to Al-Mg casting alloys is essential to reduce pick up of oxygen and nitrogen.

Commercial Al-Mg, alloys may contain upto 10% magnesium. The heat trreatment of these binary alloys produces no useful technological properties by structural hardening based upon precipitation or ageing. β' and β are the compounds which may form in those alloys. The small hardening observed in these alloys is due to dispersion of β' or β. Presence of Si and other metals in small quantities may affect their hardening response.

Aluminium-silicon alloys are casting alloys and are not regarded as heat treatable. It is however claimed that some hardening can be induced in these alloys if they are quenched from 530°.

Aluminium- Copper alloys are used as casting and forgings and invariably contain small quantities of other alloying elements like Mg, Si, Mn, Fe. These are hardened through structural changes of the following type.

Solid solution → G.P.[1] zones → G.P.[2] zones
$\theta' \rightarrow \theta$

Lower concentrations of copper atoms and higher ageing temperature favour suppression of zones in favour of precipitates. The alloys are heat-treated for high strength to contain GP[2] zones and θ'. High strength Al-Zn-Mg alloys are more complex and develop optimum strength on heat-treatment. The various structural changes that take place can be summarised as below:

Solid solution → clusters → G P zones →
G.P compounds (M') $\xrightarrow{160°C}$ M – ($MgZn_2$)
$\xrightarrow{200^{\circ}C}$ T – $Al_2Mg_3Zn_3$

It is evident from the forging discussions that strength of aluminium, alloys depends upon structural changes. The precipitates ultimately grow or decompose and their hardening effect is lost. Attempts have been made to introduce suitable foreign particles into the matrix of aluminium, which will have stability upto the melting point of aluminium. Effect of alumina and thoria dispensions have been studied and materials like S.A.P. have been put in the market. It is claimed that strength of aluminium containing such dispersion remain impaired above 400°C.

The as cast state obtained is generally not thermodynamically stable. The cast products are next reheated for extrusion or rolling to homogenize the structure by taking into solution the precipitated constituents. The working conditions depend on the structural state of the alloys and the working conditions. Complex alloys having large percentage of alloying elements are difficult to forge, roll and extrude because alloying elements set up high resistance to deformation as compared to alloys having smaller quantities of alloying elements.

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