Precipitation of Hardening

Mr. Akshay D. Dasarkar[1] Prof. Anup M. Gawande[2]
[1]Student [2]Professor
[1,2]Department of Mechanical Engineering
[1,2]STC SERT Khamgaon, Maharashtra, India

Abstract— The report deals with the comparative study based on the Age Hardening behaviour of Al-3.9%Cu & Al-5%Cu. All samples were solutionized, quenched in water & aged in Muffle Furnace. Hardness test is conducted on all the samples after ageing by Vicker's Hardness tester. Microstructure of the samples indicates that Cu precipitates form circular structure. Segregation of Cu rich phase (CuAl2) has been found in the vicinity of particle matrix interface. Results after aging shows that the hardness of age hardenable Al-Cu alloy depend on the rate on which alloy is cooled after solution heat treatment. The peak hardness is found to be 128.75 HV1 when the sample is solutionized at 490◦c and aged naturally at room temperature. A maximum of different heat treatment cycles are taken and different results are observed which are discussed in the further report.

Key words: Age Hardening, Precipitation of Hardening

I. Introduction

Aluminium alloys are widely used in aerospace and automobile industries due to their low density and good mechanical properties, better corrosion and wear resistance, low thermal coefficient of expansion as compared to conventional metals and alloys. The excellent mechanical properties of these materials and relatively low production cost make them a very attractive candidate for a variety of application both from scientific and technological viewpoints. Aluminium metal composites with Al_2O_3, SiC and ceramic fiber used to substitute steel. Also they exhibit excellent heat and wear resistances due to the superior hardness and heat resistance characteristics.

Cast Al-Si-Mg alloys have been widely used in automotive and aircraft industries for their good properties and high strength- to- weight ratio. It is well known that heat treatment is one of the important methods for improving mechanical properties of aluminum alloys. The heat treatment of age hardenable aluminum alloys involves solutionizing the alloys, quenching and then either aging at room temperature (natural aging) or at an elevated temperature (artificial aging). Quenching is a crucial step to suppress the precipitation to retain the supersaturation of solid solution, control the distortion and minimize the residual stress in Al alloys. Quenching media commonly used for aluminum alloy include water, brine solution and polymer solution. The basic requirement of a precipitation-hardening alloy system is that the solid solubility limit should decrease with decreasing temperature.

II. Literature review

Alfred Wilm [1] Precipitation Hardening in Al base alloys was discovered almost 70 yrs ago by Alfred Wilm in Germany he was trying to imitate the hardening of steel. Wilm formulated Duralumin, an Al-4% Cu, 0.5%Mg, 0.5%Mn alloy. Although he didn't know it, Si was present as an impurity. Wilm heated the alloy to 525˚ C. quenched it into water. The resulting metal was rather soft. The result was checked after two days and the alloy was much stronger. The experiment was continued and the complete Natural Aging curve was obtained. Wilm published the result in 1911 without explanation since he was not able to see any structural change in the Optical Microscope. In the late 1919 when Merica, Waltenberg and Scott published their paper which proved that formation of second phase particle increases the strength of precipitation hardenable alloy which is one of the most important papers in metallurgical history

Paul D. Merica [2] Precipitation hardening, also called age hardening, is a heat treatment technique used to strengthen malleable materials. It relies on changes in solid solubility with temperature to produce fine particles of an impurity phase, which impedes the movement of dislocations, or defects in acrystal's lattice. Since dislocations are often the dominant carriers of plasticity, this serves to harden the material. Unlike ordinary tempering, alloys must be kept at elevated temperature for hours to allow precipitation to take place. This time delay is called ageing. The primary species of precipitation strengthening are second phase particles. These particles impede the movement of dislocations throughout the lattice. You can determine whether or not second phase particles will precipitate into solution from the solidus line on the phase diagram for the particles. Physically, this strengthening effect can be attributed both to size and modulus effects, and to interfacial or surface energy. The presence of second phase particles often causes lattice distortions. These lattice distortions result when the precipitate particles differ in size from the host atoms. Smaller precipitate particles in a host lattice leads to a tensile stress, whereas larger precipitate particles leads to a compressive stress. Dislocation defects also create a stress field. Above the dislocation there is a compressive stress and below there is a tensile stress. Consequently, there is a negative interaction energy between a dislocation and a precipitate that each respectively cause a compressive and a tensile stress or vice versa. In other words, the dislocation will be attracted to the precipitate. In addition, there is a positive interaction energy between a dislocation and a precipitate that have the same type of stress field. This means that the dislocation will be repulsed by the precipitate.

T. W. Clyne [3] Aluminium alloys are used in advanced applications because their combination of high strength, low density, durability, machinability, availability and cost is very attractive compared to competing materials. However, the scope of these properties can be extended by using aluminium matrix composite materials.

Aluminium matrix composites can be defined as follows:

- It must be man-made.

- It must be a combination of at least two chemically distinct materials (one being aluminium) with a distinct interface separating the constituents.
- The separate materials must be combined three dimensionally.
- It should create properties which could not be obtained by any of the individual constituents. This definition differentiates aluminium matrix composites from aluminium alloys which are achieved via control of naturally occurring phase transformations during solidification or thermo mechanical processing.

P.J. Withers [4] The al-cu alloy is first solutionized by heating into a single phase region at about 490-500^{0}c. Soaking for sufficient time to permit required diffusion. Here theta phase is completely dissolve in alpha phase. Alloy is quenched in water to get supersaturated solid solution (SSS). Ageing (natural, artificial at 130^{0}c) to allow fine precipitation within the matrix that lead to local distortions and strain fields which restricts dislocation movement. These increase the strength of alloy.

WERNICK S., PINNER, R. [5**]** The appearance and the serviceability of an aluminium product depend to a great extent on surface treatments which precede the actual finish. Often problems occuring in the surface finish are related to a poor surface pretreatment. These pretreatments may be divided under three headings, according to whether they are mechanical or chemical or electrochemical in nature. The extent to which they are, respectively, used is dependent on the initial state of the surface, the method of manufacture of the article and the finish required. In this lecture an overview will be given of the various surface pretreatments.

It is not the aim to treat in detail the exact process technology to perform the treatment. The information is more concentrated around the impact of the treatment on the aluminium surface, the important parameters and the mechanism which are leading to the necessary surface alterations. Quite a number of treatments can be imposed,

No unique set of pretreatments is normally given for a required finish; often different combinations are possible to obtain a required finish.

R S KHURMI [6] Precipitation hardening stainless steels are chromium and nickel containing steels that provide an optimum combination of the properties of martensitic and austenitic grades. Like martensitic grades, they are known for their ability to gain high strength through heat treatment and they also have the corrosion resistance of austenitic stainless steel.

The high tensile strengths of precipitation hardening stainless steels come after a heat treatment process that leads to precipitation hardening of a martensitic or austenitic matrix. Hardening is achieved through the addition of one or more of the elements Copper, Aluminium, Titanium, Niobium, and Molybdenum.

The most well known precipitation hardening steel is 17-4 PH. The name comes from the additions 17% Chromium and 4% Nickel. It also contains 4% Copper and 0.3% Niobium. 17-4 PH is also known as stainless steel grade 630.

The advantage of precipitation hardening steels is that they can be supplied in a “solution treated” condition, which is readily machinable. After machining or another fabrication method, a single, low temperature heat treatment can be applied to increase the strength of the steel. This is known as ageing or age-hardening. As it is carried out at low temperature, the component undergoes no distortion.

Alfred Wilm [7] Precipitation hardening, also called age hardening, is a heat treatment technique used to increase the yield strength of malleable materials, including most structural alloys of aluminium, magnesium, nickel, titanium, and some stainless steels. In superalloys, it is known to cause yield strength anomaly providing excellent high-temperature strength. Precipitation hardening relies on changes in solid solubility with temperature to produce fine particles of an impurity phase, which impede the movement of dislocations, or defects in a crystal's lattice. Since dislocations are often the dominant carriers of plasticity, this serves to harden the material. The impurities play the same role as the particle substances in particle-reinforced composite materials. Just as the formation of ice in air can produce clouds, snow, or hail, depending, is a heat treatment technique used to increase the yield strength of malleable materials, including most structural alloys of aluminium, magnesium, nickel, titanium, and some stainless steels. In superalloys, it is known to cause yield strength anomaly providing excellent high-temperature strength. upon the thermal history of a given portion of the atmosphere, precipitation in solids can produce many different sizes of particles, which have radically different properties. Unlike ordinary tempering, alloys must be kept at elevated temperature for hours to allow precipitation to take place. This time delay is called "aging". Solution treatment and aging is sometimes abbreviated "STA" in metals specs and certs.

III. THE PROCESS OF PRECIPITATION OF HARDENING

A. Solution Treatment

It is the first step in precipitation hardening. To take advantage of precipitation hardening reaction, it is necessary first to produce a solid solution. The process by which this step is accomplished is called solution treatment or solutionizing. It aims to take into solid solution the maximum practical amount of the soluble hardening elements in the alloy. The process consists of soaking the alloy at a temperature sufficiently high and for a time longs enough to achieve a nearly homogenous solid solution.

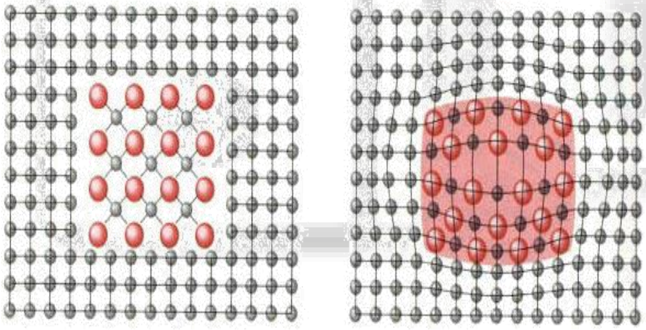
The nominal commercial solutionizing treatment is determined by the composition limits of the alloy. During solutionizing, Overheating and Underheating are to be avoided. Overheating may cause formation of Surface Blisters, Excessive grain growth and eutectic melting in some alloys. On the other hand underheating may lead to incomplete solutionizing prior to precipitation. During solution treatment can vary from less than a minute for thin sheet to as much as 20 hrs for large castings.

B. Quenching

Quenching is the most critical step in sequence of heat treating operation. The objective of quenching is to preserve the solid solution formed at the solutionizing temperature by rapidly cooling to some lower temperature usually near room temperature. This statement applies not only to retain solute atoms in solution but also to maintaining a certain minimum number of vacant lattice sites to assist in promoting the low temperature diffusion required for zone formation. The solute atoms that precipitate either on grain boundaries, dispersolids or other particles as well as the vacancies that migrate with extreme rigidity to disordered regions, are irretrievably lost for practical purposes or fail to contribute to the subsequent strengthing. Cold water immersion quenching is most common because it produces the most effective quench. It presents problems involving residual stress and warpage.

C. Coherent Lattice Theory

There are several theories of precipitation hardening amongst them; the most useful is the Coherent Lattice Theory. After solution treatment and Quenching the alloy is in a supersaturated condition with the solute atom distributed at random in the lattice structure during an incubation period, the excess solute atoms tend to migrate to certain crystallographic planes, forming clusters of the precipitates. During aging, these clusters form an intermediate crystal structure or transitional lattice, maintaining coherency with the lattice structure of the matrix. The excess phase will have different lattice parameters different from those of the solvent, and as a result of coherency there will be considerable distortion of the matrix. The distortion of the matrix extends over a large volume then would be the case if the excess phase were a discrete particle. It is the distortion that interphases with the movement of dislocation and accounts for the rapid increase in hardness and strength during aging.



(a) (b)

Fig. 2: Coherent Lattice Theory

D. Aging

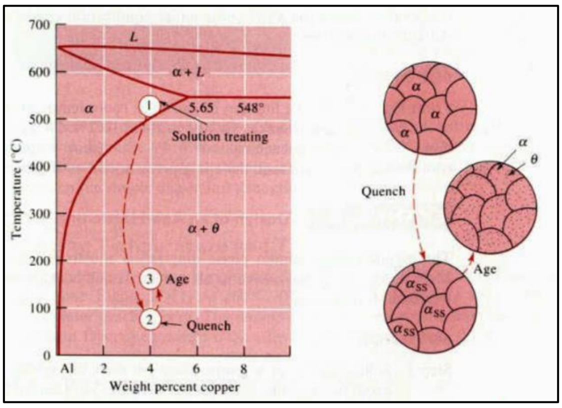


Fig. 2: The aluminum rich end of the Al-Cu phase diagram showing the three steps in the age-hardening heat treatment and the microstructures that are produced.

Aging is the third step where the supersaturated α, αSS, is heated below the solvus temperature to produce a finely dispersed precipitate. Atoms diffuse only short distances at this aging temperature. Because the supersaturated α is not stable, the extra copper atoms diffuse to numerous nucleation sites and precipitates grow. The formation of a finely dispersed precipitate in the alloy is the objective of the precipitation-hardening process. The fine precipitates in the alloy impede dislocation movement by forcing the dislocations to either cut through the precipitated particles or go around them. By restricting dislocation movement during deformation, the alloy is strengthened.

E. Flow Chart of Precipitation Hardening

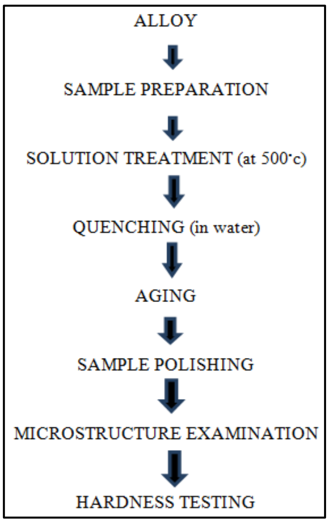


Fig. 3: Flowchart of Precipitation Hardening

F. Precipitation Hardening Applications

- For metal parts and components which call for an increased yield strength
- Aluminum, magnesium, nickel, titanium and stainless steel parts
- Gate valves
- Engine parts
- Processing equipment
- Shafts, gears, plungers
- Valve stems
- Balls and bushings
- Turbine blades
- Molding dies
- Nuclear waste casks
- Fasteners
- Aircraft parts

REFERENCES

[1] ASM Handbook - Heat Treatment", Volume - 4.

[2] T.V.Rajan,C.P.Sharma, Ashok Sharma, "Heat treatment principle & Techniques " PHI learning private limited, Second Edition, Page No -282 to 296, January 2012,(ISBN No- 987- 81 – 203 – 4095 - 4)

[3] Sidney H.Avner, "Introduction to Physical Metallurgy", Tata McGraw – Hill publication, Second edition , Page No. 31 & 190–194 , 2010, (ISBN No – 13: 978-0-7 - 463006-8)

[4] V.D.Kodgire & S.V.Kodgire, "Material Science & Metallurgy", Everest Publication House, 38th Edition, Page No-511 to 526, 2012. (ISBN No – 81 -86314- 00-8)