HEAT TREATMENT OF CERAMIC REINFORCED ALUMINUM MATRIX COMPOSITES-A REVIEW

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ABSTRACT

In recent years the use of Ceramic Reinforced Aluminum matrix composite material has increased very rapidly due to their high weight to strength ratio, low density, low thermal expansion coefficient, low maintenance and high temperature resistance. Metal Matrix Composites are widely used in aerospace and automotive engine components. The aluminum alloys are reinforced with ceramics like Alumina, Boron Carbide and Titanium Carbideetc and fabricated by stir casting,spray deposition, powder metallurgyprocedures etc. Heat treatment significantly affects the microstructure and enhances mechanical properties of these composites.In this paper the various research studies on heat treatment of aluminum matrix composites is reviewed with major focus on the heat treatment procedures, parameters ,microstructure and mechanical properties. The scope for further research in this area is also discussed.

Keywords:Aluminum Matrix Composites,Heat Treatment, T4, T6, Solution heat treatment,Quenching, Age hardening, Microstructure, MechanicalProperties.

1. INTRODUCTION

The recent worldwide interest shown in metal matrix composite (MMC) materials has been fuelled by the fact that mechanical and physical properties of light alloys can be enhanced by incorporating reinforcing fibers, usually ceramic.The major reinforcements used in Aluminum based MMC's are Boron, Graphite, Silicon Carbide and Alumina .Aluminum alloys such as 6061 Al reinforced with ceramic particles have found wide range of applications in automotive parts such as pushrods, cylinder, piston and brake disc etc,sports, aerospace, marine and in many other fields owing totheir low coefficient of thermal expansion, low density, highthermal conductivity, high wear resistance, better corrosionresistance and high strength to weight ratio. The strength of the composite can be further improved by thermal treatments[2]. . Heat treatment is an operation in the fabrication of an engineering materials system. The main objective of heat treatment is to make the material system structurally and physically fit for engineering application[1] These thermal treatments are similar to those ordinarily used for hardening aluminum alloys .Widely used treatments like T4 and T6 treatments involve solution heattreatment ,quenching and subsequent natural and artificial aging respectively and is the common method to increase the strength of the composite[2],The type of reinforcement and synergic effect of heat treatment plays a prevailing (dominant) role command in the final mechanical properties of MMC, still limited information is available, pertaining to the heat treatment of Al based composites.[1].

2. MATERIALS

2.1. Matrix:

The aluminum alloy families are represented by 1XXX, 2XXX, 3XXX etc. The commercially available heat treatable aluminum alloys are the 2xxx, 6xxx and 7xxx series wrought alloys except 7072. The use of heat treatment frequently is restricted to the specific operations employedto increase strength and hardness of the precipitation-hardenablewrought and cast alloys. These usually are referred to asthe "heat-treatable" alloys to distinguish them from those alloys in which no significant strengthening can be achieved byheating and cooling. The latter, generally referred to as "non-heat-treatable" alloys,depends primarily on cold work toincrease strength. The 1XXX, 3XXX and 5XXX series arenon heat treatable.

Commercial alloys whose strengthand hardness can be significantly increased by heat treatment include 2XXX, 6XXX, and 7XXXseries wrought alloys (except7072) and 2*xx*.0, 3*xx*.0, and 7*xx*.0 series casting alloys. Some of these contain only copper, or copper and silicon, as theprimary strengthening alloy addition(s). Most of the heat-treatable alloys,however, contain combinations of magnesiumwith one or more of the elements such as copper, silicon, and zinc. Characteristically, even small amounts of magnesium inconcert with these elements accelerate and accentuate precipitation hardening, while alloys in the 6*xxx* series containsilicon and magnesium approximately in the proportions required for formulation of magnesium silicide (Mg_2Si).Although not as strong as most 2*xxx* and 7XXXalloys, 6XXXseries alloys have good formability, weldability, machinability,and corrosion resistance, with medium strength [3].

2.2REINFORCEMENT:

Ceramic materials like Silicon Carbide,Alumina,Boron Carbide,TitaniumDioxide etcimprove the properties of the composites. The reinforcement provides highstiffness, specific strength, abrasion resistance, creep resistance, thermal conductivity and dimensional stability.These materials may be utilized at higher service temperatures than theirbase metal counterparts[4].

3.FABRICATION

On the basis of the reinforcement the fabrication techniquescan vary considerably. Some of the techniques for thedevelopment of the composites are stir casting method,powder metallurgy, plasma spraying and squeeze casting etc. The simplest and most commercially used techniques known as stir casting method. This is also called as the vortex technique. In this technique the pre-treated ceramic particles are introduced into the vortex of molten alloy created by the rotating impeller. Ceramic particles and ingot grade aluminum are mixed and melted. The melt is stirred slightly above the melting point temperature. Stir casting offers better matrix-particle bonding due to stirring action of particles into the melts. Homogeneous mixing and good wetting can be obtained by selecting appropriate processing parameters like stirring speed, time, and temperature of molten metal, preheating temperature of mould and also uniform feed rate of particles.The fabrication technique of powder metallurgy is followed to a lesser extent than stir casting.

4. HEAT TREATMENT

Out of the various heat treatment tempers available the T4 and T6 tempers are the most commonly used. Heat treatment to increase strength of aluminum alloys is a three-step process:

- **Solution heat treatment**: dissolution of soluble phases
- **Quenching:** development of super saturation
- **Age hardening**: precipitation of solute atoms either at room temperature (natural aging i.e. T4) or elevated temperature (artificial aging or precipitation heat treatment i.e. T6) [3].

Solution heat treatment of aluminum alloys allows the maximum concentration of hardening solute to dissolve into solution. This process is carefully carried out by heat treatment of an alloy to a temperature at which one single, solid phase exists. By this heat treatment, the solute atoms that were originally part of a two phase solid solution dissolve into solution and originates (create) as one single phase. Once the alloy has been heated to the recommended solutionizingtemperature (over heating should be avoided to prevent eutectic melting), it is quenched at a rapid rate such that the solute atoms don't have enough time to precipitate out of the solution. As a result of the quench, a super saturated solution now exists between solute and aluminum matrix [1].

Quenching is the process of rapid cooling of material systems to room temperature to preserve the solute in solution. The cooling rate needs to be fast enough to prevent solid-state diffusion and precipitation of the phase. The rapid quenching creates a saturated solution and allows for increased hardness and mechanical properties of the material system [1].

After solution treatment and quenching, hardening is achieved either at room temperature (natural aging) or with aprecipitation heat treatment (artificial aging). In some alloys, sufficient precipitation occurs in a few days at roomtemperature to yield stable products with properties that are adequate for many applications. These alloys sometimes areprecipitation heat treated to provide increased strength and hardness in wrought or cast products. Other alloys with slowprecipitation reactions at room temperature are always precipitation heat treated before being used [3].

The aging sequence for 6061 Al alloy and its composite are asfollows: Super-saturated solid solution -> clusters of soluteatoms and vacancies (Primitive Guinier-Preston [GP] zones)->needle shaped GP zones -> rod shaped, metastable, semicoherentβ' phase -> stable, incoherent, Mg2Si precipitate (βphase) [3].

D.Ramesh et.al (2012) heat treated Al 6061 reinforcedwith Fritparticulates (0-10 wt %) fabricated by stir casting route to the T6 condition which involved solutionizing at 530 ^{0} c for 2 hours, quenching in different media i.e. Air,Water,ice. The quenched specimens were subjected to artificial age hardening at 175^{0} C for different time durations of 2 to 10 hours. Microstructure,density and hardness tests were conducted both on Al6061 matrix alloy and Al6061-Frit particulate composite before and after heat treatment [1].

N.R. PrabhuSwamy et. al(2010) solution heat treated Al 6061/SiC composites (4 to 10 wt %) at 530^{0} c for 1 hour in a muffle furnace and then quenched them to room temperature in air,water and ice media,and finally ageing was carried out at 175 ^{o}C for 4,6 and 8 hours. The effect of heat treatment on microstructure and strength, abrasive behavior was studied [5]. Chacko and Nayak(2014)studied the aging behavior of Al 6061-15% vol. SiC composites in T4 and T6 condition by solutionizing at 530^{o} c for 30 minutes ,quenching in water and ageing at 140,160,180 and 200^{o}c for T6 and room temperature for T4 for various durations of time (1-5 hrs) and conducted Rockwell hardness tests on all specimens.[2].

L.H. Manjunath et.al(2012) heat treated Al 6061-MWCNT composites in three stages, i.e. solutionization at 555^{o} c for 8 hours ,quenching in air, boiled water and ice and finally artificially ageing at a temperature of 175^{o}c for 4,6,8 and 10 hours in order to get better properties for 0-3 wt % of MWCNT. Wear, hardness and compressive tests were conducted[6].Reddappa et al(2011) subjected 10 wt % Beryl reinforced –Al 6061 composites to solution heat treatment of 530^{0} c for 18 hours followed by quenching in ice, and studied the effect of cold quenching on the wear rate.[7].

Sridhar Bhatt et. al. (2014) performed T6 heat treatment on Al-Fly Ash-SiC hybrid composites in which the solution heat treatment was done at 530^{0}c for 2 hours, followed by ice quenching, and ageing at 175^{o}c for 2-10 hours. Microstucture and mechanical properties on as cast and heat treated specimens were studied [8].Gopi K.R. et.al (2013) conducted solution heat treatment of Al 6061-Zircon Sand-Graphite particulate composite samples in the furnace for 530^{0} c for 3 hours, followed by quenching in water and then age hardening at 180^{o} c for 5 hours and finally air cooled to room temperature .Characterization of as cast and heat treated specimens was done [9].

Gupta et.al. (1998) heat treated Al 6061-12 wt % SiC composites to T6 condition which involved solution heat treatment of 530^{o}c for 1hour, quenching in water and then age hardening at 177^{0}c for 2-14 hour durations .Mechanical properties were studied [10]. Jeevan et.al (2012) produced

Al 6082-5 Wt % Sic by powder metallurgy route and further subjected it to T6 heat treatment condition that involved solutionizing at 529^{o}c for 2 hours quenching in water and age hardening at 179^{o}c for 18 hours [11].

VeerabhadrappaAlgur et.al(2015) performed T6 heat treatment of Al_2O_3(0-9 Wt %)reinforced Al 6061 composite specimens, in which solution heat treatment was done at 530^{o}c for 2 hours ,followed by water quenching ,and ageing treatment was done at 199^{o}c for 6 hours. Microstructure and Mechanical properties were studied [12].

MukeshSahu et.al studied the effect of hot forging and heat treatment on wear properties of Al 6061-Al_2O_3nano composites by hot forging at 500 ^{o} C followed by solutionizing at 530 ^{0}c for 2 hours ,quenching in water media and artificial ageing at 175^{o}c for 2 to 8 hours in steps of 2 h.[13].AnupHanji et.al(2015) studied corrosion behavior of heat treated Al 2219 reinforced with Boron Carbide and Graphite(8% & 3% wt resp.) in T6 condition by solution heat treatment of 530^{o}c for 2 hr, quenching in ice ,followed by ageing treatment at 165 ^{o}C for 18 hrs.[14].

Alaneme (2013) fabricated Al 6063-Alumina composites by stir casting method followed by cold rolling. Further solution heat treatment at 550^{0}c for 1 hr followed by water quenching was carried out. Tensile, hardness and fracture toughness were studied [15].

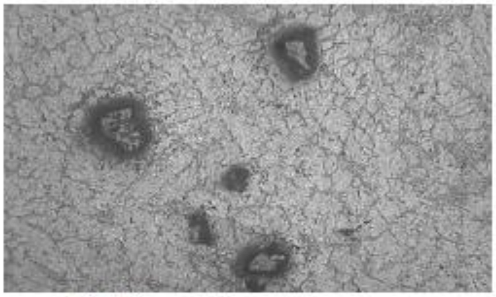
Kini et.al (2015) investigated the mechanical behavior of Al 2024-Fly ash composites in Pre and Post heat treated condition by solution heat treating at 550 ^{o}C for 1 hour, quenching in water and ageing treatment at 150^{o}c for 1-3 hrs in muffle furnace [16].

5. MICROSTRUCTURE

In the extensive literature studies conducted, microstructural studies revealed that there was uniform distribution of reinforcement particles in matrix in both as cast and heat treated compositesand showedexcellent bond between matrix and the reinforcement. It is observed that a refinement of grain size is seen at higher percentage of reinforcement. Heat treatment leads to further refinement of grain .Examinations of these materials in the heat treated state indicate to the reduction of the presence and size of the intermetallic precipitations. Due to the heat treatment performed the precipitations get dissolved in the solid solution in the quenching process.It is observed that fine inter-metallic of Mg_2Si are formed within the matrix alloy on heat treatment in case of Al 6xxx series after the ageing hardening process. Ageing duration and temperature dodictate the extent of formation of this intermetallic.

The fig 1.1 and 1.2 below illustrates the effect of heat treatment on the microstructure Al based metal matrix composites

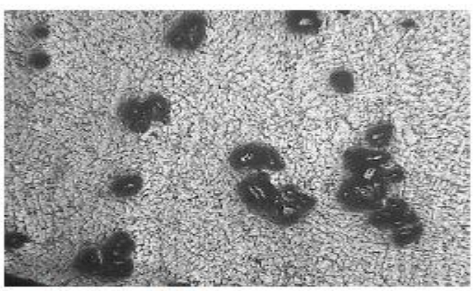
(IJAER) 2016, Vol. No. 11, Issue No. I, January **e-ISSN: 2231-5152/ p-ISSN: 2454-1796**



Before Heat treatment

After Heat treatment

Fig1.1: Microscopic View of 2% SiC-2%FA hybrid MMCs (Sridhar Bhat et.al 2014)



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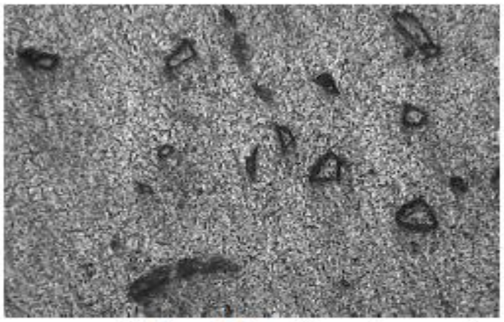

After Heat treatment

Fig 1.2: Microscopic View of 6% SiC-2%FA hybrid MMCs (Sridhar Bhat et.al 2014)

6. MECHANICAL PROPERTIES

6.1: HARDNESS:

In the extensive literature survey conducted it was found that hardness increased with increased reinforcement %.Under identical heat treatment conditions composite exhibited significant improvement in hardness compared to Al alloy.Ice quenching displayed maximum improvement in hardness followed by water at room temp. And finally air.

D.Ramesh et.al (2012) observed that on air quenching and ageing for 8 h, the matrix alloy displayed a maximum improvement in hardness around 33%, while Al6061-10 wt % frit composites displayed a maximum improvement in hardness around 11% over the as –cast specimen.On water quenching and ageing for 6 h, the matrix alloy displayed a maximum improvement in hardness around 52%, while Al6061-10 wt% frit composites displayed a maximum improvement in hardness around 33%. Ice quenching and ageing for 6 h, the matrix alloy displayed a maximum improvement in hardness around 58%.[1].N.R. PrabhuSwamy et.al(2010) observed that maximum hardness achieved i.e. peak ageing occurred at ageing duration of 6hrs for ice and water,8 hrs for air quenching.Ice quenching gave a 67% improvement in hardness [5]

This marked improvement in strength of both Al6061alloy and its composites on heat treatment can beattributed to larger extent of formation of fineintermetallicprecipitates which act as the points of obstacles for pinningdown the dislocations. This phenomenon of multiplicationof dislocations curtails the mobility of dislocations, thereby reducing the extent of plastic deformation [5].

Chacko and Nayak (2014) based on the hardness profile of the aged specimens categorized theminto three groups namely a) under aged b) peakaged and c) over aged. The variation in hardness is associatedwith the microstructural evolution. The formation of Mg andSi clusters takes place initially. These contribute marginally tothe increase in hardness. Peak-aging is associated with a densepopulation of β needle-shaped precipitates. Only a part ofthese precipitates remain in themicrostructure during overagingas the metastable phases like 'β' form which results in thelowering of hardness values , In T6treatments, the temperature for under-aging, peak-aging andover-aging was determined using aging curves. The compositewas under-aged at 140°C and 160°C, Peak-aged at 180°C andover-aged at 200°C.Fig 2. Below shows the ageing curves plotted with varying ageing temperatures [5].They also noted that the effects of reinforcing material on the age-hardeningbehaviour have not been reported consistently. But it wasfound that the age-hardening is accelerated since the times toreach the peak hardness were considerably shortened by thepresence of reinforcement inSiCp/ 6061 Al alloy composites [5]

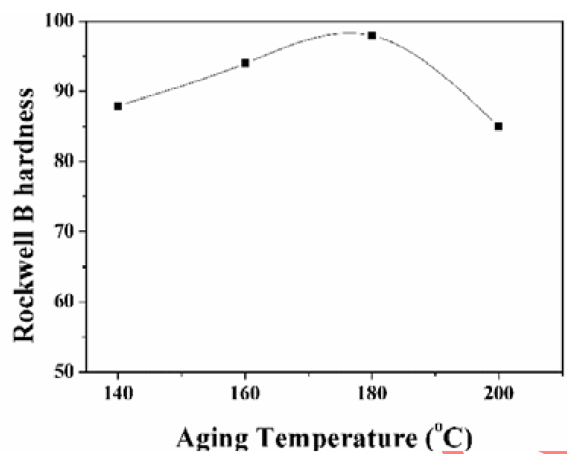

FIG 2:Peak hardness variation with aging temperature in T6treatment (Chacko and Nayak 2014)

6.2: TENSILE STRENGTH:

In the extensive literature survey conducted tensile strength increased with increased reinforcement %.Under identical heat treatment conditions composite exhibited significant improvement in tensile strength compared to Al alloy.Ice quenching displayed maximum improvement in UTS followed by water at room temperature and finally air, but the% increase in UTS was higher compared to the hardness values.

D.Ramesh et.al (2010)reported a 79% increase in UTS values forAl6061–10 wt% SiC on heat treatment wherein the quenching media was ice [5].Thismarked improvement in tensile strength of both Al6061alloy and its composites studied on heat treatment can beattributed to larger extent of formation of fine intermetallicprecipitates after age hardening [5].

Fig 3 illustrates variation of UTS in different heat treatment conditions.

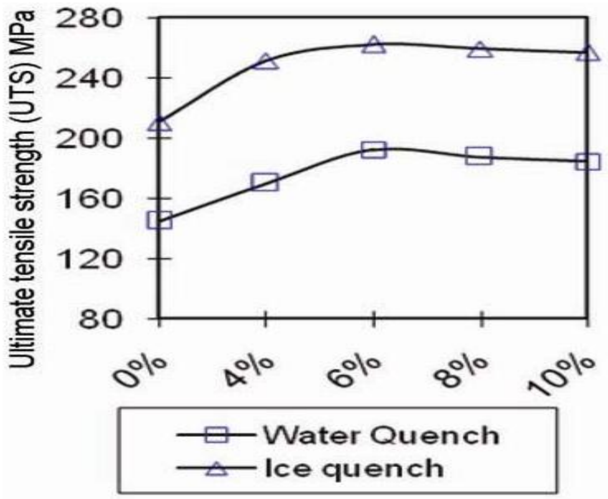

FIG3: Variation of UTS with increased content of SiCpinAl6061 alloy under different heat treatment conditions. (D.Rameshet.al (2010))

6.3: <u>ABRASIVE WEAR</u>:

Increased content of reinforcement in thematrix alloy enhances the abrasive wear resistance of composites which can be attributed to the fact that reinforcementitself being hard can combat the abrasion, thereby resulting in lower material removal. Higher the hardness of composites better will be its abrasion resistance.Under identical heat treatment conditions, composites possess betterabrasive wear resistance when compared with matrix alloy. The heat treatment of matrix alloy and its compositeshas a significant effect on the abrasive wear behavior of matrix alloy and its composites as shown in figure 4. For a given load and grades of abrasive wheel used, ice as quenching media has resulted in the least abrasive wear loss when compared to non heat treated matrix alloy and its composites.

(IJAER) 2016, Vol. No. 11, Issue No. I, January **e-ISSN: 2231-5152/ p-ISSN: 2454-1796**

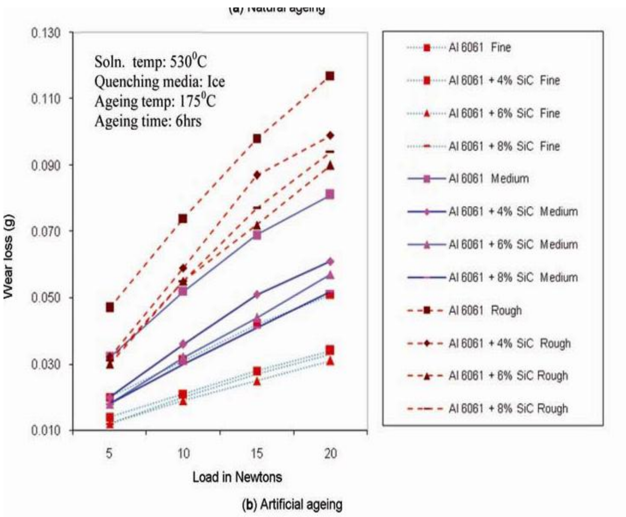

Fig4:**Effect of different ageing conditions on abrasive wear loss of matrix alloy and its composites for different grades of abrasive wheels. (D.Rameshet.al (2010))**

6.4: <u>CORROSION BEHAVIOR</u>:

Through the limited work carried out it was found that corrosion resistance of heat treated composite is much more than the un-heat treated composite. This is due to the internal stress relieving and gaining solid solution form of alloy during heat treatment.There is no noticeable pit formation in heat treated composite .This is due to release of internal stresses which is cause for stress corrosion cracking.[14]The table below illustrates the corrosion rate difference in heat treated and un heat treated composite.

Table 2: E_{corr}, E_{pit}, I_{corr} and CR values of composites in NaCl solution.

Composition	Ecorr (mV)	Epit (mV)	Icorr (mA/cm2)	CR(mmpy)
T0 Al	-848.29	-833.33	0.1749	1.8931
T0 Al+8wt%B4C	-869.43	-855.55	0.2206	2.6037
T0 Al+8wt%B4C+3wt%Gr	-877.75	-838.64	0.2468	3.0184
T6 Al	-672.55	-	0.0794	0.8358
T6 Al+8wt%B4C	-857.68	-835.53	0.2715	2.1153
T6 Al+8wt%B4C+3wt%Gr	-869.72	-849.96	0.3127	2.3821

Fig 5: Corrossion heat treated and un-heat treated composite (AnupHanji et.al 2015)

7. DISCUSSION

After extensive literature study,it was observed that researchers adopt either powder metallurgy or metal stir casting technique, mostly the later one for fabrication which may be due to the economic viability of the method.T6 temper is mostly followed for the heat treatment of aluminum based metal matrix composite.Any of the 2xxx,6xxx or 7xxx series aluminum alloy can be heat treated ,but the Al 6061 is the matrix commonly used in majority of the studies possibly due to itsextensive applications in aerospace and automobile industry.

Silicon Carbide has been most widely used as reinforcement in majority of the studies done on heat treatment of metal matrix composites, followed by Alumina.Chacko and Nayak(2014)have stated that the effects of reinforcing material on the age-hardening behaviour have not been reported consistently[5].Hence there is scope for further research in this area.To fully understand the effect of reinforcement on age hardening behavior heat treatment studies have to be conducted using different reinforcements like Beryl, Titanium Carbide ,Zirconium,Boron Carbide etc.Since the majority of studies have mostly concentrated on SiC as reinforcement researchers are not able to know the exact effect of different reinforcements on the age hardening behavior of metal matrix composites.

The most commonly used quenching media in the studies are air, water and ice.Water quenching has high cooling rate and produces good hardenability. But the disadvantage of water quenching is that it can generate higher residual stresses in the material which inturn will lead to distortion and cracking. Also, the prolonged duration of vapour blanket stage during quenching is also a major issue concerned with water quenchant. Aqueous solution of polymers such as PAG (Poly Alkylene glycol), PEG (Poly Ethylene glycol) etc. are commonly considered alternatives. Thegenerations of thermal residual stresses are minimized when the polymer quenchants are used. Oil is suitable quenching medium for crack sensitive parts.Brine solution can also be used .Thesequenchants are regularly used in heat treatment of Aluminum Alloys[5].But use of these quenchantsin heat treating mmc's has not been reported in the literature which has been surveyed. Quenching is the most critical step in the sequence of heat treating operations. Hence it is importantto understand the effect of quenching on the mechanical properties of metal matrix composites. Over the above mentionedquenchantsnon biodegradable oils like castor oil ,palm oil ,groundnut oil can also be tried as quenchants .The extent of effect of different quenching media in heat treating of mmc's is yet to be explored.

Excluding a few researchers like Chacko and Nayak(2014) and D.Rameshet.al (2010) who studied the ageing behavior of Aluminum based metal matrix composites very few researchers in the literature surveyed have done in depth studies on the effect of ageing temperature on the mechanical properties of metal matrix composites but have focused on ageing duration only.Chacko and Nayak(2014) categorizedthe aged specimens into three groups namely a) under aged b) peakaged and c) over aged.The study of the properties obtained at different temperatures is critical to identify under aged, peak ageing and over ageing points,since over ageing leads to decrease in the mechanical properties. Meager information regarding this aspect with respect to mmc's is available and hence there is much scope for further work in this area.

The effect of various solution heat treatment temperatures and time on the microstructure and mechanical properties of mmc's has also not been explored much.

CONCLUSION

An attempt has been done to outline various heat treatment proceduresused for aluminum based metal matrix composites with emphasis on the T6 tempers.Various steps in this method have been described briefly and emphasis has been given to key points like solution heat treatment temperature andtime,quenching media,ageing temperature and duration.The effect of heat treatment on the microstructure and mechanical properties has also been covered. The scope for further work in this area has been discussed.

REFERENCES

1.)D.Ramesh,R.P. Swamy and T.K. Chandrashekar, "Role of heat treatment on Al6061-Frit Particulate composites",Journal of Minerals & Materials Characterization & Engineering, Vol .11,No.4,2012,pp.353-363.

2.)Melby Chacko and JagannathNayak, "Aging Behaviour of 6061 Al-15 Vol% SiC composite in T4 and T6 Treatments" ,World Academy of Science, Engineering and Technology International Journal ofChemical,Nuclear,Materials and Metallurgical Engineering Vol.8,No.3,2014,pp.214-217

3.) ASM Handbook, Heat Treating, Vol. 4, ASM Publication, Materials Park, Ohio, 2001.

4.) WilliamCallister,Material Science & Engineering, 7thedition, John Wiley & Co., 2007.

5.)N.R. PrabhuSwamy,C.S. Ramesh and T.Chandrashekar,"Effect of heat treatment on strength and abrasive wear behavior of Al6061-SiC Composites", Bull Mater.Sci.,Vol 33,No.1,February 2010,pp.49-54.

6.) L.H. Manjunath ,Dr.P.Dinesh and S.B. Halesh,"Influence of Heat treatment on Strength and Abrasive Wear Behaviour Of Al 6061-MWCNT Metal Matrix Composites",International Conference on Challenges in Mechanical, Industrial and Management studies,2012.

7.)H.N. Redappa,K.R. Suresh,H.B. Niranjan and K.G. Satyanarayana,"Effect of Cold Quenching on Wear rate of Al 6061-Beryl Composites",International Journal of Engineering Science and Technology,Vol. 3,October 2011

8.)Sridhar Bhat,B.S. Mahesh,"Effect of Heat Treatment on Microstructure and Mechanical Properties of Al-FA-SiC Hybrid MMCS",International Journal Of Innovative Research in Science ,Engineering and Technology,Vol. 3,issue 6,June 2014.

9.)Gopi K.R. ,Mohandas K.N. ,Reddappa H.N.,M.R. Ramesh ,"Characterization of As cast and Heat treated Aluminum 6061/Zircon Sand/Graphite Particulate Hybrid Composites" ,International Journal of Engineering and Advanced Technology ,Vol 2, issue 5,June 2013.

10.)M.Gupta,M.K. Surappa,S.Qin,L.M. Tham,"Regarding the effect of aging heat treatment on the failure behavior of SiC reinforced Al based Composite",Indian Journal of Engineering & Materials sciences ,Vol. 5,February 1998,pp.1-8

11.)Jeevan V.,C.S.P. Rao and N.Selvaraj ,"Compaction ,Sintering and Mechanical Properties of Al-SiCcomposites",International Journal of Mechanical Engineering and Technology(IJMET),Vol 3,issue 3,pp.565-573,September 2012.

12.) VeerabhadrappaAlgur, Balaraj , Kori Nagaraj " Effect of T6 type heat treatment on the Mechanical characterization of Al6061-Al2O3 particulate composites" International Journal of Emerging Trends in Engineering and Development Issue 5, Vol. 3 (April.-May. 2015)

13.)MukeshSahu, Mahesh KumarDargar, Dr. V.N. Bartaria,"The effect of hot forging and heat treatment on tribological properties of Al6061-Al_2o3 nanocomposites", International Journal of Science ,Engineering and Technology,pp.669-674,

14.)AnupHanji, Siddeshkumar N , Ravindranath V and G.S. Shivashankar, "Study on Corrosion behaviour of Heat Treated Hybrid Metal Matrix Composites Reinforced with B4C and Graphite Particles", Journal of Material Science and Mechanical Engineering (JMSME) Volume 2, Number 9; April-June, 2015 pp. 41-46

15.) KennethKanayoAlaneme," Mechanical Behaviour of Cold Deformed and Solution Heat-treated Alumina Reinforced AA 6063 Metal Matrix Composites". The West Indian Journal of Engineering Vol.35, No.2, January 2013,pp.31-35

16.)Chandrakant R Kini, Shivaprakash Y.M, Gowrishankar M.C, S.S Sharma, K.V.Sreenivasa Prasad," Investigation on the behaviour of alfa composite in pre and post heat treated conditions**",**IJRET: International Journal of Research in Engineering and Technology,Vol. 4,Issue 2,Feb 2015,pp 28-38