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Microstructures and Mechanical properties of Spray deposited and Heat-treated Al-25Mg_2 Si-2Cu alloy

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Abstract

The microstructural characteristics and mechanical properties of Al–25Mg_2Si-2Cu alloy were investigated. The alloy produced by spray atomization and deposition techniques followed by hot compression(HC) and age hardening(AGH) at 180°C for 2h and 2h intervals after the solution heat treatment. The microstructure features of as cast, spray deposited (SD),hot compressed and heat-treated alloys were studied. the results show the microstructure of spray-deposited alloy mainly comprised of a uniform distribution of intermettalics β-Mg_2Si phase, θ- Al_2Cu and Q phase in Al-matrix. Eliminating the porosity of deposit and fragmentation of the θ And Q phases is the main features during hot compression. After solution treating and age hardening, the microstructure found to be comprised of mainly Mg_2Si phase in a fine spherical form. Large quantity of θ- Al_2Cu phase and Q Phase less than 50 nm in size uniformly distributed in the Al- matrix during aging. These fine β particles combined with the θ can significantly increase the tensile strength and hardness of the alloy. In the peak-aged condition is because of high concentration of Mg_2Si and Al_2Cu metastable phases. The microstructural features of alloys been investigated through Optical (OM) and Scanning electron microscopy (SEM) and analyses of phases were carried out using Energy dispersive X-ray(EDS).The improvement in the tensile and hardness properties of studied alloys was investigated by tensile test and micro- hardness.

Keywords: Al-Mg_2Si alloy, Spray deposition, Age hardening, Microstructure, Mechanical properties,

Micro hardness

1. Introduction

In recent years, the stringent needs of automotive and aerospace industries have prompted the design of newer lightweight (high strength to weight ratio) materials (T.Takami,2000. A. Jambor, 1997). The hypereutectic Al–Si alloy having excellent high temperature strength, low density, excellent wear and corrosion resistance. Therefore, suitable for automobile engine cylinders, cylinder heads pistons and cylinder liners (J..LJorstad, 1971. A..Pohl, 2006 J.EFoss,2006). The properties of Hypereutectic Al–Si alloys can improve by alloying with

Cu, Mg, Fe, Ni, and Mn (T.H.Lee,1997. F. Wang ,2004). Aluminum - Silicon alloy with high content of Mg forms an intermetallic compound Mg_2Si which shows a high melting temperature of 1085℃, low-density of $1.99x10^3$ kg m^{-3} high hardness of 4500 MNm^{-2}, low coefficient of thermal expansion (CTE) of $7.5x10^{-6}K^{-1}$ and a reasonably high elastic modulus of 120 GPa (L Lu& M.O.Lai ,1998 G. Frommeyer,1994).Adding Cu and Mg in hypereutectic Al-Si alloy forms precipitation hardening phases such as Al_2Cu, Mg_2Si and Al_2CuMg. The precipitation hardening at high ratios of copper to magnesium is achieved in the sequence GP zones through a coherent phase (θ') to Al_2Cu (θ). Precipitation hardening at lower ratios of copper to magnesium achieved in the sequence GP zones through a coherent phase to Al_2MgCu. These intermetallic precipitates are coherent with main structure and affects the mechanical and physical properties of the material (M.M.Sharma & MF Amateau,2005.J.L.Cavazos&R.Cola,2001,C.Meriç&R.Varol,1993. E.Atik & C.Meriç1996. N. Tenekedjiev,1990) However, conventional techniques of processing of these materials lead to coarse and segregated microstructure with long plates of intermetallic transition metal compounds that gives rise to inferior mechanical properties (Grant P.S .1995)]. Spray deposition comprised of molten metal atomized by N_2 gas, and its deposition on a copper substrate forms a rapidly solidified dense billet. The alloys produced by this show refined and equiaxed grain microstructure, sharply decreased segregation and increased metastable solid solubility (C.Cui& A.Schulz,2009). However, there always exists some porosity in the spray deposited alloys. Forming porosity may be because of the dissolved gas in the molten metal, during solidification of molten aluminum, and dissolved hydrogen over the low solid solubility may precipitate in the form of gas pores (GUO Shu, &NING Zhl -lliang ,2009) The number, size, distribution and morphology of porosity in spray-deposited material depend to a larger extent on the processing conditions. However, some amount of plastic deformation needs for complete densification of material. In the present study, Al-25Mg_2Si alloy with copper 2% (mass fraction) synthesized using the SDP, followed by hot compression and heat treatment to get end-product performance. The main work done on characterization of microstructural evolution and mechanical properties in the spray deposited as well as heat-treated conditions.

2. Experimental details

The nominal composition of alloy was Al-1.86Si-13Mg-1.98Cu-0.5Fe-0.5Ni (wt%). The summary of the spray deposition process parameters used in the present study represented in Table:1.The alloy was melted and superheated to 100℃. The molten material disintegrated into a dispersion of micron sized droplets by free fall nozzle using nitrogen at a pressure of 4 MPa. Subsequently, the atomized droplets deposited onto a water-cooled copper substrate collected as a coherent, dense preform. The preform ofter being cut into billet was hot compressed (HC) at 460˚C after soaking for 1h. In this study heat treatment for the sprayed and hot compressed alloy applied, which involved solution treating at 530 ˚C for 1h followed by water quenching, and artificial aging at 180 ˚C for 1h.and 2h age time. To reveal the microstructures of as-cast, spray deposited as well as heat treated samples were polished and etched by kellers reagent and then analysed by optical microscopy (OM) and S-3400N Hitachi make Scanning Electron Microscope (SEM) attached with energy dispersive X-ray spectroscopy (EDS) employed to analyze the intermetallic compounds and precipitates. The tensile tests carried out in Universal Testing Machine (make and model: UNITEK-9550) at a cross head of 5 mm/min, and hardness using Micro-hardness tester (Mitutoyo ATK-600) at a load of 300gm.

3. Results and Discussion

Optical microstructure of as-casting Al-25Mg_2Si-2Cu alloy shown in Figure:1. The primary α-Al dendrites; intermetallic β phase is of much larger interconnected dendrite and Mg_2Si particles become large agglomerations. The coarse acicular, plate-like morphologies of θ-Al_2Cu phase and Q phase formed under a low solidification rate resulting from the eutectic reaction. The SEM image of as-cast alloy (Figure: 2) shows the existence of β-$Mg_{57}Si_{27}$ (point. 2) appeared in polyhedral shaped sharp edge particles with unevenly distributed in α-Al matrix, the θ-Al_2Cu phase identified using EDS as the whitest coarse intermetallic phase appear in Chinese script, star like and other compact shapes. The light grey intermetallic Q-$Al_2Cu_2Mg_8Si_7$ (Point. 3) phase with an intertwined structure shown in the Table: 2. The SEM micrograph and EDS of different phases of SD alloy shown in Figure :3 and table:3. The microstructure is comprise mainly θ-$Al_{65}Cu_{35}$ phase (the clearest white phase) around a very small needle of Q-$Al_{17}Mg_{42}Si_{30}Cu_{11}$ phase. But Most of the second phase distributed relatively uniformly throughout the matrix length and amount of Q needles were significantly smaller than the cast samples. It is possible to recognize an equiaxial refined α - Al matrix and near-uniform distributed primary β-Mg_2Si phase particles crystallized from the melt, and grows in the presence of particulate-like dispersoids with faceted manner and develops various complex rounded edge polygon shapes attributed due to relatively high cooling rates during the spry deposition . The size, shape and distribution of primary β phase depend on the process parameter.

3.1. Microstructural development during hot compression process

Figure:4 and Figure:5 Shows OM and SEM image of the SD and hot compressed sample the microstructure shows the elimination of porous defects .The θ and Q phases in spray-deposited alloy are so small in size that a preheated treatment before deformation process can make the microstructure more uniform. Secondly, hot deformation leads to a micro structural refinement and a solid-state phase transformation. The severe stress imposed by hot-compression generates high density dislocations in the grains. Subsequently, the movement and arrangement of dislocations forms lot of small angle grain-boundaries, refining initial grains into several substructure. In addition to the refinement of grains, hot deformation also promotes homogeneous precipitation of hardening of θ phase and Q phase which can pin the movement of dislocations to restrain grains coarsening during recrystallization effectively (J.L.Estrada,1990.A.Mocellin,1993.21-23]. No significant difference in size, aspect ratio and distribution of the intermettalics of brittle β phase.

3.2. Heat treatment

Solutionizing studies carried out on the sprayed and hot-compressed alloy. Figure:6 and table: 4 shows SEM micrograph and EDS analysis of the alloy after solution heat treatment. Most of secondary phases (θ and Q) dissolved in the α - Al matrix, thus the supersaturated solid solution in the matrix increased. However, the spherodisation and coarsening occurred for β-$Mg_{65}Si_{35}$ phase after solution treating. Because of quenching, large amount of Q phase precipitates around the Mg_2Si particle interface. Easier and faster diffusion occurs along the grain boundaries and interfaces, obviously the Mg_2Si:Al interface play significant role during the morphological change of Mg_2Si partcles**.** Controlled ageing of solution treated alloys engenders high hardness [17]. Figure: 7 shows SEM micrograph of the alloy after age hardening treatment of 2 hour at 180 ℃. It can be seen that a large quantity of white precipitates less than 50 nm size uniformly distributed in the matrix. The precipitates are identified as intermetallic θ -Al_2Cu phase and Q Phase. The increase of Al-Mg_2Si eutectic phase and area fraction of precipitation along the interface of primary β-Mg_2Si phase could be easily observed. The β phase re-precipitates in a very fine spherical form during aging, also an increase in β- $Mg_{67}Si_{33}$ phase area fraction. Fine β precipitates combined with the θ precipitates can significantly increase the strength of the alloy. In the peak-aged condition, the higher hardness of alloy is clearly due to the high concentration of θ-Al_2Cu and β-Mg_2Si intermetallic phases, where the thermal activation energy is enough to nucleate these intermediate phases which are coherent with the matrix. The additional 2 h of aging at 180 ℃ resulted in a significant coarsening of structural particles. The precipitates were much larger in size, and elongated precipitates observed in the SEM image Figure: 8. Increasing aging time or aging temperature, increase in size of particles with a gradual change in chemical composition, resulting in the equilibrium θ- Al_2Cu and β- Mg_2Si phases becomes incoherent particles, which are responsible for drop in the alloy hardness**.**

3.3. Tensile properties

Table:5 shows the tensile properties of the alloy under different states. The typical dendritic microstructure of the as cast alloy with the existence of β phase appeared in polyhedral shaped sharp edge particles, Q and θ phases are exist in vermiform and long acicular shapes, unevenly distributed in α-Al matrix , can be terribly teared because of stress concentration and results decrease in the mechanical properties especially plasticity. The high strength and ductility observed in spray deposited and hot compressed alloys are attributed to the refinement and modification in the microstructure of the alloy during the spray deposition process. The tensile strength of the solution treatment and aging condition alloy are much higher than hot compression condition. Controlled ageing of solution treated alloys engenders high strength hardness (GRANT.P S.1995) The increase of strength after the aging treatment was attributed to the effects of precipitates in the Al-matrix. During the deformation, the precipitates restrict the movement of dislocation and the dislocation density increased around these precipitates. The decreasing of elongation after the precipitation heat treatment may be related with the mechanism of the growth of micro voids. In the spray-deposited material, the precipitates were numerous and uniformly distributed in the matrix, which served as the nucleation sites of voids reducing the resistance of the cavitations of the matrix and also causing the connection of micro voids in a shorter interval of time. Both of these effects decreased the ductility significantly

3.4. Hardness

The hardness of the investigated alloys as shown in figure: 9.The hardness of spray-formed alloy is higher than that of as -cast alloy, which may be attributed due to the uniform distribution of intermettalic β- Mg_2Si and Q phase. Therefore, the deformation caused by the micro hardness indentation was restricted by the brittle β- Mg_2Si particles around the indentation. The hardness of sprayed and hot compressed alloy is higher than as sprayed one due to the fragmentation and refining of θ and Q phases also due to the densification of material. When the specimen quenched from the solutionizing temperature, point defects and line defects formed around the Mg_2Si particles due to the large thermal stress generated by the significant difference of thermal expansion coefficients between Mg_2Si and Al. These defects interacted with the dislocations results in the increase of hardness. The hardness of age hardened alloy is higher than the solution treated alloy, the increase of discontinuous β phase area fraction compared to the state after solution treatment. In age hardening as precipitation proceeds and the size and number of precipitates increases, precipitate particles that usually provide an appreciable impediment to plastic deformation by slip. The alloy reaches the peak hardness of 174 HV at 2h of aging time. As the aging time increased hardness decreases, because precipitates transformed gradually from metastable to stable state and incoherent interfaces between precipitates and matrix**,**

4. Conclusion

1. The Spray deposited alloy had a fine grained microstructure, extended solid solubility, refinement of the second phase particle sizes, increased chemical homogeneity by reducing segregation, with uniform dispersion of fine with faceted of rounded edge polygon shape Mg_2Si intermattallics in the Al –matrix . Hot compression provides further refinement in the microstructure with reduced porosity of perform. After solution heat treatment an important reduction of the aspect ratio and spherodisation of the Mg_2Si particles occurred. In age hardening process, large quantity of θ phase and Q Phase precipitates were uniformly distributed in the matrix. The β phase re-precipitates with increase in phase area fraction in a very fine spherical form

2. The evaluation of mechanical properties of spray-deposited alloy exhibits high strength and ductility over that of the as cast alloy. After age hardening treatment of spray deposited and hot compressed alloy exhibited an ultimate strength of 290 Mpa and elongation of about 4.4%. The low value of the elongation was associated with the numerous micro voids generated by the numerous precipitates, which are quickly connected with each other during deformation.

3. The maximum hardness is achieved after being aging at 180 ℃ for 2 h. which was attributed to the effects of small spacing between Mg_2Si particles, larger amounts of quenched-in defects, smaller grains, and in associated with a massive precipitation of intermediate θ and Q phases in the matrix

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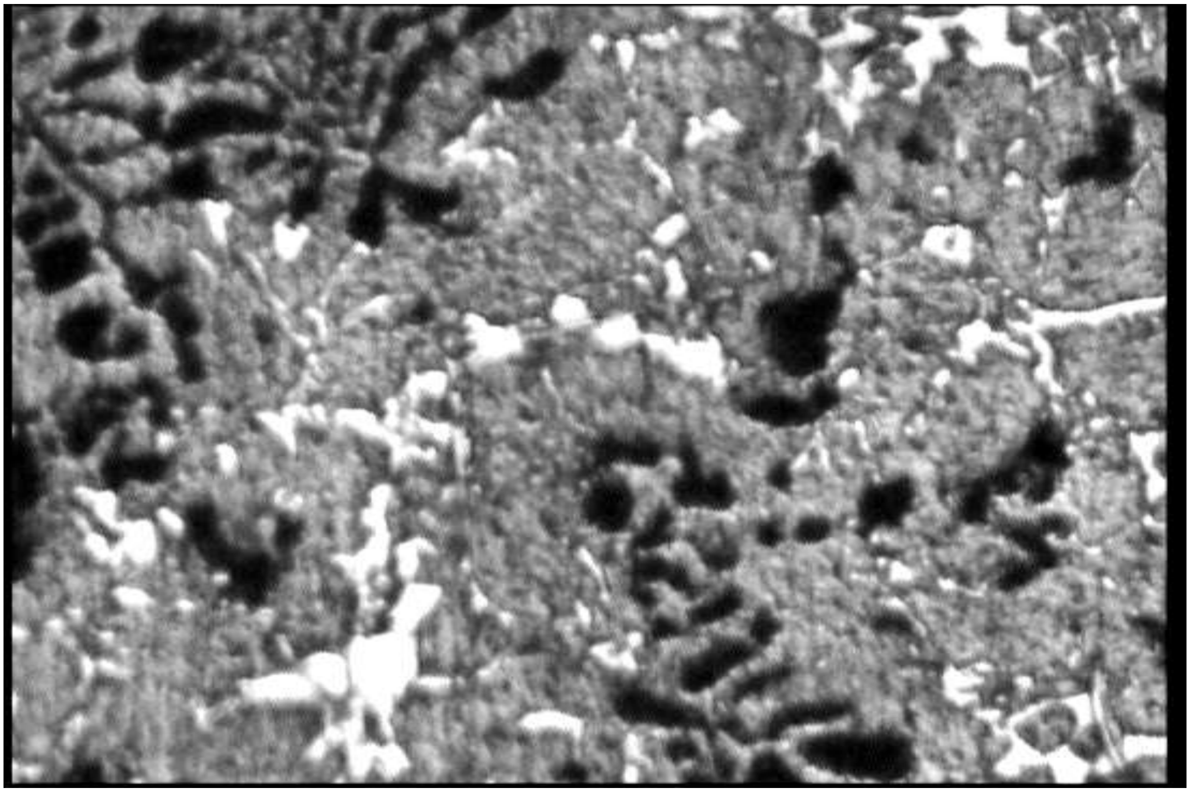

Figure1. Optical micrograph of as cast alloy

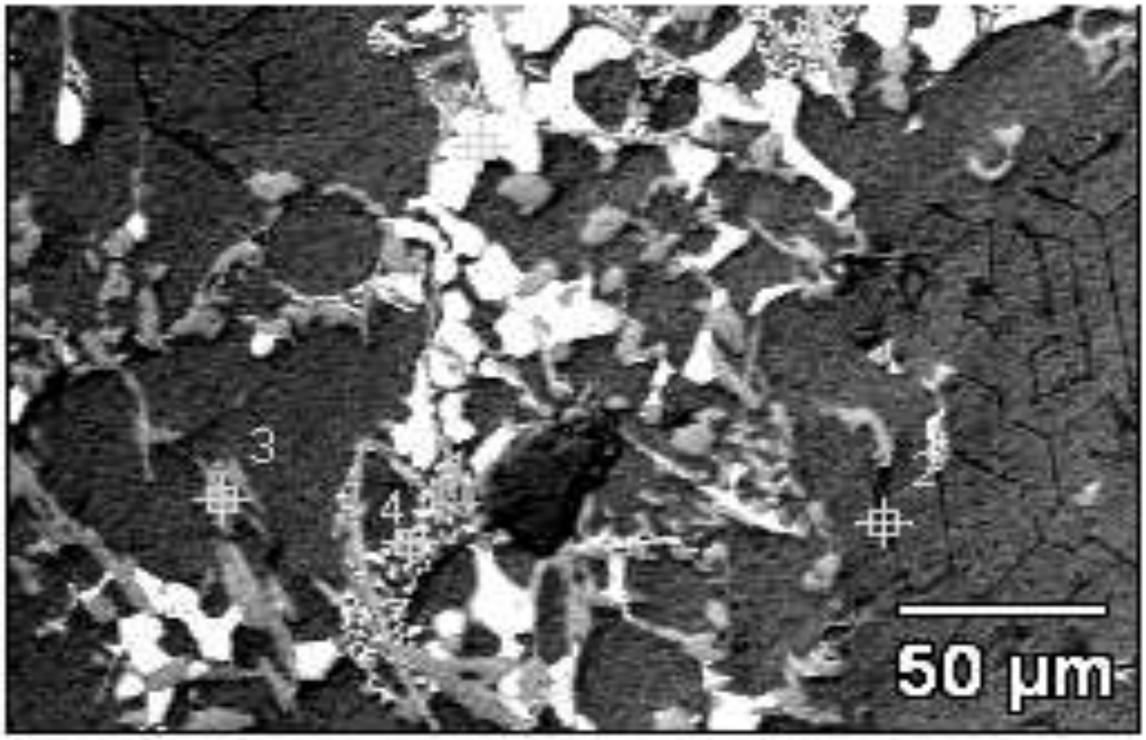

Figure2. SEM of as - Cast alloy

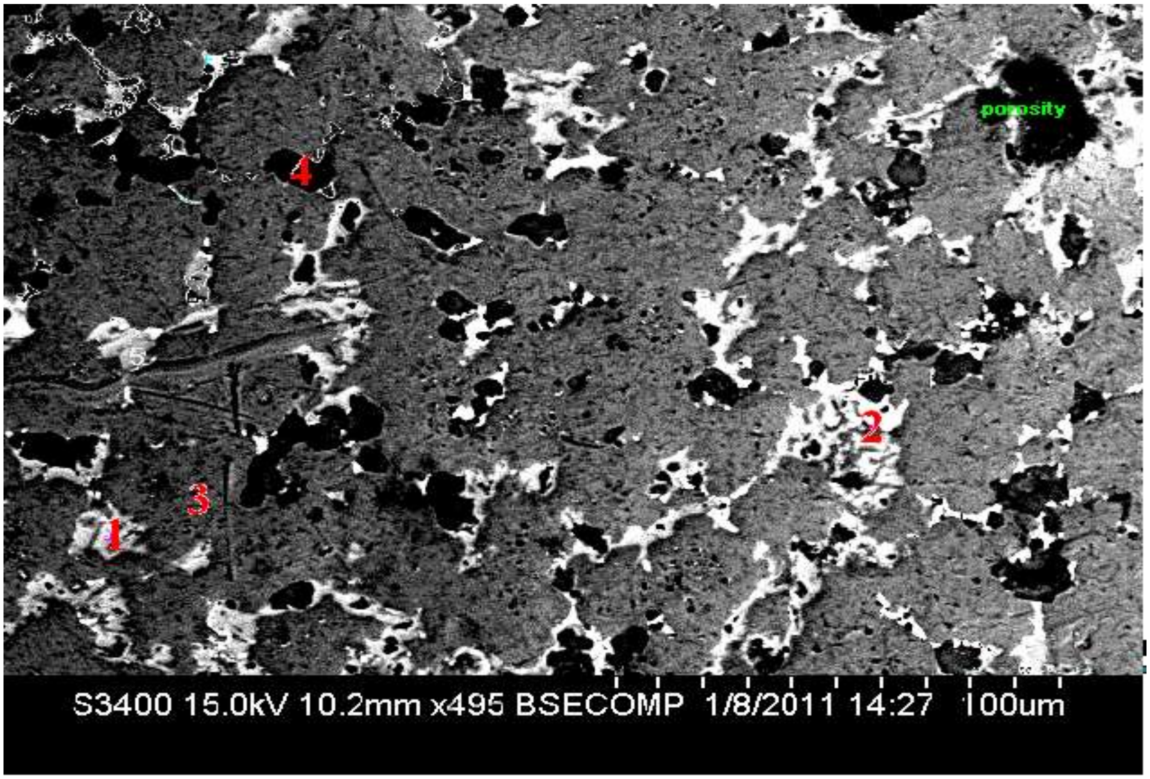

Figure 3. SEM image of the Spray deposited alloy.

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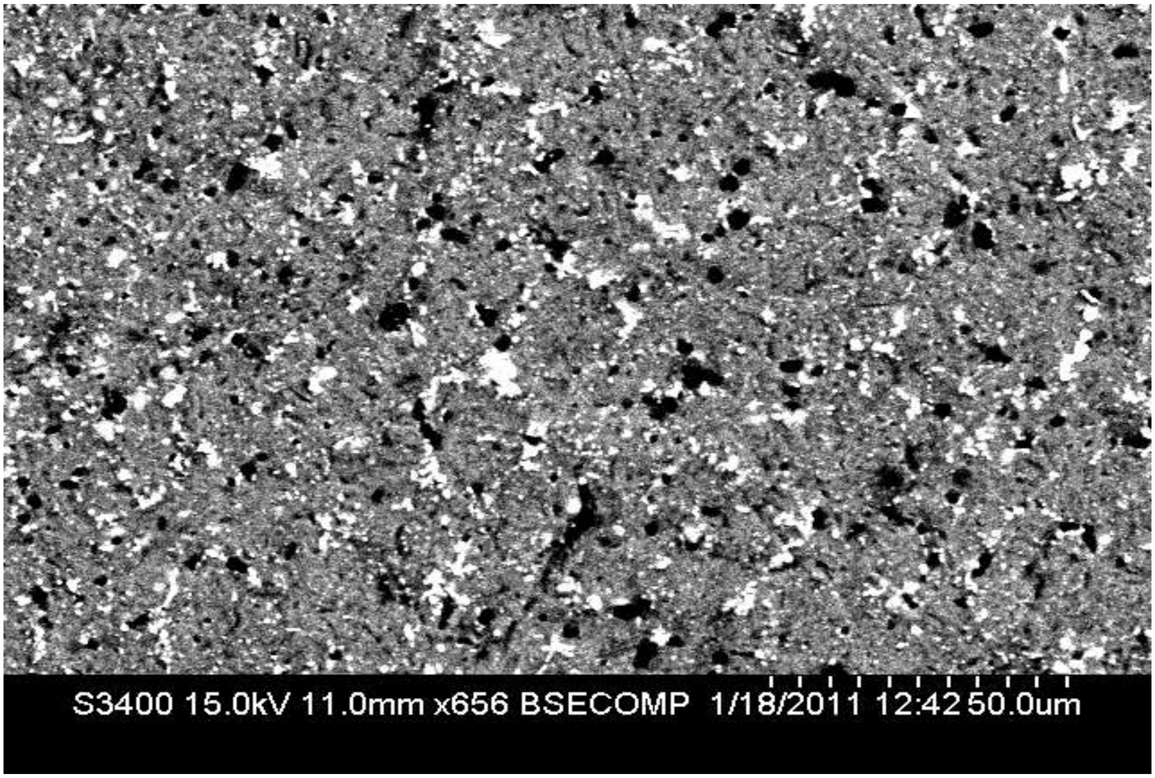

Figure 4. SEM image of Sprayed and Hot compressed alloy

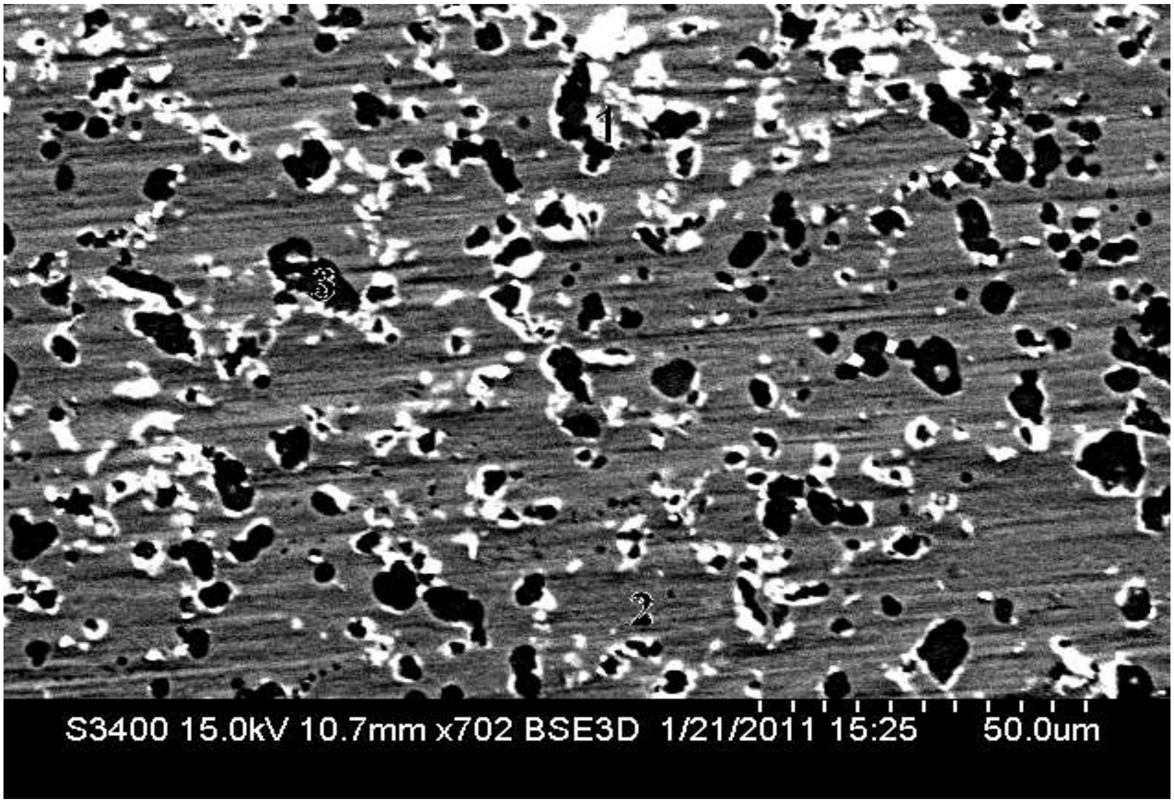

Figure 5 . SEM image of Solution heat treated alloy.

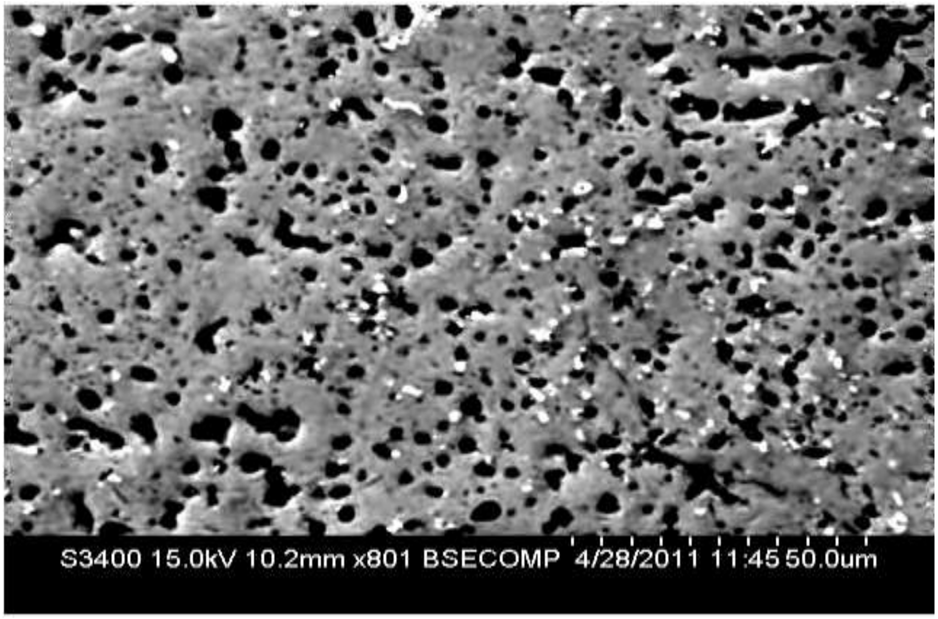

FIGURE: 6 SEM of Age hardened alloy (AGH2).

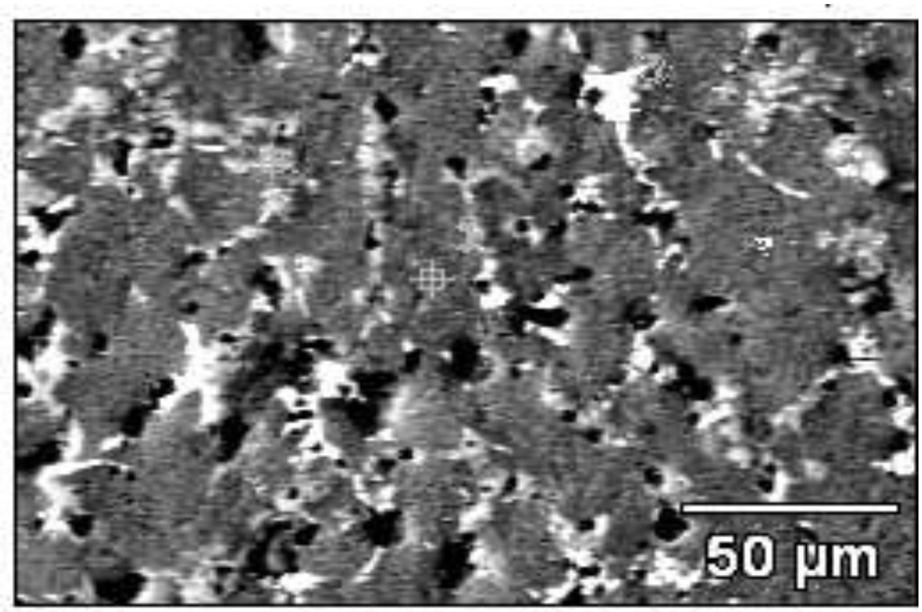

Figure 7. SEM photoograph of Age hardened alloy (AGH4)

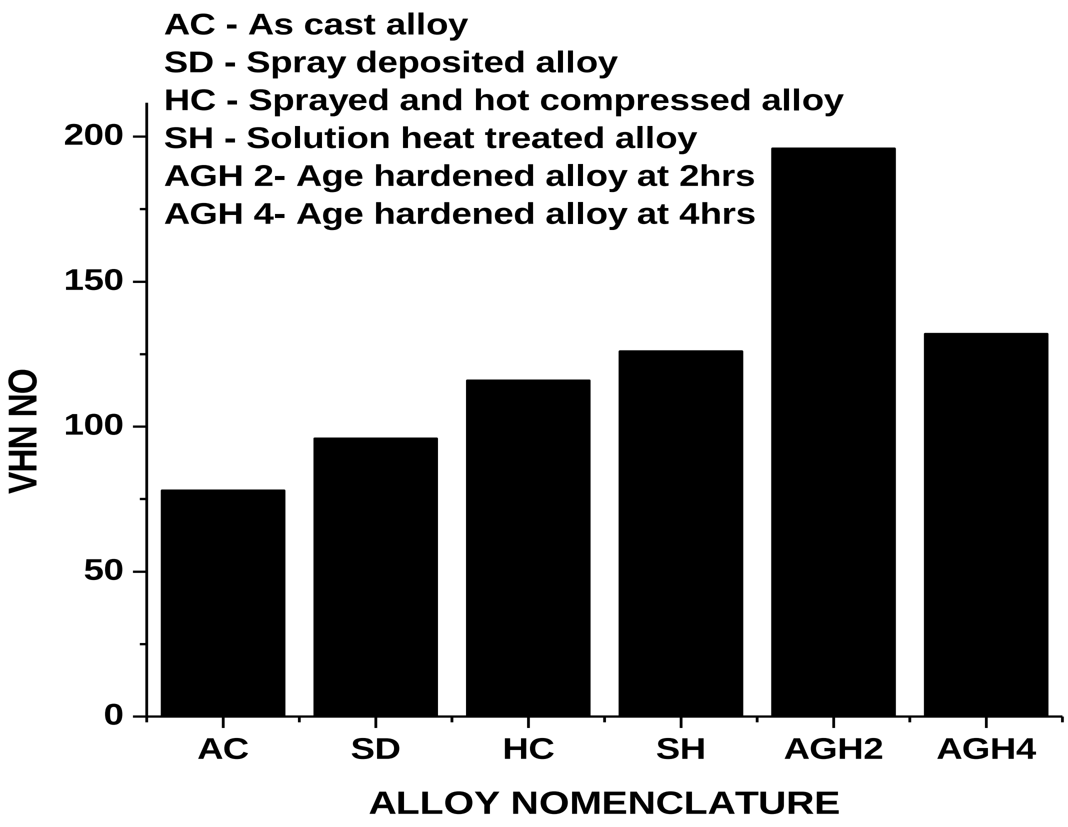

Figure 8. Micro hardness of investigated alloys.

Tables

Process parameter	Value
Atomization pressure Kg/cm^2	5.5
Super heat temperature ^{o} C	100
Gas-metal mass flow rate ratio	2.43
Deposition distance (mm)	400

Table 1. Primary Spay deposition process Parameters

Location	Phase	Composition (mass %)			
		Al	Mg	Si	Cu
PT1	θ- $Al_{64}Cu_{36}$	22.2	0.16	0.10	29.60
PT2	β- $Al_{14}Mg_{57}Si_{27}$	0.96	1.86	18.4	Nil
PT3	Q-$Al_2Cu_2Mg_8Si_7$	6.93	53.88	33.2	Nil
PT4	θ- $Al_{64}Cu_{36}$	22.2	0.16	0.10	29.60

Table 2. EDS Analysis of as–Cast alloy

Location	Phase	Composition (mass %)			
		Al	Mg	Si	Cu
PT1	Q-$Al_{11}Mg_{61}Si_{20}Cu_7$	11.0	44.7	16.6	15.6
PT2	θ- $Al_{65}Cu_{35}$	25.4	0.16	25.4	31.7
PT4	β- $Mg_{65}Si_{35}$	Nil	58.9	35.9	Nil

Table3. EDS Analysis of Spray deposited alloy.

Location	Phase	Composition (mass %)			
		Al	Mg	Si	Cu
PT1	Q -$Al_{16}Mg_{49}Si_9Cu_7$	16.3	44.7	30.	15.7
PT3	β - $Mg_{65}Si_{35}$	7.4	50.3	33.2	2.2

TABLE: 4. EDS Analysis of Spray deposited alloy, hot compressed solution heat treated alloy.

State of alloy	UTS (MPa)	Elongation %
As cast alloy	117	3.2%
Spray deposited alloy (SD)	165	4.156
(SD+HC) alloy	178	5.92
SD+ HC + Solution treated alloy	270	7.63
Age hardened alloy 2hr	290	4.4

Table 5. Tensile properties of SDP, HC and Heat treated alloys.

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