

Eutectic Instability and Phase Selection of Al-Sm Alloys

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ABSTRACT

Microstructure evolution over a wide range of growth rates has been examined in the Al-Sm system in which different microstructure selection, from eutectic to dendritic to amorphous material, with increasing growth rate can occur. Experiments were carried out for compositions between 11 and 25 wt.% Sm and the velocity was varied from 2×10^{-4} to 635 mm/s. Low velocity studies were carried out using the Bridgman technique, whereas high velocity studies were carried by using the laser scanning technique. The maximum velocity for eutectic growth was determined, and the results were compared with the theoretical predictions. A transition from eutectic to α -Al dendrites was observed when the eutectic became unstable, and a coupled zone boundary on the Al side was determined. The present results were compared with those in the Al-Cu alloys, and the velocity at which the eutectic becomes unstable was found to be an order of magnitude smaller, which is related to the higher activation energy for diffusion in the Al-Sm system.

Control of Monotectic Solidification by a High Static Magnetic Field

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ABSTRACT

Effect of magnetic field on the microstructure developed during the unidirectional solidification was investigated and the in-situ observation of the monotectic solidification was performed using synchrotron radiation X-ray for Al-10at%In hypermonotectic alloy. Coarse In rods and fine In rods could coexist during the unidirectional solidification when a magnetic field was not imposed. The static magnetic field exceeding several T promoted formation of the regular structure in which cylindrical In rods with the same diameter are regularly aligned in the growth direction. The in-situ observation showed that the coarse In-rich droplets that were continuously pushed by the Al solidifying front produced the coarse In rods. The continuous pushing prevented the selection of the rod spacing and resulted in the coexistence of the coarse and the fine rods.

The Multidisciplinary Facets of Particle Engulfment and Pushing

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ABSTRACT

Since 1964, when the first paper on this subject was published by Uhlmann, Chalmers and Jackson, our understanding of the physics of the problem and ability to describe it through mathematical models has increased dramatically. Numerical models that can calculate the behavior of the particle as a function of solidification velocity and taking into account the non-steady-state nature of the problem as well as the complex fluid flow around the particle are currently available. Progress has been also achieved in the effort to produce models that allow visualization of particle movement and of the interface shape on the computer screen. Still unresolved is the calculation of the interaction force between the particle and the solid. Current approaches are based on unreliable surface energy data or generic "disjoining pressure" numbers. Little progress has been made in the study of particle interaction with complex but practically significant dendritic interfaces. Also there is much scope in the experimental work on particle clustering and the measurement of interaction forces. This paper presents a critical examination of the status of the problem of particle engulfment and pushing by a solidification interface and identifies key issues that remain unsolved.

Microstructure Characterisation and Creep Properties of AE42 Based Hybrid Composites Prepared by Squeeze Casting Process

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ABSTRACT

Magnesium alloy based hybrid composites with varying levels of δ -alumina short fibers (Saffil[®]) and SiC particles (SiC_p) reinforcements have been prepared by the squeeze casting technique. Microstructure evaluation by optical microscopy and scanning electron microscopy on these composites reveal the presence of Mg₂Si and Al-RE precipitates. The presence of these precipitates was found to enhance the creep resistance of AE42 hybrid composites. The interfacial reaction products were MgO and Mg₂Si. The interfacial reaction product MgO is more pronounced along the Saffil[®] compared to SiC_p. Heat treatment of the composites improved the distribution of the precipitates in the composites. Hardness characteristics of the composites have been studied.

Planar Front-Equiaxed Growth Transition in Semiconductor Solidification: Application to Photovoltaic Silicon

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ABSTRACT

The conversion efficiency of crystalline silicon solar cells depends on the solidification process of the silicon material. During solidification, several kinds of grain structures can build up and some of them induce a decrease of the solar cell efficiency. The objective of our model is to predict the transition from large grains to small detrimental grains as a function of solidification parameters. As an abnormally high number of SiC particles have been observed in the small grains regions, the first hypothesis of our model is that segregation of C occurs during growth and provokes the precipitation of SiC. In a further step, free Si grains nucleate on the SiC particles and lastly, a competition between the planar front and the free Si grains takes place. This phenomenon can be compared to the columnar to equiaxed transition. From a simple analytical model, in a thermal gradient - growth rate diagram, we were able to draw transition maps between the different domains: equiaxed, planar+equiaxed and planar. This model allowed giving efficient recommendations to avoid the occurrence of the small detrimental grains during the industrial process.

Processing Space Resource to Enable the “Vision for Space Exploration”

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ABSTRACT

The NASA human exploration program as directed by the “Vision for Exploration” (G.W. Bush, Jan. 14, 2004) includes developing methods for in situ processing the materials of the Moon, Mars and beyond to enable safe and affordable human exploration of the solar system. Recent advances in materials technologies could make it possible to achieve mass, energy, and life support self sufficiency at far lower costs than were projected during NASA studies in the 1970s. If the “Exploration Vision” program is executed with an emphasis on the utilization of space resources, it could provide a path for human self reliance beyond Earth orbit. This path can lead to an open, non-zero-sum, future for humanity with safer human competition and with limitless potential for growth.

Lead-free Bearing Alloys for Engine Applications Results of the ESA-MAP Project MONOPHAS

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ABSTRACT

Recent developments to reduce fuel consumption, emission and air pollution, size and weight of engines for automotive, truck, ship propulsion and electrical power generation lead to temperature and load conditions within engines that cannot be provided by conventional bearings. Therefore a European project has been established to develop a technically usable aluminium based lead free bearing material with sufficient hardness, wear and friction properties and good corrosion resistance to be produced with semi-continuous casting process. The paper describes the scientific challenges, approaches to tackle the solidification and casting problems and presents some illustrative research results.

Wear Behaviour of Al-Si Alloys Reinforced with *in-situ* formed TiB₂ Particles

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ABSTRACT

Dry sliding wear behaviour of hypoeutectic "Al-7Si" and eutectic "Al-12Si" alloys reinforced with *in-situ* formed TiB₂ particles were compared using a pin-on-disc apparatus. The tests were conducted at different normal loads varying from 19.6 to 78.4 N. The composites were prepared by the reaction of molten alloy with K₂TiF₆ and KBF₄ salt in a stoichiometric ratio corresponding to fixed weight fraction of TiB₂. Prior to wear testing, the composites were characterized for their microstructure using X-Ray diffraction and scanning electron microscopy. The results of the wear studies indicate that incorporation of TiB₂ particles into the base alloys lead to a significant decrease in their wear rates, particularly in case of the hypoeutectic alloy at higher loads. The wear surfaces and wear debris were examined to have an idea of the possible wear mechanism in these *in-situ* MMCs.

Characteristics of Aluminum Based Composites Synthesized Using Mechanical Disintegration and Deposition Technique

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ABSTRACT

An innovative and cost effective process, called as mechanical disintegration and deposition technique has been used to synthesize aluminium based metal matrix composites in the present study. This technique consists of using a mechanical device to carry out disintegration of the molten composite slurry followed by depositing on a metallic substrate to obtain the solidified ingot. Microstructural characterisation studies revealed a reduction in the grain size of the specimens with increasing amount of reinforcement. The density and porosity of the composites were found to increase with an increase in the amount of reinforcement. The extruded composite specimens revealed a fairly uniform distribution of SiC particulates and good Al-SiC interfacial integrity. The Al-SiC interfacial microhardness, matrix hardness, elastic modulus, 0.2% yield strength and ultimate tensile strength of the composite material increased while the ductility was adversely affected with an increase in the weight percentage of SiC particulates in the Al matrix.

The Study of the Aluminum Metalfoam Produced by Powder Metallurgy Method

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ABSTRACT

This paper describes manufacture of the ϕ 5cm billet-type precursor by powder metallurgy method. The billets are extruded into the large plate (8.5*1.8*200 cm) through extrusion machine. The large plate is cut into small plate-type precursor (8.5*1.8*25 cm) to produce the aluminum metalfoam product. After foaming finish, the composition and cell structure analysis of elements were carried out by scanning electron microscope (SEM) equipped with an energy dispersive X-ray spectrometry (EDX).

Grain Refiners as Liquid Metal Foam Stabilisers

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ABSTRACT

The present work reports on the foaming of liquid aluminium containing TiB₂, TiC or TiAl₃ particles (4-11.5 vol.%) which were prepared in-situ by flux-assisted melting using fluorides. This procedure was in analogy to the production of composites containing grain refining particles. The particle size was kept below 1 µm for TiB₂ and TiC and around 10 µm for TiAl₃. Foams were successfully produced using TiB₂ and TiC particles and thus it could be demonstrated for the first time that metal foams can be stabilised by sub-micrometre particles. The influence on foam stability of alloying with Si and dilution of the melt with pure Al was studied in addition. Microstructural analysis of the foams showed that the particles segregate to the surfaces of cell walls leading to an almost dense coverage, thus helping in stabilising the foams.

Anomalous Behaviour of Aluminium Foams During Solidification

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ABSTRACT

Solidification of metal foams was studied by in-situ X-ray radiography. Precursors were prepared by uni-axial hot compaction of metal/blowing agent powder blends, foamed in a X-ray transparent furnace and were then solidified. Foam evolution was continuously monitored. The cross-section of the foam at any instant was determined from the images by automatised image analysis. During cooling of the sample an unexpected small transient expansion stage was observed. In order to explain this behaviour different possible effects are proposed and evaluated. Experiments were carried out for alloys with and without blowing agent, for different heating times and cooling rates to separate the various possible mechanisms. It was observed that the transient expansion strongly depends on heating time and cooling rate. Some transient expansion is also observed for alloys without blowing agent demonstrating that the effect can only be partially ascribed to the behaviour of the blowing agent.

Fluid Flow Effects on Intermetallic Phases in Al-cast Alloys

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ABSTRACT

In this paper we present an experimental study of the influence of controlled fluid flow conditions during solidification on the morphology and spatial arrangement of intermetallic phases in the alloy Al-7wt.%Si-1wt.%Fe. The forced convections are induced by a rotating magnetic field with a magnetic induction of 6mT at a frequency of 50Hz. The ternary alloy Al-7wt.%Si-1wt.%Fe and its binary counterpart Al-7wt.%Si are solidified directionally over a range of constant solidification velocities (0.015- 0.18mm/s) at a constant temperature gradient G of 3K/mm. The scientific results reached so far indicate a strong influence of the electromagnetic stirring on the microstructure of the samples: It is found that the coarse β -phase (β -Al₅FeSi) platelets, which form during solidification of Al-cast alloys containing Fe, in interaction with the rotating magnetic field change all relations between microstructural parameters like primary and secondary dendrite arm spacing and solidification velocity and time respectively.

An Analysis of the Differences in the Glass Forming Tendency of Melts on Earth and in a Low - Gravity Environment

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ABSTRACT

Experiments conducted up to this time on glass forming melts in the low gravity environment of space show that glasses prepared in low gravity are more chemically homogeneous and more resistant to crystallization than comparable glasses prepared on Earth. This result is somewhat in contradiction to the accepted concept of glass formation for a melt. A hypothesis based on "shear thinning" of a melt, a decrease in viscosity with increasing shear stress, is proposed as an explanation for the observed low-gravity results. This paper describes results from numerical simulations to test the role of natural convection in introducing shear stress in glass forming melts, using a Li₂O-2SiO₂ melt as a model. The simulation system in its idealized version consists of a cylinder that is subjected to a longitudinal temperature gradient with the gravity vector oriented perpendicular to the temperature gradient. The governing equations of motion and energy are solved in primitive variables and the parametric influence of the gravity level on the buoyancy induced convection in the melt is calculated. The shear stress in the system is then computed as a function of the gravity level and its possible influence on affecting the melt viscosity (shear thinning) is then assessed.

Quantitative Characterisation of Macrosegregation Produced by Forced Melt Flow

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ABSTRACT

Unidirectional solidification experiments were carried out on ternary Al-7Si-0.6Mg alloys using the Bridgman-method. The samples were moved downwards inside the furnace tube during the solidification. The average temperature gradient was ~6 K/mm, the samples were translated at three different constant velocities (0.01, 0.05 and 0.2 mm/s) during each solidification process. The experiments were performed with and without rotating electromagnetic stirring of the melt, too. A four-pole, three-phase inductor generated the electromagnetic field (B: 19 mT, f: 150 Hz). This magnetic field produced a strong melt flow in the whole samples during the solidification in contrast to the experiments described in the literature, where the magnetic field was much lower (2-6 mT) and/or only a small part of sample was stirred.

The influence of this flow on the solidified microstructure of alloys was studied. It was stated that the columnar structure disappeared as an effect of the forced melt flow and a significant enrichment in silicon in the centre and in the latest solidified parts of samples could be observed. Microstructural parameters related to the amount of the second phase (Si) and to the primary Al dendrite were measured using an image analyser.

Controlling Heat and Mass Transport during the Vertical Bridgman Growth of Homogeneous Ternary III-V Semiconductor Alloys

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ABSTRACT

Large separations between the solidus and liquidus curves in the pseudo-binary phase diagrams are characteristics of all III-V ternary semiconductor alloys such as $Ga_{1-x}In_xSb$, $Ga_{1-x}In_xAs$, $InAs_{1-y}P_y$, etc. Hence during crystal growth from melt, alloy segregation and constitutional supercooling is a major issue due to which the mechanical properties of the crystals suffer. Since the solidification temperatures vary with alloy composition, a control over both heat and mass transport during crystal growth is necessary for achieving spatial compositional homogeneity in the grown crystals. In this paper, it has been demonstrated that by appropriately choosing axial temperature gradient, melt mixing scheme, growth rate and solute feeding rate, homogeneous bulk $Ga_{1-x}In_xSb$ crystals could be grown.

Solidification Behaviour Under Intensive Forced Convection

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ABSTRACT

Solidification, both in scientific research and in engineering practice, is usually conducted under quiescent conditions. During solidification both nucleation and growth of the primary phase occur when the liquid metal remains largely static. Under such conditions, nucleation takes place in a "Big Bang" manner. Most of the nuclei created in the first instance dissolve into the oncoming hot liquid, resulting in a typical growth-controlled microstructure, which is often coarse, non-uniform and with severe chemical segregation. To achieve a fine and uniform as-cast microstructure with no chemical segregation, we have recently developed a dynamic approach to solidification control. In this approach intensive forced convection is applied to the solidifying liquid through a twin-screw device. Extensive research on solidification under intensive forced convection has led to the discovery of a number of new solidification phenomena, such as continuous nucleation, effective volume nucleation, spherical growth and physical undercooling. In this paper, we offer an overview of our work in this exciting new field.

The Microstructure Response to Fluid Flow Fields in Al-Cast Alloys

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ABSTRACT

The effect of controlled fluid flow conditions on the microstructure formation in cast Al-alloys was studied experimentally. A pure ternary Al-6wt.%Si-4wt.%Cu alloy has been directionally solidified upwards under a medium temperature gradient (3K/mm) in an aerogel-based furnace facility over a wide range of constant solidification velocities (0.015-0.15 mm/s). A coil system around the sample induces a homogeneous rotating magnetic field being able to generate a controlled fluid flow in the melt close to the growing solid-liquid interface. The application of rotating magnetic fields during directional solidification results in pronounced segregation effects. For high magnetic induction and therefore high fluid flow velocity a change to pure eutectic solidification at the axis of the sample is observed. The investigations show that the microstructural features like the primary dendrite and the secondary dendrite arm spacing change in a unique manner with solidification speed and rotating magnetic induction, clearly revealing the dramatic effects of fluid flow on the solidification kinetics.

Modeling Automotive Casting Process

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ABSTRACT

This paper summarizes the developments in numerical solidification modeling of automotive castings. The challenges involved in modeling the solidification phenomena are described. Two distinct scales at which the solidification modeling is carried out is presented. At the macroscopic scale the key factors which affect the solidification process are the mold filling, heat transfer, fluid flow, macrosegregation, and residual stresses. At the microscopic scale, phenomena such as the microsegregation and microporosity formation control the microstructure that evolves. By modeling these phenomena in a tightly coupled manner, predictions of the microstructural parameters along with thermal histories at various locations in the casting can be carried out.

Simulation of Microstructure Evolution During Solidification of Magnesium-Based Alloys

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ABSTRACT

Magnesium alloys are becoming increasingly important for weight reduction of components in transportation and electronic industry. The solidification microstructure of most Mg-cast-alloys is dominated by the hexagonal closed-packed structure of the Mg solid solution. Nucleation and dendritic growth of this phase strongly depend on the alloy composition, the process parameters and on the size and number of nucleant particles.

The general aim of the present work is to examine these dependencies in order to assist the design of improved alloys and processes. Therefore, a multiphase-field model for multicomponent alloys is adapted to magnesium-based alloys. A hexagonal anisotropy function is integrated to describe the growth of the hcp-magnesium phase and a special nucleation model addresses heterogeneous nucleation on grain refiner particles. Simulations are run by online-coupling of the phase-field software to a thermodynamic calculation software using a Calphad database for the Mg-Al-Zn-Mn system. Applications to the commercial Mg-Al-Zn based alloy AZ31 are presented, showing directional as well as equiaxed dendritic growth.

Simulation of Cooling Rate of Alloy Drops during Spray Casting

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ABSTRACT

Estimation of cooling rates of liquid droplet during spray casting and its dependency on design and process parameters is one of keys for achieving best processing conditions to produce quality castings and also bulk metallic glasses of alloys. The estimation of the cooling rate involves modeling the heat transfer and solidification of liquid metals and alloys during the flight period as well as that in contact with the solid substrate. Computation of cooling rates during the flight period has been carried out and model for heat transfer during the collision of droplet with the substrate has been evolved. Experimental set up has been fabricated to carry out the spray casting processing and to validate the model. Al-Cu eutectic alloy is one of the systems studied to corroborate the model and the experiments.

An On-site Industrial Experimental Heat Flux Study during Solidification of Pure Copper in the Southwire Process

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ABSTRACT

To study the production of pure copper and copper alloys in the Southwire process the temperature in the mould has been measured on-site in the production process in a number of positions. To increase the accuracy and robustness of measurements a new type of thermocouple based temperature sensor has been developed and tested. The test system includes wireless transmission of measured data from the moving mould. The results from the measurements are then used to calculate the energy transfer rate from the solidifying shell as a function of time. An initial in-situ measurement campaign has been performed and the results are very promising.

Continuous Casting Simulation of Nonferrous Metal Wire Rods

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ABSTRACT

Since the casting quality could be influenced by many factors during the continuous casting process of metal wire, it is helpful to numerically analyze the effects of different operation conditions. In this study, a steady mathematical model is built to simulate the heat-transfer behavior of the metal wire bars during the casting process. The numerical method is the finite difference method. With different casting speeds and cooling conditions, the computer programs are used to analyze the continuous casting of copper, silver and gold wires, whose diameter is 8 mm. The computing results are compared with the experimental ones from the Metal Industries Research and Development Center in Taiwan.

A Comparative Study of Mechanical Properties and Wear Behaviour of Al-4Cu-TiB₂ and Al-4Cu-TiC *in-situ* Composites

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ABSTRACT

Al-4Cu based composites reinforced by *in-situ* TiB₂ and TiC particles were fabricated by the reaction of molten Al with halide salts and graphite. The processing conditions were controlled to get only TiB₂ and TiC particles by suppressing the formation of brittle Al₃Ti phase in these composites. The composites show significant improvement in strength without any significant loss of ductility. The mechanical properties are better than the conventional Al-SiC and Al-Al₂O₃ composites. The wear results indicate that the addition of reinforcement decreases the wear rate significantly and an increase in the amount of the reinforcement increases the wear resistance of the composites.

Unconstrained Growth along Ternary Eutectic Solidification Path in Al-Cu-Ag Alloy: Analysis of Microgravity Experiment

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ABSTRACT

The Al-Cu-Ag alloy samples of two near eutectic compositions were isothermally solidified at two different cooling rates under microgravity conditions during a long duration sounding rocket flight MAXUS 6 following solidification path:



The overall objective of this experiment is to investigate the formation of the microstructure along the entire solidification path during unconstrained eutectic growth in a ternary alloy system without disturbing effect of gravity.

Post flight analysis of the samples with $\theta\text{-Al}_2\text{Cu}$ primary phase has revealed that the increase of cooling rate leads to microstructure refinement. Moreover, the growth of univariant and invariant eutectics becomes more competitive regardless of the gravity level. The reduced gravity environment produces higher and more uniformly distributed porosity, but no significant difference in the microstructure is observed between the ground reference and low-gravity samples.

Similar samples with $\alpha(\text{Al})$ primary phase, studied in the ground based program, showed a gravity dependent segregation. Unfortunately, these samples failed during the flight experiment.

Investigation and Visualisation of Melt Flow Under Rotating Magnetic Field

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ABSTRACT

The solidified structure of the different types of alloys (e.g. hypoeutectic Al-Si alloys) can be modified by melt stirring during the solidification. According to the solidification experiments it has been stated that it is very important to know the method and intensity of stirring. In order to check the flow conditions during the solidification preliminary tests were carried out. Liquid gallium as model material was chosen for the "cold" experiments. Gallium is a suitable material for visualisation of the melt flow near the room temperature because of its low melting point (29.8°C). The aim of experiments was to measure the revolution number of rotating liquid gallium and to compare this value to the synchronous revolution number of rotating magnetic field. A three-phase inductor generated the magnetic field. The revolution number of flow was determined numerically with two different methods. On the basis of these measurements the characteristics of melt flow caused by rotating electromagnetic field in case of solidification of Al-Si-Mg alloy can be well followed.

Characterization of Recycled PRMMCs Fabricated by Low-Pressure Infiltration Process

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ABSTRACT

To investigate the effect of separation process on the mechanical properties of recycled matrix alloy and reinforcement particle, particle reinforced metal matrix composites, i.e. PRMMCs were fabricated and examined for the characteristics of the recovered matrix alloy and reinforcement particles. The SiC_p/Al-mass4% Cu alloy composites (SiC particle size: 75µm) were fabricated by a low pressure infiltration process (LPI process). Then the PRMMC specimens were remelted and separated by a novel separation process (Nozzle Filtering Method). In the separation process, the PRMMC specimen was placed in a silica tube container with a small nozzle (nozzle size: 0.75mm) at the bottom and was melted by H.F. induction heating. The molten PRMMC specimen was forced to flow out through the nozzle by applying a certain pressure of Ar gas on the melt surface. Most of the molten matrix alloy flowed out through the nozzle and the remainder in the container consisted of SiC particles and a part of the matrix alloy. The microstructures of separated matrix alloy and SiC particles were examined by EDX-SEM. Before and after separation process, the mechanical properties of the matrix alloy and PRMMC specimens were evaluated by tensile test and Vickers hardness test.

Metallic Nanowires Electrodeposited in Nano-Porous Polycarbonate Membrane

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ABSTRACT

A nuclear track-etched polycarbonate membrane filter was used as a nano-porous template to obtain metallic nanowires with high-aspect-ratio. To make a cathode, a gold thin film was sputtered on one side of the membrane filter with pore length of 6 mm, pore diameter of 100-150 nm and pore density of 4×10^8 pores/cm². Nickel, cobalt, iron, zinc and copper were electrodeposited in the nano-porous templates with numerous cylindrical nano-pores. An optimum deposition potential for growing nanowires was determined from a cathodic polarization curve of a nano-porous template. Electrodeposition of nanowires was carried out potentiostatically at an optimum cathode potential. Time-dependence of deposition current was monitored to investigate the growing process of nanowires. SEM images of nanowires revealed that the diameter and length of nanowires correspond to those of nanopores in the template. TEM images and diffraction patterns of nanowires confirmed that nickel and iron nanowires composed of a single crystal.

Microstructure and Mechanical Properties of Ti-Fe-(Sn) Ultrafine Eutectic Alloys

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ABSTRACT

Nano-/ultrafine-scale eutectic microstructures are prepared in $(\text{Ti}_{70.5}\text{Fe}_{29.5})_{100-x}\text{Sn}_x$ alloys ($x = 0, 3.85$) through arc melting and cold crucible casting. The nano-/ultrafine-scale composites consist of a mixture of FeTi (B2) and β -Ti (A2) solid solution phases. The average eutectic spacing of the binary Ti-Fe alloy is larger than that of the ternary Ti-Fe-Sn alloy indicating a refinement of the eutectic microstructure upon alloying. Furthermore, the room temperature plastic strain of the ternary Ti-Fe-Sn eutectic alloys is significantly larger ($\approx 7.4\%$) than that of the binary Ti-Fe alloy. The difference in the plastic strains is correlated with the corresponding microstructure, supersaturation of the phases and elastic constants.

Wear Behaviour and Microstructural Evolution in Cast and Hot-rolled Al-4.5Cu-5TiB₂ Composite on Mushy State Rolling

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ABSTRACT

The in-situ Al-4.5Cu-5TiB₂ composite plates were processed by stir casting through mixed salt route process involving K₂TiF₆ and KBF₄ salts. Mushy state rolling has been carried out at temperatures above the solidus of the alloy matrix, corresponding to the presence of 10, 20 and 30 volume percent liquid to obtain 2.5, 5, 7.5 and 10 percent reduction in thickness. Alligatoring has been noticed during mushy state rolling of the as cast composites, except when the liquid content is 30 volume percent and thickness reduction is 2.5 and 5 percent. Prior hot rolling leading to chemical homogenization accompanied by modification of dendritic microstructure into that with equiaxed grains has led to the prevention of alligatoring during mushy-state rolling of the composite for reduction in thickness of less than 10%. Study of microstructural evolution and its effect on hardness as well as minimization of rolling defects in the products has been carried out. The wear properties of as-cast and mushy state rolled composites were also investigated, and correlated with microstructure.

Microstructural Evolution in Twin-Roll Strip Cast Mg Alloys

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ABSTRACT

Mg-6wt.% Zn-1wt.% Mn-1wt.% Al (ZMA611) alloy was strip cast into 2 mm thick strip. Microstructure of the as-cast ZMA611 alloy strip shows equiaxed α -Mg dendritic structure across the thickness of the strip. Continuous metastable phase and primary Al₈Mn₅ particle are formed in the interdendritic region. It has been found that, in T4 condition, interdendritic phases are disappeared within α -Mg except thermally stable primary Al₈Mn₅ particles. In addition, fine secondary Al₈Mn₅ dispersoids precipitate from supersaturated as-strip cast α -Mg after solution treatment. These dispersoid particles retard the motion of dislocations to increase strength and at the same time the blocked dislocations change the slip systems by cross-slip to maintain good ductility.

Effect of Alloying Elements on the Microstructural Evolution of Mg-Sn Based Cast Alloys

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ABSTRACT

A study has been made on the effect of Sb and Sr on the microstructure and mechanical properties of Mg-Sn-Al-Si based (TAS) alloy. When Sb is added more than 3 wt.%, Mg_3Sb_2 particles acted as nucleation sites for Mg_2Si and Mg_2Sn particles. Increased volume fraction and decreased shape factor of the particles improved the hardness of the alloys. When Sr is added, a few kinds of particles such as rod-like $MgSi_2Sr$, $SiSr_2$ and polygonal Sr_5Sn_3 particles are formed within the microstructure. Large volume fraction and uniform distribution of the particles greatly improved the hardness of the alloys. These microstructural changes by Sb, Sr addition are also expected to have beneficial effect on the room and high temperature mechanical properties.

Non-Newtonian Behaviour of Liquid Metals

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ABSTRACT

Viscosity is the most structure-sensitive physical property of liquids, and is of great importance to diverse scientific and engineering disciplines. However, the shear rate dependence of the viscosity of liquid metals is so far not clear. A long-standing belief is that liquid metals are Newtonian liquids. Here we show for the first time that liquid metals are non-Newtonian liquids. We found that at temperatures close to their melting temperature, the viscosity of liquid metals increases linearly with increasing shear rate. The viscosity data obtained by extrapolation to zero shear rate are in good agreement with the literature values. Furthermore we found that the slope of viscosity against shear rate is proportional to the liquid density, the atomic diameter and the atomic packing density. We believe that this discovery will have a profound influence on research into the atomic structure of liquid metals, nucleation during solidification, and viscosity measurement. It will provide a dynamic approach to the research in such disciplines.

Role of Combined Addition of Sr and Sb on the Microstructure and Mechanical Properties of Cast A356 Alloy

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ABSTRACT

Present paper describes the effect of melt inoculation of A356 alloy using Sb and Sr on its microstructural and subsequent influence on the mechanical properties of the same. The effect of melt holding time has also been investigated. The results show that Sr is better modifier for shorter holding time, and its modification efficiency is lost on longer holding of the melt. Interestingly, modification efficiency of Sb increases with the holding time. The results show encouraging behavior of these modifiers both at short as well as longer holding. The tensile and wear properties of A356 alloy modified using combined addition of Sr and Sb are promising.

Pattern Formation During Slow Solidification Studied by means of a Phase-Field Method

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ABSTRACT

An extended phase-field method has been used to compute the cellular structures in the range of 10th of μm up to some mm, which occur during a slow growth process of $\text{Ge}_x\text{Si}_{1-x}$ single crystals.

Methodology to Characterize Microsegregation

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ABSTRACT

Chemical microsegregation resulting from solidification of metallic alloys is most often characterised by EDS or WDS microanalysis using spot measurements located along a regular grid. Due to experimental limitations, the wave lengths of both dendrite arms and analysis grid are often of the same order of magnitude. Although this fact is generally eluded, it complicates the statistical analysis of the results, in particular when the objective is to validate a given solidification model or to prove the occurrence of solid state diffusion. This is first illustrated in the present work by means of experimental analysis performed on an Al alloy. The problem is then tackled using 2D simulations of more or less periodic solidification structures which are sub-sampled along periodic or random point distributions of different surface densities. Statistics tools are used to compare the resulting chemical distributions with the solidification model (Gulliver-Scheil model) injected in the simulation. This allows pointing out the limitations of classical statistical approach in that case, and finally to propose an optimum –at least less bad- procedure to characterise microsegregated structures.

Stereological Characterization of Solidification Microstructure

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ABSTRACT

Formation and evolution of microstructure during solidification involves nucleation and growth of different phases from a liquid melt. In general these solidifying phases have complex shapes and orientations depending on their crystal structure and thermal & compositional gradients. In order to develop a solidification micro-model one needs to be able to mathematically describe these complex microstructures and provide a quantitative description. This paper presents a set of stereological techniques based on differential-geometry formulation, which provide the necessary framework for such analysis. Particular emphasis is given to curvature measurements and application of concepts of spherical image.

Effect of Brownian Motion on Microstructure of Al-Sn Alloy

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ABSTRACT

CA based models coupled with CFD methods have been extensively used for prediction of cast microstructure. In the present work, the approach has been tested for Al-22Sn alloy. However, the CA based model was enhanced by incorporating the movements of newly formed nuclei due to Brownian movement. The average grain size predicted by the model incorporating Brownian motion was higher than the experimentally determined value and the model without incorporating the Brownian motion under predicted the average grain size. The grain size distributions obtained experimentally and by simulation suggests that further improvement in CA based model is required to bring the predictions closer to the experimental data. However, the present work establishes that Brownian motion significantly modifies the grain size distribution for Al-22Sn alloy and thus can not be ignored.

***In situ* Synchrotron X-ray Imaging of the Solidification Progress in Metallic Alloys**

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ABSTRACT

In situ X-ray imaging of the solidification progress can be carried out, nowadays, in front of the synchrotron sources, by combining X-ray radiography with X-ray topography. Thereby it is possible to obtain information directly, on the one hand on the shape and the velocity of the growing interface by means of X-ray radiography, and on the other hand, thanks to X-ray topography, on the strains and the defects generated at the moving interface by the growth process as well as in the grain volume by internal stress centres and external thermomechanical stresses. In addition, the interaction of strains and defects, contributing to the formation of the solidification microstructure observed after cooling, can also be followed during this combined imaging. Some of these feasibilities are highlighted by presenting various examples of the solidification of opaque alloys, displaying faceted or dendritic growth, we have studied with the apparatus we have developed to perform such experiments at the ID 19 ESRF (European Synchrotron Radiation Facility – Grenoble - France) beamline.

Growth Structures, Interface Dynamics and Stresses in Metallic Alloy Solidification: *In situ* Synchrotron X-ray Characterisation

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ABSTRACT

In solidification processing, the physical properties are primarily controlled by the microstructure built in the solid. Thus, materials engineering requires detailed understanding of microstructure formation dynamics. Using *in situ* and real-time synchrotron X-ray imaging at the European Synchrotron Radiation Facility, the solidification progress in thin metallic alloys is characterized. On Al - 3.5 wt% Ni alloys, disorienting induced by stress accumulation with the development of columnar dendrites is observed. In particular, X-ray radiography shows bending of secondary dendrite arms which, in the columnar to equiaxed transition, can be furthermore precipitated by equiaxed crystal sedimentation. Ledge growth and faceted solid-melt interface are found on AlPdMn quasicrystals. Increasing the solidification rate, the kinetic undercooling becomes sufficient for nucleation and growth of new grains ahead of the columnar grains.

Simulation of the Microstructure Evolution during Directional Solidification and Solution Heat Treatment of Superalloys

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ABSTRACT

Superalloys are a class of alloys aiming at high temperature applications. Single crystal turbine blades are manufactured through directional solidification and subsequent heat treatment, in a highly sophisticated process. Detailed knowledge of microstructural evolution is a key issue. A phase-field based method for the simulation of microstructural evolution in a spatial resolved manner is presented.

The simulations are done using a unit cell model to represent transverse sections through directionally growing dendrites. Within the unit cell the microstructure formation is simulated with the phase-field code MICRESS[®]. The constitution of phases and diffusion of the alloying elements is taken into account via coupling to thermodynamic calculations. The as-cast microstructures obtained from the solidification simulations define the starting conditions for the homogenization simulations.

The simulations were supplemented by experiments. Samples of a 5 component superalloy were directionally solidified under various conditions. Metallographic sections were analysed in terms of primary spacing, microsegregation, phase formation and the solidification interval. Selected samples were exposed to solution heat treatment for different durations and temperatures.

Good agreement between the simulations and experimental results is found.

Microstructure Evolution During Laser Surface Cladding and Remelting of Al-10wt%Bi-10wt%Cu

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ABSTRACT

Laser surface cladding and remelting provides a route to synthesize functional microstructures on the surface of structurally important materials. Alloys containing fine soft particles embedded uniformly in a hard matrix find applications as bearing materials with low friction coefficient. Elemental powder mixtures are used to clad Al + 10wt%Cu + 10wt%Bi on the surface of aluminium base metal in both single and multi-track mode at two different cladding speeds. The clad layers are remelted at speeds varying from 500 mm/min to 2500 mm/min to simulate different solidification speeds. Microstructure evolution during the process is studied by measuring particle size distribution and alignment to identify optimum processing conditions. Pin on disc experiments show a low friction coefficient of 0.22 for the samples remelted at 2500 mm/min.

Rapidly Solidified Immiscible Aluminium Alloys

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ABSTRACT

In order to explore the potential of rapid solidification of immiscible alloys detailed investigations of the microstructure of different Al-Pb alloys were carried out, varying over a wide range of alloy concentrations and cooling rates. The experimental results, obtained with the help of different methods are compared with numerical simulations of the decomposition and the microstructure evolution process.

Effect of Cooling Rate and Undercooling on Solid Fraction Evolution in an ASTM F75 Alloy

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ABSTRACT

Quenching during directional solidification, QDS, experiments of a biocompatible Co-based alloy were performed in order to study the effect of the solidification conditions on the evolution of the solid fraction as a function of temperature, $f_s(T)$. Five extraction rates were chosen in the range of 1.2 to 18 mm/min. Two temperature gradients were employed: 6 and 12 °C/mm. The solidification of this alloy initiates at 1407 °C and ends around 1206 °C with the precipitation of a second phase. Experimental data show that $f_s(T)$ evolution is slower at higher cooling rates, and therefore, microsegregation increases as secondary dendrite arms become smaller. However, differential thermal analysis, DTA, experiments performed for this alloy suggest that the onset temperature of solidification has also an important effect on the final microsegregation. In these DTA experiments it was observed that the thermal peak associated with the end of solidification, i.e. precipitation of the second phase, disappeared when the onset temperature of solidification was lower than 1354 °C. The experimental results presented in this paper show that both cooling rate and undercooling effects must be taken into account in order to be able to predict the final microsegregation in this kind of alloys. Simulations performed with Thermocalc and DICTRA are in good agreement with the experimental results on a semi-quantitative point of view.

Microstructural Control During Spray Deposition Processing of Liquid Immiscible Alloys

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ABSTRACT

Alloys based on Al-Pb and Cu-Pb systems were gas atomized and spray deposited on a copper substrate. Microstructure of spray deposited Cu-20Pb alloy showed an equiaxed grain morphology of the primary α -phase in contrast to cellular-dendritic morphology of a wide size range of powder particles. A uniform distribution of ultrafine Pb particles was observed in the deposit of Al-4Cu-20Pb alloy against a bimodal size distribution of Pb particles in atomised powder particles of this alloy. The wear rate of Cu-20 Pb alloy was observed to be higher than that of Al-4Cu-20Pb alloy at low load and sliding velocity. However, the former indicated a low wear rate in severe wear regime of high load and sliding velocity. The mode of solidification of liquid immiscible alloys is discussed and their wear behaviour analysed in light of solidification structure of alloys generated during spray deposition processing.

Understanding Bulk Metallic Glass Formation in Zr-Cu-Al System by Thermodynamic Approach

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ABSTRACT

A key issue in metallic glass research has been a conceptual understanding of their formation. The richness of this topic arises from interplay of various factors like thermodynamics, kinetics, electronic structure and local geometry. This paper briefly reviews the various approaches towards understanding glass formation and introduces very simple schemes for integrating the various factors thereby proposing a synergistic model for understanding glass formation.

Bulk Nanostructure – Dendrite Composites: Solidification, Microstructure and Mechanical Properties

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ABSTRACT

Because of their unique properties, bulk metallic glasses and nanocrystalline materials are attractive candidates for structural and functional applications. Their strength is significantly higher than of conventional crystalline alloys. However, one major drawback is their low ductility and their rapid failure. In order to obtain both high strength and high ductility, heterostructures with different phases and different length scales have been developed. This work reports on Ti-based alloys with an *in-situ* formed composite microstructure, produced in bulk form in a one-step process. The microstructure consists of dendrites distributed in a nanocrystalline matrix whose volume fraction and morphology depend on the nominal composition of the alloy. Structural and compositional analyses of the different phases will be presented as well as the solidification process that leads to such composites. The microstructure will be correlated with the mechanical properties. We will show that, by tailoring the microstructure, high strength or high ductility or different combinations of both can be reached.

Creation Process of Metallic Glasses by Electromagnetic Vibrations

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ABSTRACT

A new method for producing the bulk metallic glasses by using electromagnetic vibrations is proposed and also the effects of the electromagnetic vibrations on the glass forming ability of MgCuY alloys are investigated. It is found that the new method by using the electromagnetic vibrations is effective in enhancing the glass-forming ability of these alloys. Disappearance of the clusters by the electromagnetic vibrations applied to the liquid state is presumed to suppress crystalline nucleation, namely, enhancing the glass-forming ability. The effects of the intensity and frequency of electromagnetic vibrations on the apparent glass-forming ability in Mg-Cu-Y bulk metallic glasses have been clarified. The apparent glass-forming ability of these glasses increases with increase in the frequency of electromagnetic vibrations up to 5000 Hz and also with increase in the intensity of them.

Moreover, in order to clarify the effects of the electromagnetic vibrations on glass-forming ability for other alloy systems, influence of the intensity of electromagnetic vibration force on glass-forming ability in the Fe-Co-B-Si-Nb alloys have been studied. As a result, it has been found that the glass-forming ability of Fe-Co-B-Si-Nb alloys also increases with increasing the intensity of electromagnetic vibration force.

Planar Flow Melt Spinning of Soft Magnetic Amorphous Ribbons

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ABSTRACT

Amorphous ribbons have been produced in Fe₇₃..5Si₁₃.5B₉Nb₃Cu₁ alloy through Planar Flow Melt Spinning (PFMS) process for soft magnetic core applications. The effect of different process parameters especially nozzle dimensions, nozzle wheel gap, ejection pressure and melt temperature on the quality of the ribbons was investigated in details. In this paper we present our experimental observations in producing long and wide amorphous ribbons (30 g batch size). It has been observed that the amorphous phase formation is not only dependent on the thickness of the ribbon but also superheat temperature of the melt.

Effect of Solidification Rate and Composition on Microstructure and Crystallization in Al-Ni-La Metallic Glasses

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ABSTRACT

Al₈₇La₇Ni_{6-x}Ag_x (x = 0,1) alloys, prepared by copper mould casting and melt-spinning at different wheel speeds, were studied by X-ray diffraction, scanning electron microscopy, differential scanning calorimetry and microhardness measurements. The Cu-mould cast ingot shows a hypereutectic microstructure. At the highest cooling rate (wheel speed 40 m/s) the ribbon is completely amorphous, while at lower wheel speeds mixed structures comprising amorphous and crystalline phases or only crystalline phases were observed. Both the ribbons (with and without Ag containing alloys) show two-stage crystallization process on annealing. Crystallization kinetics was analysed by Kissinger and Johnson-Mehl-Avrami approaches. The low values of activation energy reflect the instability of these amorphous alloys. Microhardness of all the ribbons was examined at different temperatures and was correlated with the corresponding evolution of phases.

Solidification of Hybrid Aluminium Alloy Matrix Composites

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ABSTRACT

Hybrid metal Matrix Composites (HMMC) are second generation composites containing more than one type, shape and size of reinforcements in the matrix alloy. These composites offer combined properties of the reinforcements, some times improved and special properties with synergistic effects. The properties of these composites depend strongly on the distribution profile of the reinforcements. However, the nature of the distribution of the reinforcements depends on the size, shape and the morphology of the reinforcements and their sequence of addition. The other factors affecting the solidification conditions and microstructure of the composites are thermal characteristics of the reinforcements and the interfacial reaction taking place between the reinforcements and the matrix. In the present investigation, the hybrid composites are synthesized by stir casting technique and solidification behavior of hybrid Al-SiC_p-graphite particle reinforced composites is studied using thermal analysis and Differential thermal analysis (DTA) and compared with corresponding microstructures.

A Thermodynamic Assessment of the Inoculation Process in Al-base Alloys

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ABSTRACT

The binary Al-Ti and the ternary phase diagrams Al-Ti-B and Al-Ti-C are calculated from normal thermodynamic laws. The calculated phase diagrams are used to discuss the formation of Al₃Ti during the cooling process. In the binary Al-Ti phase diagram an undercooling of only 30 K is shown to be necessary to nucleate new crystals of Al₃Ti. It is shown that both Al₃Ti and TiB₂ are formed during cooling of an inoculated Al-melt. TiB₂ is more easily nucleated than Al₃Ti due to its lower solubility product. Al₃Ti is assumed to be nucleated on the TiB₂ particles. TiC is not stable at the melting point of aluminium and will decompose into Al₄C₃ and Al₃Ti during cooling. It is suggested that Al₃Ti is the active reagent for nucleation of Al.