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Abstract

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SSM Research: Comments on Recent Contributions, and a Look to the Future

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ABSTRACT

Results of researches presented at the S2P conference in 2018 demonstrate the continuing significant contributions of SSM researchers throughout the world. This talk will include comments on a number of such studies, and also on what the studies suggest for future developments in SSM and related technologies.

ABOUT RESIDUAL STRESS STATE OF CASTINGS: THE CASE OF HPDC PARTS AND POSSIBLE ADVANTAGES TROUGH SEMI-SOLID PROCESSES

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ABSTRACT

Nowadays, one of the most important focus in the aluminium-foundry sector is the production of high-quality castings. Particularly, High-Pressure Die Casting (HPDC) is largely adopted, since by this process is possible to realise aluminium castings with thin walls and high specific mechanical properties. On the other hand, this casting process may cause tensile states into the castings, namely residual stresses. Residual stresses may strongly affect the life of the product causing premature failure of the casting. These stresses states can be assessed by various methods, but the non-destructive X-Ray method is the most commonly adopted. Namely, in this work the residual stress analysis has been performed by means of Sinto Pulstec μ-X360s and detailed measurements have been done on powertrain components realised in aluminium alloy EN AC 46000 through HPDC processes, with the aim to understand and prevent dangerous residual stress states into the aluminium castings. Furthermore, a comparison with stresses induced by Rheocasting processes is under way. In fact, it is well known that Semi-Solid metal forming combines the advantages of casting and forging, solving safety and environmental problems and possibly even the residual stress state can be positively affected.

SEMISOLID CASTING AND DIE CASTING OF AL-4.8%MG-2%SI ALLOY

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ABSTRACT

Al-4.8%Si-2%Si was cast by conventional die casting, low temperature die casting and thixocasting, and tension test was conducted to investigate the effectiveness of semisolid casting on Al-4.8%Si-2%Si. In the low temperature die casting, the super heats of molten metal when it was poured into sleeve of die cast machine was 5 and 10 °C. It is estimated that the molten metal became semisolid slurry in the sleeve. Therefore, the low temperature die casting can be considered as rheocasting. Specimens for tension test were cast by conventional and low temperature die castings. In the thixocasting, the low temperature cast ingot and strain induced ingot were heated up to semisolid temperature and water cooled, after that the specimens for tension test was machined. The UTS and elongation of the thixocasting was inferior to that of the low temperature and conventional die castings. The primary Al became globular in the thixocasting. Eutectic of the ingots for rheocasting was coarse lamella structure. This coarse lamella structure remained unchanged after heated up to semisolid condition and water quenched. It is thought the coarse lamella structure made the UTS and elongation worse. The UTS and elongation of the low temperature die casting was almost same as that of the conventional die casting. In the low temperature die casting, the primary Al was fine globular, and the coarse lamella structure did not exist. The low solid fraction rheocasting by the low temperature die casting is suitable for Al-4.8%Mg-2%Si than the thixocasting.

COARSENING AND DEFORMATION BEHAVIOR OF SEMI-SOLID LIGHT ALLOYS:

KNOWLEDGE LEARNED FROM SYNCHROTRON STUDIES

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ABSTRACT

Semi-solid alloys differ from the pure liquid or solid alloys due to the presence of combined liquid and solid phase, and thus have unique physical properties and phenomena. For instance, coarsening exists in many semi-solid alloys processing and the deformation behavior of semi-solid alloy is totally different from its solid counterpart. Understanding the microstructural evolution of semi-solid alloys during fabrication or/and under external loading is key to optimizing the compositions and processing parameters, and thus to obtaining advanced material performance. In this talk, coarsening of semi-solid Mg alloys will be presented using advanced synchrotron imaging technique. The synchrotron images along with the quantitative microstructural characteristics reveal the dominating coarsening mechanisms of Mg alloys. Regarding deformation behavior of semi-solid alloys, in situ compression of semi-solid particle reinforced Al composites will be presented to show the 3D pore/defects evolution under external loading. Quantitative image analysis of the semi-solid deformation behavior of three alloys (base, nano- and micro-particle reinforced) reveal the influence of the particulate size on both microstructural formation and dominant deformation mechanisms. The results demonstrate the influence of alloy composition and processing parameters upon final microstructure, and will also act to inform and validate numerical models of microstructural evolution in a wide range of semi-solid metallic materials.

Keywords: Mg alloy; Al matrix composites; Semi-solid processing; Deformation behavior; Synchrotron imaging

Variation of microstructure and mechanical properties of ZW61 magnesium alloy solidified under different pressures

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Abstract

There is little datum related to microstructure and properties of Mg alloys squeeze-casted with pressure over 200 MPa. In this study, the microstructure and properties of Mg-6Zn-1.4Y (ZW61) alloy solidified under 100MPa to 800MPa were investigated. The results show that a remarkable microstructure refinement and porosity reduction can be reached through solidification under high pressure. The average grain size and the volume fraction of second phase, i.e. quasicrystal *I*-phase, decrease continuously with the increase of applied pressure. The tensile properties, especially elongation, are obvious enhanced because of the microstructure refinement and castings densification under high pressure. The ultimate tensile strength and elongation of ZW61 alloy in as-cast state are 243 MPa and 18.7% when the applied pressure is 800 MPa, which are increased by 35% and 118% respectively, compared with that of the gravity castings.

Keywords: high pressure, Mg-Zn-Y alloy, squeeze casting, microstructure, mechanical properties

MICROSTRUCTURE EVOLUTION OF A SEMISOLID MAGNESIUM ALLOY SLURRY OBTAINED VIA AN INTERNAL RAPID COOLING STIRRING PROCESS (IRCSP)

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ABSTRACT

Grain refinement of magnesium alloys is an effective way to improve their tensile strength and ductility and meet industrial application requirements. Herein, a new rheocasting process, internal rapid cooling stirring process (IRCSP), was used to obtain a fully grain-refined spherical semisolid slurry. A rapid quenching method was used to study the microstructure evolution during IRCSP. The experimental results showed that the solid fraction was mainly determined by nucleation, and grain growth played only a minor role. The particle density was determined by a combination of a fragmentation mechanism and the coalescence of solid particles. The change in grain size over time followed a 1/3 power law ripening coefficient. In addition, the particle distribution was determined using shear stress flow and cooling rates. Microstructural analysis suggested that a fast cooling rate led to grain refinement, and rapid stirring enhanced the interfacial energy and stability of the solid-liquid interface. As a result, fine globular primary α-Mg particles were obtained during IRCSP.

SHORT-TERM OXIDATION BEHAVIOR, MICROSTRUCTURE EVOLUTION AND COMPRESSION BEHAVIOR OF NICKEL-BASED SUPERALLOY GH4037 IN SOLID AND SEMI-SOLID STATES

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ABSTRACT

Semi-solid processing combines the advantages of traditional forging and casting methods, so it has received much attention recently. However, the research on semi-solid behaviors of Nickel-based superalloys has been rarely reported. In order to investigate the behaviors of Nickel-based superalloy at solid and semi-solid states, oxidation experiments, isothermal treatment experiments and deformation experiments of GH4037 alloy were studied. Short-term oxidation experiments of GH4037 alloy were carried out at a solid temperature (1200 °C) and a semi-solid temperature (1360 °C). The results indicated that the oxides formed at 1200 °C were mainly composed of TiO_2, Cr_2O_3 and a small amount of spinels $NiCr_2O_4$, while the oxides formed at 1360 °C consisted of the spinels of $NiCr_2O_4$, $NiWO_4$ and $NiMoO_4$ besides TiO_2 and Cr_2O_3. Microstructure evolution of GH4037 alloy after semi-solid isothermal treatment at 1370 °C and 1380 °C was studied. The results indicated that semi-solid microstructures consisted of equiaxed solid grains and liquid phases. The average grains size and shape factor of solid grains were affected by melting mechanism and grain growth mechanism. Compression behaviors of GH4037 alloy after compressed at 1200 °C and 1360 °C were investigated. The results indicated that the flow stress of 1360 °C decreased significantly compared to that of 1200 °C. The deformation zones in the specimens were divided into three parts: the difficult deformation zone, the large deformation zone, and the free deformation zone. At 1200 °C, the deformation mechanism was plastic deformation mechanism. At 1360 °C, sliding between solid particles (SS), liquid flow (LF), flow of liquid incorporating solid particles (FLS), plastic deformation of solid particles (PDS) coexisted in the compression specimen.

Keywords: Nickel-based superalloy; semi-solid processing; oxidation behavior; microstructure evolution; deformation behavior.

ROLE OF IRON-RICH PHASES AND POROSITY ON THE DUCTILITY OF RHEOCAST AL-MG-SI ALLOYS

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ABSTRACT

Treatment of the slurry is important during RheoMetal™ casting. In this work, semi-solid slurries were prepared under different stirring intensities, using two types of stirrers: a naked rod (for regular stir) and a rod with two blades (for intensified stir). Tensile tests were performed, investigating fracture surfaces, as well as metallographic samples. The results show that intensified stir produces castings with finer primary particles and more homogeneous microstructures. On the other hand, more faceted Fe-rich phases are found along the α-Al grains boundary as well, due to the dissolution of Fe from the stirrers. Moreover, for intensified stir castings, the porosity found on the fracture surfaces are smaller, while more brittle eutectic phases and second (intermetallic) phases, especially Fe-rich phases, are observed. Consequently, the castings with intensified stir show worse ductility. Finally, a quantitative analysis was made regarding ductility, affected both by porosity and the presence of Fe-rich phases.

EFFECT OF SOLUTE TA ON GRAIN REFINEMENT OF AL-7SI-0.3MG BASED ALLOYS

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ABSTRACT

In this paper, different Ta concentrations together with stochiometric grain refiner (Al-2.2Ti-1B) were investigated with the aim to elucidate grain refinement mechanisms. Post-solidification microstructure was characterised using optical microscopy and scanning electron microscopy (SEM), with a special focus on the Ta-rich layer (more likely to be Al_3Ta) on the basal planes (0001) of TiB_2. A significant grain refinement was observed by using the solute Ta together with stochiometric grain refiner (Al-2.2Ti-1B). In order to further elucidate the formation of Ta-rich layer on the basal planes (0001) of TiB_2, the Density Functional Theory (DFT) calculation were also performed to determine the interface energies of different interfaces and sandwich configurations, including Al (111), Al_3Ti (112) and Al_3Ta (112) at the interface of TiB_2 basal plane (0001). It was found that the interface energy for Ti-terminated TiB_2 at the interface throughout all configurations involved in this paper is lower than that for B-terminated TiB_2, indicating that Ti-terminated TiB_2 is more favourable. It was also found that the Al_3Ta configuration yields the same interface energies as the Al_3Ti configuration. Furthermore, the interface energy of the sandwich configuration also shows nearly identical values along the TiB_2 // Al_3Ti and TiB_2 // Al_3Ta interface energy, strongly indicating that the solute Ti can be fully replaced by the solute Ta. On the other hand, it also strongly indicates that the interface energy as a single parameter cannot be used to interpret the interface evolution on the TiB_2. Other factors (i.e. interfacial adhesion, stability, wetting, and bonding nature) should be taken into consideration when discussing the grain refinement of Al-Si-Mg alloys caused by the TiB_2.

Key words: Al-Si-Mg alloy, Grain refinement, DFT, TiB_2, Ta, Nucleation

PHASE TRANSFORMATION OF M2 HIGH SPEED STEEL DURING SEMI-SOLID COOLING AND CONVENTIONAL COOLING

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ABSTRACT

In this paper, the fundamental microstructure evolution of M2 high speed steel was investigated during semi-solid controlled cooling and conventional cooling, respectively. Semi-solid controlled cooling was conducted at 1260 ºC with cooling rates from 0.1 to 10 ºC/s, while conventional cooling was conducted at 1200 ºC and 890 ºC with different cooling rates. The continuous cooling transformation curves were plot according to the microstructure evolution. The results showed that microstructure transformation behavior of cooling structure in semi-solid temperature range was different from that of conventional process. For semi-solid specimen, the solid austenite dissolved more alloy elements, and the austenite stability was increased. The solid matrix was pearlite structure in the samples with cooling rate of 0.1℃/s and 0.5℃/s. When the cooling rate reached 5℃/s, the granular pearlite disappeared and martensite lath was formed. The structure was relatively uniform, on which there were large carbide with regular shape. The liquid phase was more uniform and continuous during lower cooling rate, while the liquid phase became network and block during higher cooling rate. There were a lot of carbides in the liquid-phase eutectic structure, and M_6C and MC carbides were observed. For conventional cooling process, there existed plenty of undissolved large carbides during the austenitization. The matrix structure mainly suffered martensite transformation after cooling from 1200 ºC and 890 ºC.

Key words: M2 high speed steel, microstructure evolution, semi-solid controlled cooling

MICROSTRUCTURE AND MECHANICAL PROPERTIES OF RHEO-DIECASTING MG-10GD-3Y-1ZN-0.4ZR (WT.%) ALLOY

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ABSTRACT

The rheological slurry of Mg-10Gd-3Y-1Zn-0.4Zr (wt.%) alloy was prepared using Swirled Enthalpy Equilibrium Device (SEED), and then injected into a self-designed mold of mobile phone medium plate for high pressure die casting. The preliminary experimental results show that the rheo-diecasting can greatly reduce the porosity in conventional diecasting. The mean size of the external solidification grains (ESG) of the rheo-diecasting (about 50μm, accounting for 57%) is significantly larger than that of conventional diecasting (about 22μm, accounting for 22%). In contrast, the mean size of secondary solidification grains in rheo-diecasting and conventional diecasting is about 2.2μm and 3.6μm, respectively. However, contrary to expectation, the tensile strength, yield strength and elongation of conventional diecasting are higher than those of rheo-diecasting, which may be related to the larger mean grain size in rheo-diecasting. In future, it is necessary to further optimize the slurry preparation and diecasting processes to improve microstructure and mechanical performance.

INFLUENCE OF SOLUTION TREATMENT ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF SEMI-SOLID PROCESSED NANO-SICP/AL-CU COMPOSITES

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ABSTRACT

In this study, the evolution of microstructures and properties of 1 wt% nano-SiC_p/Al-Cu composites during solution treatment has been systematically investigated. Comparison of the solution treatment between composites and matrix alloy has been made to investigate the effect of nano-SiC_p particles on heat treatment. Results indicate that nano-SiC_p particles in the matrix of the composites fabricated with semi-solid process can prevent the Al_2Cu phase from dissolving into the α-Al phase to some extent. Besides, the composites exhibit the highest hardness and tensile properties in the T6 state after solution treated at 540 °C for 10 h. Its hardness and ultimate tensile strength are 150 HV and 502 MPa, which are increased by 120% and 84% than the as-cast properties, respectively, while the elongation remains good.

Keywords: Aluminum matrix composites; Nano-SiC_p particles; Solution treatment; Mechanical properties; semi-solid process

MICROSTRUCTURE AND PROPERTIES OF SEMI-SOLID CUSN10P1 ALLOY SHAFT SLEEVE UNDER DIFFERENT MELT TREATMENT PROCESSING

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ABSTRACT

Abstract: The semi-solid slurry of CuSn10P1 alloy was prepared by a self-developed melt constrained flowing induced nucleation device and a cavity four-mold shaft sleeve part are formed. Microstructure and properties of shaft sleeve by liquid squeeze casting and semi-solid direct squeeze casting and semi-solid squeeze casting with similar isothermal are studied. The results show that microstructure of shaft sleeve by liquid squeeze casting is dendrite, microstructure of shaft sleeves by semi-solid direct squeeze casting has obvious solid-liquid separation and agglomeration, microstructure of shaft sleeve by semi-solid squeeze casting with similar isothermal is equiaxed crystal and uniformly distributed. The properties of shaft sleeve by semi-solid squeeze casting with similar isothermal is the best, and the ultimate tensile strength and elongation of shaft sleeve reached 417 MPa and 12.5%, which were improved by 21.9%、90.6% and 20.3%、231.6%, respectively, as compared to that of liquid squeeze casting and semi-solid direct squeeze casting.

Keywords: CuSn10P1 alloy, semi-solid, similar isothermal, microstructure and properties, squeeze casting

RECYCLING Al-Si ALLOYS BY SEMISOLID MATERIAL DRAGGED DURING CONTINUOUS-CASTING STRIP PROCESSING

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ABSTRACT

Recycled Al–Si (9.2% – 10.7%) alloys contaminated with Fe (0.3% - 0.6%), Pb (0.2% - 3.0%) and Sn (1.4% 11.3 %) were cast and poured at 650 ºC, 50 ºC above liquidus line approximately, in a cooling slope to obtain a semisolid material that feeds a ceramic nozzle designed to performance a good contact area for solidification and improve the strip cast quality. The internally cooled rolls by soluble oil (1 oil / 9 water) at a rate of 0.2 L/s worked as heat exchanger which drags the metallic slurry puddle generated at the roll surface at different speeds (0.12 m/s, 0.17 m/s, 0.21 and 0.25 m/s) forming a metallic strip with a thickness of 2 mm and width of 45 mm, approximately. The cooling system combined with four springs placed at the housing screw prevented the sticking of the metallic strip on the rolls. The flow of the solidified strip from the strip caster was better controlled using lower roll speeds. Cracks were observed on the strip surfaces in all conditions, but these defects did not interrupt the continuous flow of the solidified strip during manufacturing. The strip's poor surface quality could be related to the Pb and Sn contamination. This subject is discussed in this paper. The fine globular structures with smaller finely distributed Al-Si eutectics with lower Pb and Sn contamination resulted in a metallic strip with higher mechanical strength and ductility.

COOLING CURVE ANALYSIS OF A356 ALLOY BY CONVENTIONAL CASTING AND THE EFFECT OF STIRRING

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ABSTRACT

In recent years, great progress has been made in thermal analysis techniques, which provide information about latent heat of solidification, fraction solid evolution and dendrite coherency point characteristics. Cooling curve analysis by a Newton method has shown to be capable to achieve quantitative information. Besides, a conventional casting alloy (Al-Si) takes place with the dendritic formation of the alpha phase in the eutectic matrix, but when stirring the alloy, globular microstructure formed by spheroids of solid alpha surrounded by eutectic is obtained.

The subject of this work is to explore the effect of stirring during solidification of Aluminum A356 alloy, mainly focusing on the change from dendritic to the globular structure. For this purpose, samples of A356 alloy were melted in the electrical resistance furnace and cooling curves were recorded for each level agitation (without, 667, 1153, 1567, 2271 revolutions per minute).

The experimental curves were numerically processed by calculating the first and second derivatives. From these were determined temperatures and times of start nucleation of alpha, eutectic reaction, end of solidification. It is interesting to note that cooling curves show the same tendency. However, as the level of agitation increases, times and temperatures where solidification began and ended were modified.

CONTROL OF AMOUNT OF α-AL PHASE PARTICLES IN NEAR EUTECTIC AL-SI ALLOY BY ELECTROMAGNETIC STIRRING

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ABSTRACT

Al-Si alloy is widely used as a casting alloy. The α-Al phase in the semi-solid state has low Si content in the Al-Si alloy. Then by separation of these α-Al phases from semi-solid Al-Si alloy, refining of aluminum can be possible. But, in near eutectic Al-Si alloy, few primary α-Al phases can be crystallized. If the fraction ratio of the α-Al phase can be increased, near eutectic Al-Si alloy can refine, and this method can be used for recycling. In this study, the effect of electromagnetic stirring (EMS) on the microstructure, especially the amount of the α-Al phase particles was investigated. A rotational magnetic field was applied to JIS ADC12 alloy which has near eutectic content during slow cooling from the liquid state to the solid-state, by using a three-phase AC coil. By applying EMS at solidification, the shape of the α-Al phase became particle shape from dendrite shape, and the amount of α-Al phase particles was increased. Moreover, by applying unidirectional intermittent EMS, the volume fraction of α-Al phase particles was decreased with increasing intermittent applying time. In ADC12 alloy, the primary α-Al phases can be crystallized only 10% generally, but it could be obtained over 40% by applying EMS. This means that the semi-solid slurry of near eutectic alloy with over 40% of fraction solid can be obtained by applying EMS.

EFFECT OF THE MG_3N_2 SUB-MICRON PARTICLE ON THE GRAIN REFINEMENT OF AZ80 ALLOY

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ABSTRACT

AZ80 alloy has been widely used to produce high performance Mg casting and wrought parts for high-end applications due to its high mechanical properties and deformation ability. However, at least two important issues still need to be solved in order to further improve its mechanical properties and deformation ability. Firstly, the grain size of α-Mg in AZ80 alloy is relatively large (more than 1000 μm) due to a lack of efficient grain refinement methodologies. Secondly, the size of the eutectic $Mg_{17}Al_{12}$ phase is also large and the distribution of the eutectic $Mg_{17}Al_{12}$ phase is continuous, which is very harmful for the mechanical properties, in particular to elongation. In this paper, these two important issues are investigated by adding Mg_3N_2 sub-micron particle into AZ80 alloy and thereby refining the α-Mg and the eutectic $Mg_{17}Al_{12}$ phase. Firstly, the Mg_3N_2 sub-micron particle was directly added into AZ80 alloy by using mechanically stirring in the semi-solid state, subsequently the melting temperature was increased above the liquidous temperature, and finally the melting was casted in the liquid state. It was found that the grain size of α-Mg can be refined from 883.8 μm to 169.9 μm. More importantly, the eutectic $Mg_{17}Al_{12}$ phase was also refined and the distribution became discontinuous. It should be noted that directly adding the Mg_3N_2 sub-micron particle into AZ80 alloy leads to a great loss of the Mg_3N_2 sub-micron particle due to the weak wetting behavior between the Mg_3N_2 sub-micron particle and Mg melt. The second methodology through mixing Mg_3N_2 sub-micron particles with AZ91 chips using a twin extruder was also used to prepare AZ91 master alloy with 3wt.% Mg_3N_2 sub-micron particle, which was subsequently added into AZ80 alloy in the liquid state. In this way, a significant grain refinement of α-Mg and a simultaneous refinement of the eutectic $Mg_{17}Al_{12}$ phase in AZ80 alloy was also achieved. The grain size of α-Mg can be refined from 883.8 μm to 325.9 μm. However, no significant grain refinement by using UST was observed. Instead, the grain size increases from 325.9 μm to 448.6 μm, indicating that the Mg_3N_2 sub-micron particle may lose its grain refinement potency due to possible aggregation and clustering. This paper provides an efficient and simple methodology for the grain refinement of α-Mg and the simultaneous refinement of the eutectic $Mg_{17}Al_{12}$ phase in AZ80 alloy.

Keywords: AZ80 alloy, Grain refinement, Mg_3N_2 sub-micron particle, Semi-solid casting, Eutectic $Mg_{17}Al_{12}$

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PROGRESS OF SEMI-SOLID PROCESSING OF ALLOYS AND COMPOSITES IN CHINA

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ABSTRACT

Following the rapid growth of automotive and communication industries, components with high quality and low cost are eagerly demanded in China. Various technologies have been developed in China to meet the demand, while semi solid processing of alloys and composites is one of the most successfully developed and practically applied technologies. The major semi solid processing applied in China is the rhoecasting in terms of Enthalpy Equilibration methods. This paper will discuss about the mechanism of the Enthalpy Equilibration methods, and examples of successful development and applications of the techniques in China.

PREPARATION OF SEMI-SOLID 357.0 SLURRIES WITH DIFFERENT A-AL PHASE FEATURES BY SOLIDIFICATION FROM FULL LIQUID STATE AND REMELTING

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ABSTRACT

The characteristics of the solid phase, namely the volume fraction, particle size, and morphology, are dominant variables that can determine the viscosity of the semi-solid slurry. However, particle size and morphology were always being ignored and the solid fraction was simply determined using the temperature in the conventional power-law viscosity, resulting in a disagreement in the viscosity values in different researches. To make the power-law viscosity model more accurate for predicting the filling process of semi-solid die casting, it is essential to modify this viscosity model based on particle characteristics. Therefore, there is a fundamental demand to prepare semi-solid slurries with different α-Al phase features at first. This is achieved in this study by two kinds of heat history controlling methods: remelting and solidification, which can get slurries with spherical structure and dendric structure, respectively. The semi-solid 357.0 slurries with 0.11-0.43 solid fraction, 137-182μm particle size, and 0.81-0.90 shape factor were prepared in the remelting process, while dendritic structures (shape factor<0.5) with 0.1 and 0.3 solid fractions were obtained by solidification controlling from the full liquid state. Besides, the effect of parameters on the evolution of the α-Al phase has been discussed. These slurries with different solid features will be further used to quantify the influence of primary phase characteristics on rheological behavior and make the power-law viscosity model more accurate for simulation.

UNDERSTANDING THE RHEOLOGICAL TRANSITIONS IN SEMI-SOLID ALLOYS BY A COMBINED IN-SITU IMAGING AND GRANULAR MICROMECHANICS MODELING APPROACH

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ABSTRACT

Advanced pressurized casting processes such as semi-solid processing (SSP), high-pressure die casting (HPDC), twin-roll casting (TRC), and the continuous casting of steel apply compressive and shear loading on semi-solid alloys. However, deliberately applied loading can induce complex rheological response of semi-solid from suspension flow, strain localization, to cracking. To gain better understanding of these behaviors, this research conducted shear-deformation on globular semi-solid Al-Cu alloys to study the rheological behavior of semi-solid as a function of solid fraction (38% - 85%) and shear rate (10^{-4} – 10^{-1} s^{-1}) under real-time synchrotron radiography observation. By analyzing 17 X-ray imaging datasets, we define three rheological transitions: (i) the critical solid fraction from a suspension to a loosely percolating assembly; (ii) from the net contraction of a loose assembly to the net dilation of a densely packed assembly, and (iii) to shear cracking at high solid fraction and shear rate. Inspired by in-situ observations of semi-solid deformation showing disordered assembly of percolating crystals in partially-cohesive contacts with liquid flow, we reproduced a two-phase sample using the coupled lattice Boltzmann method-discrete element method (LBM-DEM) simulation approach. In DEM, each globular Al grain is represented by a discrete element, and the flow of interstitial liquid is solved by LBM. The LBM-DEM simulations show quantitative agreement of semi-solid strain localization with the experiments and are used to explore the components involved in the shear rate dependence of the transitions, and the role of liquid pressure on the initiation of shear cracking.

NEW PARAMETERS FOR CASTING PROCESSES: THE RHEOLOGY OF METAL ALLOYS IN THE SOLID-LIQUID PHASE

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ABSTRACT

Knowledge about the rheology of metal alloys in the solid-liquid phase is critical for optimization of thixo- and rheocasting processes. Unlike in traditional casting processes, those thixo- and rheocasting processes employ the material in a semisolid state that is injected into dies at high shear rates. One of the main advantages of the solid-liquid state (semi-solids) in contrast with conventional casting is the reduced porosity in the cast part and significantly lower temperature and solidification time.

The high-temperature rheometers from Anton Paar enable the rheological investigation of metal alloys to a sample temperature of 1730 °C. To exemplify the rheology of alloys in the solid-liquid phase, we present the rheological characterization of two aluminium alloys by applying rotational and oscillatory rheometry, thus probing both the forming as well as the behaviour of the semi-solid state.

Different shear stresses showed a significant influence on the rheological behaviour and thus the viscosity of the alloy. This was true for the liquid material and in the solid-liquid phase between liquidus and solidus, which is crucial for these non-traditional casting processes. The viscosity at high applied shear stresses like they are used in thixo- and rheocasting processes, is significantly lower than when measured at rest. Also, oscillatory measurement during cooling revealed residual thixotropic influences on the material. Structural changes on metallographic microsection were observed linking the loss of dentritic structure with the rheological data.

Thus high temperature rheology is shown to be a powerful tool to investigate metal alloys in modern casting processes.

EXPERIMENTAL AND NUMERICAL STUDY OF THE EFFECT OF POURING TEMPERATURE AND FLUID CONVECTION ON SPHERICAL GRAINS FORMATION

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ABSTRACT

Spherical morphology is the typical characteristic of the microstructure in semi-solid slurries, while the formation mechanism of these spherical grains is still unclear, especially the migration of the solid-liquid interface under different process conditions. This study will focus on the effect of pouring temperature and swirling on the morphology of grains. A phase-field-lattice-Boltzmann method using parallel computing and adaptive mesh refinement (Para-AMR) was employed to study the FCC α-Al phase evolution in binary Al-Si aluminum alloy. Study results represent that the pouring temperature has a significant influence on the morphology of the α-Al grains. Low pouring temperature is a benefit for the formation of spherical microstructures. And the swirling can alter the grain morphology under high pouring temperature from dendrite to equiaxed grain.

VISCO-ELASTIC PROPERTIES OF SEMI-SOLID ALLOYS

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ABSTRACT

Relaxation- and creep experiments have been performed with Semi-Solid Material AlSi7 with 35% solid fraction to investigate the early visco-elastic properties after shearing of the material in a Searl Rheometer. The preparation of the SSM has been done in situ using a standard procedure to guarantee for all experiments the same initial properties of the material. The experiments have been performed after a defined resting period.
Creep experiments are characterized by exposing the material to a sudden increase of shear stress whereas in relaxation experiments a sudden increase of strain is applied. The resolution in time for both types of experiments has been 0.01 seconds, which allows observing the dynamics of the development of visco-elastic properties.
In both sets of experiments the material exhibits viscoelastic properties which are becoming more pronounced with longer resting time. This is in accordance with previous experiments where the ratio between elastic and viscous properties increases with increasing resting time. The development of the elastic properties follows the increase of the yield stress value due to the creation of an internal structure of the material, which starts immediately after stopping shearing. A structure with a certain mechanical stability is achieved already after 0.08 seconds. This can be clearly tracked by the development of the rheological properties with time. The investigation of the short-term response of SSM can be particularly relevant for industrial practice, where material deformation during die filling is very fast and the material flow does not take place in steady-state condition.

FLOW BEHAVIOR OF SEMI-SOLID SLURRIES WITH AND WITHOUT DENDRITES

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ABSTRACT

Flow behavior of semi-solid slurry determines quality of the castings produced by semi-solid forming process. Many studies have been done to investigate the flow behavior of slurry under different conditions, and results show that the rheological behavior of slurry with dendritic structure is inappropriate for semi-solid forming. In this study, slurries with and without dendrites for the same alloy have been studied systematically using a partial filling method. The SEED process was employed and the pouring temperature was adjusted to prepare semi-solid slurries. The flow pattern and entrapped air during the filling process, and also microstructure of the samples were examined to characterize the macro- and micro-flow behavior. The results show a turbulent macro-flow, leading entrapped air, and severe segregation in the sample using slurry with dendrites. For the slurry without dendrites, none of the three phenomena was found in the sample. This investigation further showed that the detriment of dendrite on the semi-solid forming process, and implied that large size dendrite in semi-solid slurry should be avoided.

NUMERICAL STUDY OF THE INFLUENCE OF TAYLOR VORTEX ON THE VISCOSITY MEASUREMENT OF SEMI-SOLID METALLIC SLURRY BY THE CONCENTRIC CYLINDER ROTATIONAL RHEOMETER

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ABSTRACT

The apparent viscosity of semi-solid metallic slurry with low solid fraction, which is one of the most important parameters for representing the rheological behavior, is mainly measured by the concentric cylinder rotational approach. The principle of this method is based on the assumptions that the fluid is in an ideal laminar flow state and obey the Newton's internal friction law. However, as the angular velocity ω increases, the fluid undergoes a transition from a stable laminar flow state to a Taylor vortex and turbulent flow state. These unstable flow conditions such as Taylor vortex and turbulence have a serious impact on the accuracy of apparent viscosity measurement. Numerical simulations were performed to reveal the influence of Taylor vortex on the measurement accuracy of the apparent viscosity of semi-solid metal using ANSYS Fluent in current work. The results show that, under certain circumstances, the pressure distribution of the Searle rheometer cylinder wall is changed due to the appearance of Taylor vortex, the apparent viscosity relative error ε of the Searle type rheometer is 3 times as that of the Couette rheometer. In order to avoid the influence of Taylor vortex, combined with the measurement principle of the concentric cylinder rotational rheometer and Taylor's study on flow stability, the empirical equation of limiting speed to avoid Taylor vortex in the process of Searle rheometer viscosity measurement is given.

SEMISOLID MATERIALS PROCESSING: A SUSTANABILITY PERSPECTIVE

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ABSTRACT

Sustainable development is increasing in importance with restrictions on emission and carbon footprint. Similarly, energy and resources efficiency are required and at the same time as cost efficiency is required. The current paper is focusing on the embodied energy taking into account the in-house recycling of foundry returns and the melting equipment used and coupling this to an efficient use of semisolid metal casting. A detailed analysis is made on the RheoMetal process which is benchmarked to conventional HPDC casting. The analysis includes gating system and importance of the use of primary or secondary material. It furthermore includes a discussion of process yield and benefits based on process capability.

SEMI-SOLID PROCESSING OF ADVANCED STRUCTURAL ALLOYS

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ABSTRACT

The Semi-Solid Metal processing (SSM) applied to advanced alloys can lead to obtaining new non-equilibrium phase composition structure resulting in superior mechanical properties of elements. To understand changes in microstructure mechanisms the modern system alloys the detailed transmission electron microscopy studies have been conducted accompanied with mechanical properties analysis. In AlCoCrCuNi and CoCrCuFeNi high entropy alloys, SSM reveal improvement of mechanical properties mainly due to the occurrence of saturated solid solution surrounded by fine–non-equilibrium secondary phase. Thixo-casts of Super Bainite Steel (high carbon, low alloyed) contain carbide-free bainite as mixture of ferrite plates with average thickness of 63 nm, and retained austenite plates of 40 nm in thickness. Application of appropriate heat treatment eliminates cracking by grain boundaries mechanism. Recent achievements in production of in-situ magnesium matrix nano-composites through a reaction of CO_2 with the AZ91 alloy at semi-solid temperature range using thixomolding is also described. New possibilities for high performance alloys through the use of semi-solid processing create new routes for further development of SSM technology.

DETERMINATION OF THE SSM PROCESSING WINDOW

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ABSTRACT

Identification of critical temperatures is paramount for semisolid processing. Application of the principles of differential calculus to identify these temperatures on semisolid transformation curves allows the semisolid metal (SSM) processing window to be determined. This paper describes a methodology that can be used to this end, namely the differentiation method (DM). Examples are given of application of the method to 356, 355 and 319 aluminum alloys, which are commonly used in SSM processing, and the results are compared with those of numerical simulations performed with Thermo-Calc® (under the Scheil condition). The DM is applied to experimental differential scanning calorimetry (DSC) heat-flow data for cooling and heating cycles under different kinetic conditions (5, 10, 15, 20 and 25 °C/min). The findings indicate that the DM is an efficient tool for identifying critical points such as the *solidus*, *liquidus* and knee as well as tertiary transformations. The results obtained using the method agree well with those obtained using traditional techniques. The method is operator-independent as it uses well-defined mathematical/graphical criteria to identify critical points. Furthermore, the DM identifies an SSM processing window defined in terms of a higher and lower temperature for rheocasting or thixoforming operations (T_{SSML} and T_{SSMH}) between which the sensitivity is less than 0.03 $°C^{-1}$ and, consequently, the process is highly controllable.

Keywords: semisolid processing; thermodynamic characterization; CALPHAD; DSC.

PROPERTIES OF SEMISOLID PARTS: COMPARISON WITH CONVENTIONAL AND INNOVATIVE MANUFACTURING TECHNOLOGIES

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ABSTRACT

In this paper, wear properties of samples manufactured using thixocasting were compared with those of components obtained using low-pressure die-casting and additive manufacturing in order to assess the relationship between material performance and production technologies, both conventional and innovative. The investigated items were made with AlSi7Mg alloy. First, microstructural analysis and hardness measurements were carried out. Subsequently, pin-on-disk wear tests were performed. Wear behavior of the samples was studied considering both coefficient of friction and wear rate, while the damage mechanism was analyzed by observation of the worn paths using scanning electron microscope, correlating the behavior to the specific microstructure. In addition, the effect of selected heat-treated conditions, relevant for real applications, on wear properties was also evaluated.

Keywords: AlSi7Mg alloy, thixocasting, wear behavior, microstructure, additive manufacturing heat treatment

Effect of Serpentine Channel Pouring Process on the Microstructure of Semi-solid 6061 Aluminum Alloy Slurry

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ABSTRACT

The semi-solid slurry of 6061 aluminum alloy was prepared through a copper or graphite serpentine channel, respectively. The effect of pouring temperature and serpentine channel material on the slurry microstructure was analyzed. The results indicate that both copper and graphite serpentine channel can be used to prepare semi-solid slurry with spherical primary grains. Compared with a permanent casting, the microstructure of the semi-solid slurry was significantly improved and refined. With the increase of pouring temperature, the average equivalent grain diameter of the primary phase grains in the semi-solid slurry increases gradually, but the shape factor decreases gradually. When the pouring temperature increased from 675 °C to 690 °C, a high quality semi-solid slurry can be obtained. Comparing the two kinds of serpentine channel, it is found that the copper serpentine channel can make the primary grains finer, and the average equivalent grain size was 63 μm. However, the solidified shell near the inner graphite serpentine channel surface was thinner than that of the copper serpentine channel. In conclusion, the graphite serpentine channel is more suitable for preparing semi-solid 6061 aluminum alloy slurry.

Keywords: 6061 aluminum alloy; Serpentine channel pouring process; Semi-solid slurry; Microstructure

SUPERHEATED SLURRY PRINCIPLE AND ITS APPLICATIONS IN THE DIE CASTING INDUSTRY

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ABSTRACT

Superheated slurry is a new casting technology where liquid metal is converted to superheated slurry, which will then evolve to semi-solid metal. Superheated slurry is a state of metal where the slurry has the temperature above the liquidus temperature with a small superheat and there is a small amount of solid particles dispersed in the superheated liquid acting as nuclei. This technology allows the benefits of semi-solid metal to be achieved in the die casting industry with minor modifications of the process. It is being applied in the die casting industry to achieve both improved quality and reduced production cost. This presentation will discuss its principles and applications in the die casting industry.

A NEW TECHNOLOGY FOR PREPARATION OF SEMISOLID SLURRY OF ALUMINUM ALLOY AND ITS APPLICATION IN RHEOLOGICAL DIE-CASTING OF LARGE THIN-WALLED PARTS

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ABSTRACT

In this paper, an efficient and low-cost uniform solidification control process of aluminum alloy was developed for the preparation of large volume semisolid slurry, as we called air-cooled stirring rod process. During the solidification of aluminum alloy melt, the compressed air is continuously injected into the inner cavity of the stirring rod through the air pipe to stir the melt and take away a lot of heat, so as to accelerate the cooling of the melt and promote the nucleation, and quickly obtain the semisolid slurry with fine and spherical primary grains. The new semisolid slurry preparation equipments were connected with die-casting machines to form integrated and intelligent rheological die-casting production lines for rheo-diecasting of large and thin-walled aluminum alloy parts with high quality. At present, it is possible to produce 40 kg semisolid slurry with a solid fraction of 25%~35% in 20~30 seconds. The rheological die-casting process has been applied industrially in the forming of high-quality large and thin-walled aluminum alloy parts, such as new energy vehicles and 5G communications. Compared with the traditional die-casting, the aluminum alloy thin-walled parts prepared by the new process not only have fine and spherical microstructure (including primary phase, second phase, eutectic silicon and iron-rich phases), good surface quality, less internal pores, but also have excellent mechanical properties, thermal conductivity and corrosion resistance, and prolong the mold life by 1/3.

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Effect of Filling Length on Segregation, Microstructure and Mechanical Properties of a Semi-solid Die Cast Al-6Si-3Cu-0.4Mg Alloy

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ABSTRACT

The evolution of microstructure and mechanical properties of Al-6Si-3Cu-0.4Mg alloy was investigated by controlling the filling length in semi-solid die casting. Results show that various filling length leads to different segregation, which plays an important role in the microstructure and mechanical properties. With the full filling length, serious segregation of liquid phase was found at the bottom of the sample, and the average liquid fraction reaches 49.1 %. Decreasing the filling length to 2/3 and 1/3 of the full filling length, the liquid fraction is only 35.8% and 36.3%, which is much lower than that of the full filling length. Furthermore, the average ultimate tensile strength and elongation increases from 405.3 MPa and 4.4% of the full filling length to 425.0 MPa and 6.5% of the 1/3 full filling length, respectively.

STRUCTURE OPTIMIZATION OF SEMI-SOLID DIE CAST STEERING KNUCKLE AND ITS EXPERIMENT VERIFICATION

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ABSTRACT

Steering knuckles are vital functional and structural components in automotive suspension systems, requiring high strength, high ductility and complex shapes. In this study, an aluminum alloy knuckle with semi-solid die casting process was developed to replace the conventional steel components. The aim of this research is to optimize product design based on both structural simulation and casting process simulation in order to avoid defects and to meet mechanical requirements. Furthermore, the optimal design solutions need to be verified through the filling experiments and defect analysis. The results show that the support rib is located in the thick area of the shock absorber mounting arm and removal of it is helpful to avoid the rewelding defects in filling frontier of the SSM melt. Besides, the position of steering rod is of medium thickness, and two ribs from different directions come together to support that area. Rewelding defects were detected when two ribs come together. To avoid rewelding defects in local areas of steering rod position, the ribs were reduced to uniform wall thickness and overlapped. Thus, the local flow state were modified and the SSM melt were enhanced the shear effect. Ultimately, by controlling all the processes of SSM die casting process, the high performance of aluminium knuckle was successfully developed.

BENDING STRENGTH AND FRACTURE BEHAVIOUR OF METAL-CERAMIC INTERPENETRATING PHASE COMPOSITES MANUFACTURED BY USING SEMI-SOLID FORMING TECHNOLOGY

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ABSTRACT

Interpenetrating Phase Composites (IPC) belong to a special category of composite materials, offering great potential in terms of material properties due to the continuous volume structure of both composite components. As manufacturing of metal-ceramic IPC via casting and infiltration processes leads to structural deficits, semi-solid forming represents a promising technology. Thereby, a solid open pore body made of ceramic is infiltrated with a metal in the semi-solid state. Typical structural characteristics of the microstructure as the integrity of the open-pore bodies after infiltration and an almost none residual porosity within the composites have already been proven for this manufacturing route. Following on from this, this paper investigates the bending strength and fracture behaviour of such manufactured metal-ceramic IPC. Thereby, the impact on the bending strength of the liquid fraction, which is varied with 65 % and 80 % and of the velocity while forming, which is varied with 50 mm/s and 100 mm/s is examined. Furthermore, a fractographic analysis is made as the fracture behaviour while and the fracture surface after testing are observed and interpreted.

Keywords: Interpenetrating Phase Composites (IPC), Semi-Solid Forming Technology, Fracture Behaviour, Bending Strength

MANUFACTURING OF HYBRID AL-CU-HEATSINKS BY COMBINING POWDER PRESSING WITH THIXOFORMING

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ABSTRACT

Hybrid material structures allow different material properties to be combined in one single component and thus to meet high functional requirements. When manufacturing such hybrid components, particular attention must be paid to the transition zones between metallic composite partners. These transition zones need to show largely homogeneous and materially bonded structures in order to ensure ideal transmission of the material properties and to prevent component failure due to material defects. In this respect, this paper focuses on a newly developed process in which a powder metallurgical route is combined with semi-solid forming technology. Here, porous copper green bodies are inserted into a forming die and subsequently forged together with a semi-solid aluminium alloy. In this way, it was tried to combine both metal materials into a material locking or at least into a form locking manner in order to achieve ideal material properties in the final hybrid component. The aim of this paper is to find suitable process parameters to infiltrate the porous copper inlay with the semi-solid aluminium alloy during thixoforming. Therefore, different process parameters such as varying liquid fraction of the aluminium alloy and different densities of the green bodies were examined during the production of simply shaped hybrid Al-Cu-components. Afterwards the infiltration depth and produced microstructure of the components was analysed. In the future, this process allows for producing aluminium-copper hybrid heat sinks with improved heat transfer properties compared to conventional produced heat sinks.

Keywords: Thixoforming, semi-solid metal forming, green bodies, infiltration, Al-Cu heat sinks.

USING MICRO-CT SCANNING TO QUANTITATIVE CHARACTERIZE POROSITY IN CONVENTIONAL DIE CASTINGS AND SEMI-SOLID CASTINGS

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ABSTRACT

Porosity is one of the main defects that limits the performance of castings. Porosity in aluminum castings can originate from several sources, including the volumetric shrinkage occurring during solidification, the precipitation of dissolved hydrogen, and entrapment of gasses such as air, boiling water, vaporized lubricants, etc. Traditional methods of identifying and measuring porosity in castings include x-rays, sectioning and polishing, and Archimedes density measurements, but none provide a satisfactory quantitative estimate of the size, total volume and distribution of the pores. X-ray CT scanning is a relatively new method that generates not only a 3-dimensional view of the size and distribution of the pores, but can also provide quantitative information of the volume, surface area, size, shape and position of each pore within a casting. Micro-CT scanning is a specialized sub-category of CT scanning, which provides excellent resolution of fine porosity (a resolution limit of 4 microns in one of the case-stores presented in this paper), but it should be noted that the resolution limit in the CT scanning techniques is related to sample size. This paper will describe results from micro-CT scanning studies of several conventional die castings and a semi-solid casting, and will provide quantitative data on the total porosity content, and the porosity distribution. The paper will also demonstrate the capabilities of the micro-CT scanning process to provide a quantitative comparison of the porosity content in these different types of aluminum castings.

Thursday, 30th September

USING RECYCLED MATERIALS FOR SEMI-SOLID PROCESSING OF AL-SI-MG BASED ALLOY

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ABSTRACT

In order to reduce the CO_2 emission and save energy, more recycled or secondary materials have been used in foundry industry. Especially, recycled Al-Si-Mg based alloys have attracted more attention in the field of semi-solid processing. However, at least two issued still need to be elucidated. Firstly, there is still a main focus on the impurity level (i.e. the max. concentration of the recycled material) for a promising application in foundry industry, which can greatly affect the costs. Secondly, there is still a lack of detailed investigation on the addition of recycled materials on the solidification microstructure in terms of the grain size of primary Al (before semi-solid processing), the shape factor of the second Al (during semi-sold processing), modification of eutectic Si and the morphology change of Fe-containing phase (π-AlSiMgFe), which can greatly affect the mechanical properties, especially for the elongation. In this paper, recycled Al-Si-Mg based alloys up to 30 % (10, 20, 30 % respectively) have been used for semi-solid processing. A detailed investigation on the solidification microstructure using optical microscopy shows that, with the addition of the recycled materials up to 30 %, there is no significant difference on the solidification microstructure in terms of the grain size of primary Al (before semi-solid processing), the shape factor of the second Al (during semi-sold processing). Furthermore, a detailed investigation on the solidification microstructure using electron microscopy (including SEM, EDS, EBSD, TEM and atom probe tomography) shows that eutectic Si can be well modified and the morphology of Fe-containing phase (π-AlSiMgFe) can be tailored, which can be used to interpret the improvement of mechanical properties, in particular to the elongation. It should be also noted here that with increasing recycled materials, at least another two important issues should be highlighted. Firstly, more TiB_2 particles were observed, which can be due to the addition of Al-Ti-B grain refiners for the grain refinement of recycled materials. Secondly, a significant interaction between Sr and P was also observed in the recycled materials. The present investigation provides a detailed investigation on the solidification microstructure, even at atomic scale. It clearly shows that recycled Al-Si-Mg based materials at least up to 30% can be used for semi-solid processing, which can greatly reduce the CO_2 emission and save energy.

Key words: Al-Si-Mg alloy; recycled materials; semi-solid process; Electron microscopy

Development of high strength high toughness and high thermal conductivity cast aluminum alloys

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ABSTRACT

In this talk, the development and practical applications of casting Al-Si based alloys for enhanced strength & toughness and strength & thermal conductivity will be presented, carried out in high-performance metal structural materials research institute in Soochow University. The complex correlations between Mg/Cu/Fe alloying and microstructure, mechanical properties and thermal conductivities of Al-Si based alloys have been built up. Through such fundamental theoretical work, Al-Si-Mg-Cu alloys aiming for enhanced strength & toughness have been developed. This is based on the systematical work including liquid melt treatment, analysis of the solidification path and as-cast microstructure, heat treatment and characterization of the resulting mechanical properties. By a combination of squeeze casting and following T6 heat treatment, tensile strength up to 365 MPa, yield strength of 314 MPa, elongation of 7.8% have been achieved. These result from the refined as-cast structure due to the rapid solidification during the squeeze casting process and simultaneously inoculation / melt modification, and also from the precipitation strengthening of Mg_2Si, Q phase etc. during annealing. Besides, Al-Si-Mg-Fe alloys for enhanced strength and thermal conductivity have been developed via the same strategy. Tensile strength up to 280 MPa, yield strength of 220 MPa, elongation of 4%, and highly enhanced thermal conductivity of 170 W/ K·m have been achieved after die casting and T5 heat treatment. The excellent thermal conductivity while maintaining the sound mechanical properties comes from the refined as-cast structure due to the rapid solidification process, the modified morphology of eutectic Si phase, and the refined structure through the inoculation and purification using B. The aforementioned two series casting Al-Si based alloys are at present successfully applied to the fabrication of structural components in automobile, 5G mobile phones and so on.

Keywords: cast aluminum alloys, high strength, high toughness, high thermal conductivity, Al-Si-Mg-Cu alloy.

RESEARCH & DEVELOPMENT OF RHEOCASTING BY THE COUPLING OF SHEAR AND VIBRATION

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ABSTRACT

The shear-vibration coupling methodology to prepare semisolid slurry can effectively control the microstructure in the dynamic solidification process via co-action of cooling, flowing and vibration. The hot metallic melts run through the vibrating cooling-plate under the condition of near-rapid cooling rate, resulting in large increase of their nucleation rate. Therefore, the solidification structure of the casted alloy can be greatly refined and spheroidized. Moreover, the slurry is prepared at high efficiency and low-cost, since this method integrals the slurry preparation and pouring process. In the view point of industrializations, several advantages can be found, such as equipment interlinking, process parameter adjustment, and cost reduction. This method has been already applied to the fabrication of squeeze casting machine parts to improve their mechanical performance. In addition, the coarse dendrites and eutectic segregations, which often occur in traditional squeeze casting parts, are effectively avoided. Nowadays, we are seeking to expand the application of this technique into the manufacture of 5G station filter shell with large body, sophisticated configuration, and thin wall. This project is listed as one of the national key R & D projects in China.

MELT TREATMENT TECHNOLOGY FOR SUPERALLOY CASTING

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ABSTRACT

The integral superalloy castings with large size, complex shape and thin wall are extremely important and widely used as essential components for aeroengine, which have brought great challenges to the casting processing with comprehensive control of solidification processing, microstructure and defect to guarantee the performance. It is well known that the principal contradiction is to obtain the small and homogeneous grains under the premise of perfect forming. In this report, some new methods based on the melt treatment for precision casting are introduced such as thermally controlled solidification, chemical refining and melt superheating treatment. The thermally controlled solidification processing with low pouring temperature, high filling temperature and sequential solidification is developed to prepare IN718 superalloy castings with minimum thickness of 1.8 mm. With compound refiners of Co_3FeNb_2 and CrFeNb, the average grain size can be decreased to 126 μm, and the stress rupture life under 650 ℃/620 MPa is increased by 1.3 times. The melt superheating treatment can further refine the grain to 89 μm with the stress rupture life of 242 hrs under 650 ℃/620 MPa.

И-SHAPED CURVE OF HOT-TEARING SUSCEPTIBILITY AFFECTED BY SECONDARY PHASES IN CAST AL-MG-SI ALLOYS

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ABSTRACT

Al-Mg-Si series alloys containing about 6wt.%Mg can obtain good elongation in the as-cast state and meet the requirement of medium strength without heat treatment due to the second-phase strengthening of Mg_2Si. Most properties, such as mechanical properties, fluidity and hot-tearing susceptibility, are all controlled by Si content. It is instructive to study how the Si content regulates the hot-tearing susceptibility (HTS) of Al-Mg-Si alloy, because hot tearing which occurs during semi-solid stage is a key issue for mass production. The HTS of Al-6Mg-(0-6) Si alloys was measured through the use of CRC mould attached with a thermocouple and load cell connected to a data-acquisition system. Experimental results were compared with calculations by Scheil model using Pandat thermodynamic software to predict the occurrence of hot tearing in Al-6Mg-xSi alloys. The HTS values agreed with Kou's hot-tearing index precisely. Addition of Si content reduced the volume shrinkage coefficient, which caused the decreasing of maximum shrinkage stress value. The drop-in values on the contraction force could indicate the occurrence of hot tearing and predict the hot-tearing susceptibility. The types, fractions, sizes and distributions of secondary phases determined by addition of Si content and solidification conditions affected the nucleation, propagation and healing of hot-tearing cracks and made the HTS show a *И*-curve which was obviously different from the λ-curve.

Microstructure evolution and quench sensitivity characterizations of Mg-9.5Gd-0.9Zn-0.5Zr alloy

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ABSTRACT

Microstructure evolution and quench sensitivity of Mg-9.5Gd-0.9Zn-0.5Zr (wt. %) were characterized under the hot water quenching (WC), air cooling (AC) and furnace cooling (FC) conditions, respectively. It was found that the as-cast alloy was consisted of α-Mg matrix, net-like eutectics (α-Mg+Mg_3(Gd, Zn)) and lamellar 14H LPSO phases. After solution treatment at 515 ℃ for 16 hours, only rod-like Zn_2Zr_3 phases were found in the WC alloy, however, Mg_5Gd particles and 14H LPSO phases were also detected in the AC and FC alloys due to the relatively low cooling rate. The WC alloy exhibited the most obvious aging hardening behaviour at the subsequent aging treatment at 225 ℃, i.e., the WC alloy reached the highest value of the peak-hardness in the shortest time among three alloys, which was caused by the formation of densely distributed fine γ″+γ′ precipitates. The mechanical properties of three kinds of the peak-aged samples showed that the quench sensitivity of the experimental alloy was not significant due to the yield strength of the WC peak-aged alloy was only 6.64% and 17.54% higher than the AC peak-aged and FC peak-aged alloys, respectively. The contributions of individual strengthening mechanism for the experimental alloy were further evaluated, and can be listed as follows: γ" + γ' precipitates > 14H LPSO phases > solution atoms.

Key words: Mg alloys; LPSO phases; Quench sensitivity; Precipitates

CORROSION RESISTANT ADDITIVELY MANUFACTURED HIGH ENTROPY ALLOY

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ABSTRACT

The alloys processed by additive manufacturing technique are normally considered to possess better corrosion resistance than those prepared by traditional methods such as arc-melting. In this work, a hierarchically heterogeneous structured $(CoCrFeNi)_{98.2}N_{1.8}$ high-entropy alloy (HEA) is processed by additive manufacturing, which performs outstanding pitting corrosion resistance in 3.5 wt.% NaCl as well as exceptional combination of tensile strength and elongation. The passive region (1.15 V) and corrosion current density (3×10^{-8} A/cm^2) of this HEA outperform most HEAs processed by additive manufacturing and arc-melting. The outstanding pitting corrosion resistance is ascribed to the uniform elemental distribution among the heterogeneous coarse grains (weak tendency to micro-galvanic corrosion) and the dense Cr-rich amorphous passive film (~ 2 nm) on the HEA surface.

HEAT-RESISTANT AL-ALLOYS WITH QUASICRYSTALLINE AND $L1_2$-PRECIPITATES

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ABSTRACT

The production of Al-alloys is increasing strongly due to their high specific modulus, strength and other useful properties. However, the conventional Al-alloys lose their strength rapidly when heated above 250 °C. Therefore, there is a great interest to develop new heat-resistant alloys. Generally, heat resistance is improved by the incorporation of temperature resistant particles in the Al-matrix, which have a small coarsening rate and can provide convenient obstacles for dislocation movement at elevated temperatures and contribute to a low creep rate.

We have been developing Al-Mn-Cu based alloys, which are alloyed with minor additions of different elements. Small additions of beryllium enhance the formation of icosahedral quasicrystalline phase (IQC) during solidification and especially during ageing. Upon solidification, primary IQC-particles may form; with sizes ranging from 5 to 50 μm. IQC is also present as a part of binary eutectic in the interdendritic regions. More importantly, nanosized quasicrystalline precipitates can form during T5-treatment at temperatures ranging from about 250−450 °C. They are in-fact metastable precipitates so they transform to ternary $Al_{20}Mn_3Cu_2$ phase above 450 °C. This transformation occurs initially in-situ, and the shapes and sizes of precipitates are retained. The heat resistance was considerably increased by the addition of Sc and Zr, by forming $L1_2$-precipitates between quasicrystalline precipitates. The presence of dual precipitates provides efficient obstacles for dislocation motion at low and elevated temperatures. We will present the results of electron microscopy, microchemical analysis, X-ray diffraction and different mechanical tests, which show the improved high temperature stability of the developed alloys.

Recent Industrial Application and Perspectives of Rheo-diecast process in China

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ABSTRACT

The Rheo-diecast process has been rapidly developed and increasingly industrial used in China in the recent 5 years.

The applications of rheo-diecast components for heavy duty truck, communication markets and new energy vehicles will be described firstly. The truck parts such as battery bracket, post-processing bracket, cab mounting bracket, air reservoir bracket and junction plate are in mass production to replace the cast steel parts. Lightweight is the main reason for rheo-diecast components used for the truck. The rheo-diecast radiator chambers were widely used in 4G and 5G communication area because of the high thermal conductivity performance. The new energy vehicle parts such as connectors and battery end plates are also widely used. Some advantages of Rheo-diecast parts such as weldability, tightness and high ductility are very good for new energy vehicles.

The pilot production of Rheo-diecast components for buildings, automobile and electronics will be described secondly. The 5500T SSM die cast machine was developed to produce building templates with the size of 2000mm × 500mm. Some automotive parts such as mount brackets, control arm, knuckle, calliper and main bearing cover were developed by Rheo-diecast process with very excellent performance. It provides a new process for automobile lightweight. Some electronic shells and middle plates were produced using Rheo-diecast process. The Rheo-diecast electronics can be anodized with attractive appearance.

The future perspectives of Rheo-diecast process will be described at last. 1. Cost reduction. 2. Production consistency. 3. New Rheo-diecast alloys development. 4. Numerical simulation of Rheological filling. These are important for further application.

PREDICTING ALLOY SOLIDIFICATION USING CALPHAD TYPE THERMODYNAMIC AND KINETIC CALCULATIONS

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ABSTRACT

The solidification curve, defined as the fraction of solid phases in function of temperature between the liquidus (fraction solid = 0) and to solidus temperature (fraction solid = 1) is a key parameter for semi-solid processing of alloys. Thermodynamic calculation tools together with suitable CALPHAD type alloy databases, allow the calculation of the solidification curves for multi-component alloys for various model assumptions.

While solidification simulations assuming thermodynamic equilibrium are a simplification, they are nevertheless useful for gaining a general understanding of the alloy, to investigate the effect of minor tramp elements and impurities or for quantifying the influence of variability of the alloy composition. Assuming thermodynamic equilibrium will however mostly over-estimate the solidus temperature and underestimate the segregation of the last liquid to solidify, as it does not allow for concentration gradients in the solid phase that grow during solidification.

Scheil-Gulliver solidification simulations account for segregation in a simplified manner by assuming there is no diffusion in the solid phases, resulting in a more realistic prediction of the solidification curve. Recently Scheil simulations in Thermo-Calc have been significantly improved by allowing to quantitatively consider back diffusion in the primary solid phase in function of cooling rate.

The most complete understanding of solidification of alloys is obtained by more computationally demanding multi-region, moving interface diffusion calculations using Thermo-Calc's diffusion add-on module DICTRA. Such calculations show the influence of cooling rates, heating rates and processing time answering question such as: How does the fraction of solid phase and the type of phases that form change in function of cooling rate? How does the fraction of liquid phase decrease in function of time during isothermal processing? Also, the heating of alloys can be investigated showing how the incipient melting temperature is connected to the solidification history. This is important for designing post-cast homogenization treatment. An example is shown, where the incipient melting temperature is even above the equilibrium solidus temperature.

Calculations are presented for aluminium and magnesium alloys, a ball bearing steel and a tool steel. Thermodynamic criteria from literature that indicate if a given alloy is suitable for various semi-solid processing routes such as rheocasting, thixoforming or thixoforging are discussed based on the calculated solidification curves.

ENHANCED PROCESS STABILITY THROUGH NEW PROCESS CONTROL STRATEGIES AND IMPROVED MACHINE COMPONENTS IN THIXOMOLDING

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ABSTRACT

Thixomolding of Magnesium alloys offers a wide range of product and process advantages compared to conventional die casting; e.g. improved part quality, longer service time for molds and lower energy consumption of the whole production cell. However, the screw-based approach of conveying chipped feedstock, melting, homogenizing and injecting the semi-solid material into the mold remains more challenging for manufacturers in terms of process control and stability. As a result, machine components of the injection system require shorter maintenance or even replacement intervals than would otherwise be necessary. The following paper takes a look at the main causes of these accelerated wear phenomena and how to eliminate them effectively. Starting with a theoretical overview about the melting and solidification behavior of the feedstock inside screw and barrel, an FMEA of the injection phase was applied and the drivers of accelerated wear and unstable process behavior were identified. On the processing side, it could be stated that an inappropriate temperature control of the barrel lead to an unstable conveying behavior, which results in excessive torque rise of the servo drive and can damage or even break the screw. By adjusting the temperature at the specific heating zones accordingly and implementing a fail-safe process control algorithm, damage and wear of the screw and barrel system can be avoided.

VIRTUAL ASSESSMENT AND OPTIMIZATION OF SEMISOLID METAL CASTING PROCESSES

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ABSTRACT

Semisolid casting can be divided into two kinds of processes. Basically, Aluminum Rheocasting as well as similar processes only differ in the production of the partially solidified melt. However, there are hardly any differences in the structure-viscous flow with a shear rate dependent viscosity.
Compared to Aluminum Rheocasting, in Magnesium Thixomolding and similar processes, a semisolid processing was proposed, however, in nowadays industrial reality the melt is mainly poured at around liquidus temperature with approximately Newtonian flow behavior. The common ground of these two processes is the tempered permanent molds and the casting with complex process control.

For the virtual assessment of such processes, this means that depending on the process, different flow solvers have to be used, each coupled with heat flow solvers. They have to calculate stably and quickly over a range of flow velocities. In addition, all phases of the entire series casting process must be followed in detail because the transient mold temperatures are relevant.

In this article, a holistic approach for designing “semisolid metal casting processes” is presented. This approach is enabling designers and production specialists to develop components, design optimal casting tools and processes by virtually testing and optimizing these in parallel to their usual workflow. By elaborating this approach, the reliable application of the software, industrially verified models and the integration of CAD and FE analysis are equally in the focus of this presentation.

In addition, two real case examples of Aluminum Rheocasting and Magnesium Thixomolding are discussed in detail.


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