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www.iFlowFePhase.info

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Project Acronym: ***i Flow Fe Phase***

Project Title:

The melt stirring in AlMgSi alloys as the new technology of intermetallics treatment

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Materials technology, Metal technology, Al-Si alloys, Casting, Solidification, Intermetallic phases, Fluid flow,

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Miejsce realizacji projektu: Politechnika Poznańska, Instytut Technologii Materiałów
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2. PUBLISHABLE SUMMARY (2 pages)

Summary description (more on www.iFlowFePhase.info)

Aluminum-silicon base alloys are widely used in castings (foundry industry) due to their excellent castability and high strength-to-weight ratio. In the Al-Si alloys, the presence of small amounts of Fe and Mn brings about a complicated microstructure due to the formation of a rich variety of intermetallic phases (IMPs) during solidification, which generally have a negative effect on the mechanical and physical properties of a as cast part (porosity, cracks, hardness, lower strength). The classical methods of intermetallics treatment are: chemical processing, modification, Mn addition, alkali elements, heat treatment, solidification conditions). There only few publication about the influence of fluid flow on the microstructure and intermetallics. It was observed that Fe and Mn intermetallics in combination with flow have a different effect on microstructure and is possible to transform needle like Fe-phases to blocky ones. The application of rotating magnetic field (flow) could lead to better results in shortening Fe-phases than lowering Fe content.

The main goal of the project "iFlowFePhase" is to prepare new technology of Fe and Mn intermetallic phases treatment by fluid flow in Al-Mg-Si casting alloys. The project investigates problems of artificial fluid flow (melt stirring) influence on the growth, morphology and spatial arrangement of intermetallic phases in as-cast AlSi-base alloys containing especially Fe and Mn as alloying elements. Addition of Mg allows 3D visualization of IMPs, dendrites and eutectics. The "iFlowFePhase" studies concerns detailed tasks: solidification of casting specimens in MagFound facility by the presence of fluid flow and without it (in different solidification conditions), detailed analysis of the microstructure of the Al-Si alloys (dendritic pattern geometry, length, thickness, and density of IMPs, three dimensional morphology of IMPs, dendrites and eutectics), numerical modeling for physical understanding of the mechanisms leading to the anticipated changes in microstructure by the presence of IMPs and fluid flows. Project involves advanced unique facilities and modern scientific methods: solidification within MagFound, microstructure investigation by optical (Nikon) and SEM (Tescan) microscopes, x-ray Diffractometry (PANalytical Empyrean), metallography, quantitative image analysis (Multiscan, Image J), differential scanning calorimetry DSC (Netsch), yield tensile tester (Instron), x-Ray tomography (nanotom s GE).

Description of the work performed

- ***Task 1: Alloy preparation and selection,*** Alloys starting from high-purity elements have been molten, cast into a shape usable for MagFound with compositions AlMg5Si5Fe(0-1.0)Mn(0-1.0).
- ***Task 2: Solidification experiments,*** Around 70 solidification experiments in MagFound were performed with and without artificial fluid flow. We have applied slow bulk solidification conditions.
- ***Task 3: Local crystallographic analysis,*** Local X-ray diffractometry (Empyrean from PANalytical). The specimens were prepared and additional data were collected too.
- ***Task 4: Phase transition evaluation,*** Differential scanning calorimetry (Perkin Elmer DSC8500, Netsch 204 F1) . The DSC curves by different heating and cooling rates (5,10,20,50 K/min) were registered.
- ***Task 5: Microstructure determination,*** The samples were evaluated with Nikon OLM and Image J software. We measured characteristic parameters like Secondary Dendrite Arm Spacing SDAS, etc. Average length of the Fe-intermetallics β-Al_5FeSi L_β, Number density of β n_β, Eutectics spacing of AlSi eutectics, Spacing for Mg_2Si phases, Average length and Number density of Mn-intermetallics.
- ***Task 6: 3D morphology of IMPs,*** We used high-resolution x-ray tomography (X-Ray v-tome-x s, GE Phoenix located at PUT) and received 3D geometries for alloys.
- ***Task 7: Yield strength correlations,*** The solidified specimens are small and require special treatment. After receiving specimens without pores, tensile tester (Instron Mode 4001) will be applied.
- ***Task 8: Numerical modeling of the microstructure and flow,*** Thermo-Calc calculations performed for Binary and Ternary Phase Diagrams, Scheill solidification, and Property diagrams. Micress simulation were done for prediction of directional solidification and prediction of growing front.

Description of the main results achieved so far

The 2D microstructure was measured. Fluid flow for AlSi5Fe1.0 caused smaller Secondary Dendrite Arm Spacing SDAS (-12%), shorter β phases (-20%) and higher number density (+47%). For all alloys with magnesium Mg the parameters seem very slightly changed (AlMg5SiFe1.0 – SDAS -3%, L_β -5% and n_β -12%) or completely unaffected (AlMg5SiFe1.0Mn1.0 – SDAS -0.0%, L_β -2% and n_β +77%). The results revealed that stirring has very small effect on alloys containing 5% Mg. Magnesium applied for X-ray tomography caused formation of Mg_2Si phases. Calculated in ThermoCalc phase diagrams presented that in

AlSi5 Fe1.0 alloy the α-Al dendrites growth as first followed by β-Al5FeSi, and finally eutectics precipitates as the last phase. In AlMg5SiFe1.0 alloy β starts to grow at 590 °C and Mg_2Si at 580 °C but in double amount. Mg_2Si seems to diminish the flow possibilities and shortening of β intermetallics and SDAS. In AlMg5SiFe1.0Mn1.0 the leading phases are Mn and Mg containing precipitates, but not Fe intermetallics. Concluding, the stirring can be used in alloys with high Fe content and low amount of phases diminishing flow during β growth.

From Thermo-Calc Property diagrams of phases mass fraction, based on the thermodynamic calculations and applied for building 2D maps seem to offer attractive method for visualizing mushy zone in directional solidification. Property diagrams and solidification paths (Scheil-Gulliver solidification) presented the segregation effect on the temperature and sequence of phases precipitation. 2D maps revealed liquid channel in center of the mushy zone, that can reach deep into mushy zone till final solidification reaction at temperature 575 ºC. The calculations presented the spatial location and mass fraction of phases (Liquid, α-Al, β-Al_5FeSi) in the mushy zone. The study confirmed the qualitative results showing precipitation of β-Al_5FeSi phase before the formation α-Al dendrites in the specimen center. Based on 2D maps, it was estimated that about 33% of all β-Al_5FeSi phases precipitated in the liquid channel, and possibly can flow (because of magnetic stirring) into liquid melt just above mushy zone. Current results revealed local precipitation of α–Al_8Fe_2Si (before β-Al_5FeSi). The found out liquid channel with β-Al_5FeSi shows high flow possibility of melt only and melt with Fe phase and the potential influence on the microstructure. Different flow possibilities in dendritic and eutectic area impose detailed analysis of the effect of fluid flow on the microstructure of each studied specimen alloy. Micress simulations presented prediction of thermal and solutal conditions of the growing front by directional solidification.

Expected final results

- Characterization of the influence of solidification and flow conditions on the crystallographic characteristics of the IMPs (Goal 3),
- Finding out if there exist correlations between fluid flow and phase transition of intermetallic phases IMPs formation (Goal 4),
- Determination of the influence of solidification and flow conditions on the microstructure morphology (Goal 5)
- Finding out if fluid flow changes the 3D morphology (Goal 6) – X-Ray tomography
- Finding out if fluid flow changes the yield strength (Goal 7) –
- Understanding of the physical mechanisms leading to the anticipated changes in microstructure by the presence of IMPs and fluid flow (Goal 8) – Micress, ThermoCalc and Fluent – Modeling and simulation.

Potential exploitation of results

Turbulent flow during mold pouring is the negative effect because of oxides and air entrapment into casting. But the flow after complete pouring and fully filled mould improves the microstructure of solidified castings trough modification of dendritic structure (e.g. lower secondary dendrite arm spacing SDAS). The potential exploitation relies on designed stirring and controlled fluid flow (in solidifying castings), and generated through located in permanent mold electromagnetic stirrers EMS. Such technology might be applied in continuous casting and die casting (metal mould casting). Continuous casting is the process whereby molten metal is solidified in the mold into a product (called strand cast) shaped as "semifinished" billet, bloom, or slab for subsequent rolling in the finishing mills. Similar technology EMS might be applied in gravity die casting and pressure die casting for shape casting. The described fluid flow technology is improper for impermanent mold (sand mold). Another potential exploitation of the understanding of the physical mechanisms is creation of numerical models including them into casting simulation software.

Prospects of the research career development and re-integration

The aim of the Fellow is to develop his scientific research at the Poznan University of Technology PUT and extend his research on the microstructure, physical processes occurring during solidification of alloys and numerical simulation in casting technology. The Fellow owns the degree of Doctor Engineer (PhD Eng.) and position called "adiunkt" (Assistant Professor) till February 2019. For the researcher Piotr Mikolajczak, the very important is the possibility of financing studies by "iFlowFePhase" project, that lead him to professor thesis preparation. The Fellow is strongly determined to prepare the professor thesis and achieve the level of an independent expert (doctor habilitus) till February 2019. The level of an independent expert (doctor habilitus) assures long term position at the PUT.