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Design and Simulation on Cast Metal Matrix Composite By Investment Casting

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Abstract. Metal Matrix Composite (MMC) is produced normally by melting the matrix material in a vessel and the molten metal is stirred systematically to form a vortex, and then the reinforcement particles are introduced through the side of vortex formed. However, this approach has disadvantages, mainly arising from the particle addition and the stirring method. There is certainly local solidification of the melt induced by the particles during particle addition. This condition increases the viscosity of the slurry and appears as air pockets between the particles. Moreover, the rate of particle addition needs to be slowed down particularly when the volume fraction of the particles to used increases. This study proposes the new methodology of producing cast MMC by investment casting. Deformations of the die-wax and shell alloy systems are considered in a coupled manner, but the coupled deformation of the wax-shell system is not included. Therefore, this study presents the tasks pertaining to metal matrix composites and their interactions. As a result, the work on wax and wax-die interactions is discussed. This study presents the use of computer programs for determining the wax pattern dimensions based on three-dimensional finite-element simulations. The model for coupled thermal and mechanical analysis is developed by ProCAST. The wax model is described. The following factors are considered in the analysis: (1) the restraint due to geometrical features in the metal die; and (2) process parameters such as dwell time, die/platen temperature, injection pressure, and injection temperature.

Introduction

Metal matrix composites have received much research interests over several years due to their excellent mechanical and thermal properties compared with the conventional materials. By suitable arrangement of metal matrix and ceramic addition, it is possible to obtain desired properties for a particular application. Therefore, the metal matrix composites are extensively used in several industrial areas such as aerospace, automotive and electronics industries.

The microstructure analysis of the material was used to study by investment casting and explained the formation of different phases at the aluminium–steel interface and their effect on the deformation behaviour of the foam under compression, Vendra. L.J.[1]. The method of quicker solidification, after cessation of mixing, was found to improve the uniformity of the SiC distribution significantly. Characterization of the MMC samples has been produced by Naher S et. Al., [2], included the microstructure recording and image analysis thereof. The matrix phase size, morphology and distribution of SiC particles throughout the stir castings were examined.

Aluminium metal matrix composites (Al MMCs) has been used for many of research during the last two decades. A wide range of fabrication techniques have been explored for Al MMCs, which includes the vapor state method, liquid phase method (infiltration of pre-forms, rheocasting/thixoforming, melt stirring and squeeze casting) and solid state methods (powder forming and diffusion bonding) by authors Miracle DB [3], Ralph B, et, al. [4], Harrigan W.C [5], and Degischer HP [6] respectively.

The production process has been developed by Neussl, E [7] which enables the production of selectively reinforced fibre aluminium composite investment casting of high design flexibility. The modified investment casting process suggested as an economical and flexible production strategy for a broader spectrum of industrial applications.

In the experimental of metal matrix composite have been done by S.Sulaiman, et, al. [8], there were correlated between from the tensile tested samples, the reported mechanical properties for each volume fraction of silicon dioxide percentage addition to the LM6 alloy matrix. In addition the quantification of strength and hardness of quartz–silicon dioxide particulate reinforced LM6 alloy matrix composites test specimens have been tested.

In order to get the expected hybrid composites, there were necessary to study the coefficient of thermal expansion (CTEs). A material of such a low CTE was ideal for electronic packaging because of the low thermal mismatch (and therefore, low thermal stresses) between the electronic component and the substrate. To achieve similar CTEs in SiCp–Al composites, Zhao L.Z [9] has been determined the volume fraction of SiC would be much higher than that in the hybrid composites.

Dual ceramic reinforced aluminum matrix composites have been investigated at room temperature in order to get the prediction of density and tensile strengths. In the neural networks training module, it were used different SiC (lm) particle size ranges as input and density and tensile strengths in produced MMCs. Then, Altinkok [10] has been modelled the neural network is trained using the data obtained in experimental process. The density and tensile strengths in produced MMCs have been estimated for different SiC (lm) particles size range by using neural network efficiently instead of time consuming experimental processes.

The increased of Mg could increases the cooling rate of the Al(356) matrix alloy and it may due to the improved wetting of the mould surface by the melt. The cooling rate also increases with the introduction of SiCp, reaches a maximum and then decreases with increasing SiCp content due to lower heat transfer rates within the solidifying melt owing to the reduced effective thermal diffusivity of the composite system. This result introduced the silicon carbide and graphite reinforcements into the Al(356) matrix alloy could reduces the liquids temperature. Moreover, Rajan [11] described the addition of ceramic reinforcement to alloy reduces the total solidification time in all the moulds studied at lower volume fractions and increases at higher volume fractions.

One of the main problems is that investment casting technology has been based on hand-on training and experience. Technical literature is limited to experimental, phenomenological studies aimed at obtaining empirical correlations for quick and easy application in industry. The pattern die is often reworked several times to produce castings whose dimensions are within acceptable tolerances. The complexity of shape and the close dimensional tolerances required in the final casting make it difficult to determine the appropriate pattern dimensions with existent casting simulation software except by trial and error.

However, none of the authors cited above used a simulation technique to achieve their results for cast metal matrix composite by investment casting. This research will investigate how the use of three dimensional finite element simulation using ProCAST in designing of part for metal matrix composite by casting technology and will try to examine the design through the simulation methodology in order to get the required wax pattern dimension. As a result, the evaluations are carried out to study the overall performance predictions and simulation results.

Material and Method

There are six major steps in *MeshCAST* which are required in order to produce a high quality tetrahedral mesh. The works steps have to follow when using *MeshCAST* depend upon the following: the nature of the project, the intended use of the meshes generated by *MeshCAST* and the type and quality of CAD model you use as the initial input. The general workflow, outlined below, illustrates the six general steps typically followed to process geometry from an initial CAD input file to completing the tetragonal volume mesh. Figure 1 shows the engineering drawing of a spherical bracket with size of 63.5 mm x 63.5 mm x 46.038 mm as the project example. Material used for this bracket is The material that had been used is A356 Alloy.

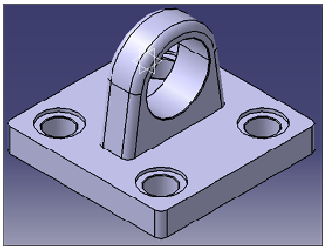


Fig. 1 Spherical bracket

The typical workflow described in Figure 2 begins with an IGES, PARASOLIDS, STEP or STL geometry and proceeds to the generation of a tet mesh. In addition, *MeshCAST* may also be used to:

i) Generate tet meshes by processing surface meshes generated by third party software packages;
ii) Evaluate and refine tet meshes generated by third party software packages.

In these cases the overall process to produce a *tet* mesh follows the same basic work steps. However, based upon the type of input file which was loaded, results perform only the steps required to continue the development process.

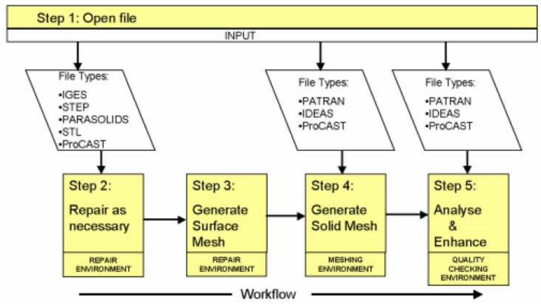


Fig. 2 Workflow of Simulation

Computer simulation and modelling provide valuable support to this iterative process. *MeshCAST* is an important tool in this process because it produces high quality meshes which may be used as input to a wide variety of other analytical software packages. *MeshCAST* supports this iterative process by allowing the designer and engineer to modify or enhance original designs, improve the quality of the mesh for critical parts of the model, and specify unique mesh densities for each part of the model. All of this can be accomplished before committing to costly prototype development and pilot project operations.

In order to determine the 3D structural finite volume schemes, a very convenient approach as described by Bruner C.W.S [12] for the computation of volume is based on the divergence theorem. The led finally formula:

$$\Omega = \frac{1}{3}\sum_{m=1}^{N_F}\left(\vec{r}_c . \vec{S}\right)_m \tag{1}$$

For the volume, where N_F denotes the number of the faces of the control volume, $(\vec{r}_c)_m$, the centre of the face m of the control volume, and $\vec{S}_m$ the face vector (outward directed) of the face m, respectively. The formula (1) is directly applicable on unstructured grids. It is exact for a volume with triangular faces, or a volume with planar quadrilateral faces.

This paper is motivated by this formula to carry out the design problem by approaching on the divergence theorem.

Results and Discussion

The preliminary simulation using *MeshCAST* showed the boundaries that have to check the geometry prior to PreCAST. Next, the 3 Dimensional finite elements is generated as a *MeshCast* result. There were 8 boundaries need to be solved. Figure 3 shows the example to check the geometry. The blue lines means that the edges connected to only one surface and it needs to be repaired during the MeshCAST step.

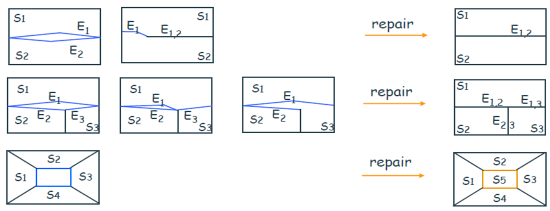


Fig. 3 Check the geometry

The ProCAST result introduced an extra step in the injection process and also necessitated extra time prior to removal of the wax pattern from the die. The following time intervals are specified during the production of each wax pattern: (a) the dwell time, during which the injection pressure is applied; and (b) the holding period, which is the time elapsed during the removal of the C-clamps. The experimental variables were as follows: injection pressure 2.5 MPa, injection temperature 50°C, dwell time 60 s, and holding time 75 s.

An intermediate period of 5 s between the dwell and holding periods, during which the injection pressure is released, was considered in the numerical simulations. Typical data for the pressure in the wax (transducer P1) and the temperature in the injection port (thermocouple T9) are shown in Figure 4. The instant at which the die was filled with wax is that at which the maximum pressure is recorded. The pressure drops almost linearly throughout the dwell time. The temperature drops steeply in the first 25 s and reaches a plateau at about 90 s. The injection temperature (50°C) is not observed in the cooling curve, since the filling time is much smaller than the response time of the thermocouple. About 130 s after the die was filled with wax, pressure ceased to be transmitted into the wax pattern. The instant at which the pressure is not transmitted through the wax pattern is also marked by an inflection in the temperature profile.

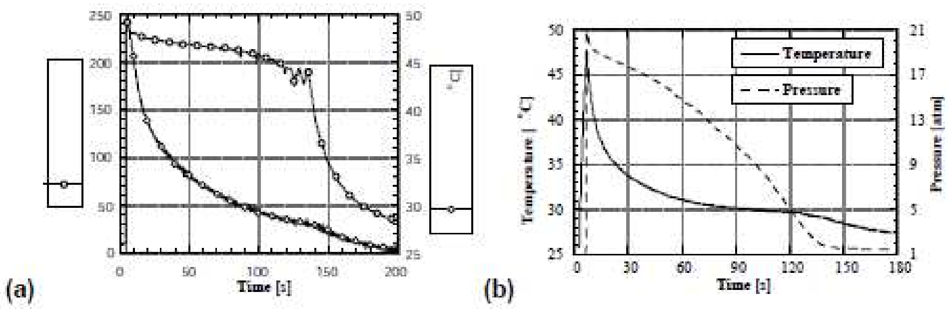
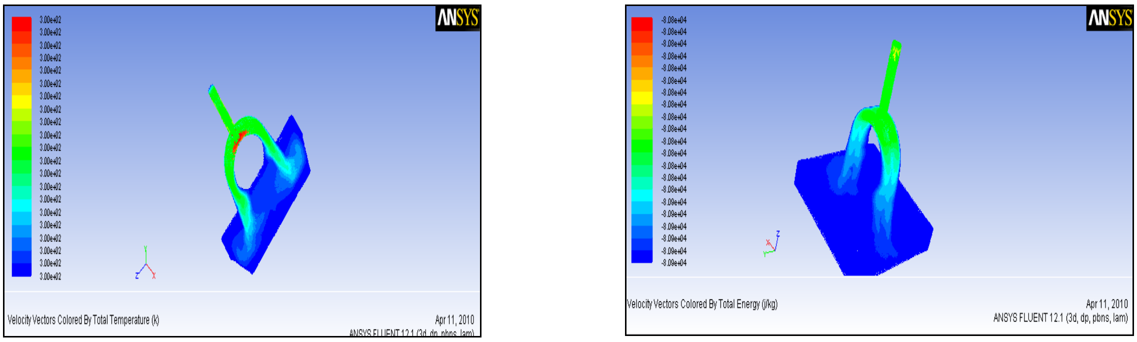


Fig. 4 Evolution in time of the temperature in the injection port (thermocouple T9) and the pressure in the wax pattern (pressure transducer P1) for (*a*) liquid injection and (*b*) paste injection.

The graph showed that the wax behaves like a paste until about 30°C. As long as the wax in the injection port is in a paste state, it continues to transmit pressure. This pressure data can be used to determine the onset of gate freezing and used to effectively determine the shortest dwell time for that injection port. The required pressure data were found to have a high degree of reproducibility.



(a) (b)

Fig. 5 (a) Velocity Vectors Coloured by Total Temperature (K), and (b) Velocity Vectors Coloured by Total Energy (j/kg)

By using investment casting technique, spherical bracket were presented with two gates. Figure 5(a) shows the velocity vector, total temeprature, and total energy. Based on the indicators on the left image, green areas are experiencing a moderate temperature. The average temperature in the Inlet area until it was down to the curvature. Then, there were areas that are red at the top of the curvature. The red color indicates that it was experienced a maximum temperature.

Based on Figure 5(b), there were areas that have a little yellow from the Inlet. After that, the movement of molten alloys of Inlet saw some areas experiencing moderate temperatures, as the area wass colored by the color green. Then following a large area of the dark blue color at the bracket which means the energy state is in low condition. Prior to that, in the curvature of the bracket shows little impressed with the blue sea. Dark blue resulted in the bracket base having a relatively low temperature.

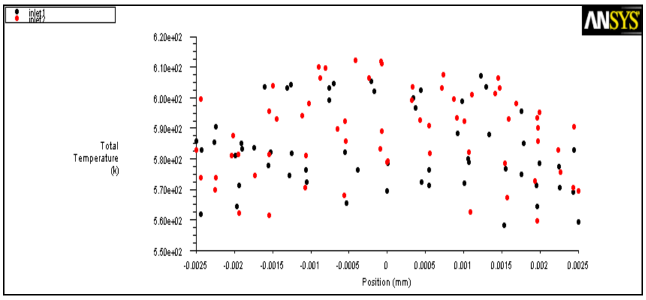


Fig. 6 Total Temperature (K) versus Position (mm)

Figure 6 shows the total temperature and position. The position is the position of the bracket at actual dimension. The graph contains two residuals of inlet 1 and inlet 2. From this graph, we could make distinctions between the two inlets which just proportional to the position. In the graph, the 0 mm position means the origin of the bracket. Positive and negative value means x-axis to the bracket. The movement of the molten alloys begins from the origin to the top of the inlet 1 while the inlet 2 starting from the position of -0.0025 mm. At first, the temperature is high based on the input entered before analysis begins. However, the amount of temperature will increase because at one point position, both the molten flow of the position will meet at -0.0005 mm and 0 mm. Nevertheless, the total temperature is decreased once it is entering the base part of the bracket due to time. As such, it will affect the design of the bracket at the critical part of fillet to the bearing compartment. Therefore, the design of the bracket will be revised and improved of its design parameter which affected from high temperature.

Conclusion

The use of three dimensional finite element simulation using ProCAST in designing of part for metal matrix composite could participate efficiently in the industrial design process in order to reduce the development time and cost of new product improvement as well as elevate the final product to investment casting technology with optimum performance and efficiency.

The results showed the examined process for the design through the simulation methodology in order to get the required wax pattern dimension has been achieved. Through the utilization of simulation analysis offers the ability to examine design parameters, which play a key role in the overall performance of casting technology.

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