Modelling of the Overcasting Reinforcement Process using the LS-DYNA® ICFD Solver

James Burt[1], Oliver Tomlin[1], Dan Howson[2], Tom Fleet[2]

[1]GRM Consulting Ltd
[2]Alvant Ltd

1 Abstract

The overcasting reinforcement process is a complex casting technique for creating lightweight aluminum components with additional strength from an aluminum matrix composite (AMC) insert. Empirical work to date has shown there are opportunities to further enhance the quality of adhesion between this AMC insert and cast aluminum. It is also evident that developing a predictive tool of bond quality will reduce the need for invasive measuring techniques.

To model this process the ICFD solver within LS-DYNA®, chosen for its ability for handling multi-physics problems, was utilized creating a coupled thermal-fluid analysis model of the AMC insert and molten aluminum. To capture important turbulence characteristics around the composite insert, use of the Large Eddy Simulation (LES) and Wall Adapting Local Eddy-viscosity (WALE) model were employed.

By replicating a series of physical tests and extracting key governing metrics from the CFD model, a tool for bonding prediction was created using response surface methodology (RSM). The accuracy of this tool and its predictions have been verified by simulating cases of alternate geometry designed to generate different characteristic flow phenomenon around the AMC insert, with comparison made to equivalent physical test results.

The predictive ability has subsequently been used to guide the required input parameters and gating system for manufacture of more complex components allowing for more design iterations to be explored before manufacture, saving large tooling costs and reducing waste material.

2 Introduction

The overcasting reinforcement process is a complex casting technique for creating lightweight aluminum components with additional strength from an aluminum matrix composite (AMC) insert. Empirical work to date has shown there are opportunities to further enhance the quality of adhesion between this AMC insert and cast aluminum. By creating a model using the ICFD solver with thermal FSI coupling, the quality of adhesion between the aluminum matrix composite (AMC) insert and cast aluminum, has been interrogated, allowing for more options to be explored in the design phase without acquiring large costs through practical testing. Developing a predictive tool of bond quality also aids in reducing the need for invasive measuring techniques.

To create this predictive tool a model was required to replicate a series of tests already conducted with evaluated grades and used to evaluate corresponding simulation values that cannot be measured during the overcasting reinforcement process. Values such as pressure, temperature and velocity were previously estimated or measured with various techniques in test, but the reasoning behind the differences between different geometry and influence on future geometry was unknown.

The ability to measure how temperature was transferred between the insert and casting melt was thought to be a key metric in the bonding quality, and as such why the ICFD solver was chosen for this application. The ability to model fluid structure integration in time dependent flows within LS-DYNA® suited the requirements appropriately.

3 Theory

Initially it was theorised that turbulence would have a major influence on the bonding quality due to observations from testing where grades varied greatly depending on the position along the insert it was measured at. For this case, where melt is poured over an flat insert the flow regime typically found on a flat plate can be applied, where there is a small laminar boundary layer at the leading edge and flow descends into a turbulent region downstream.

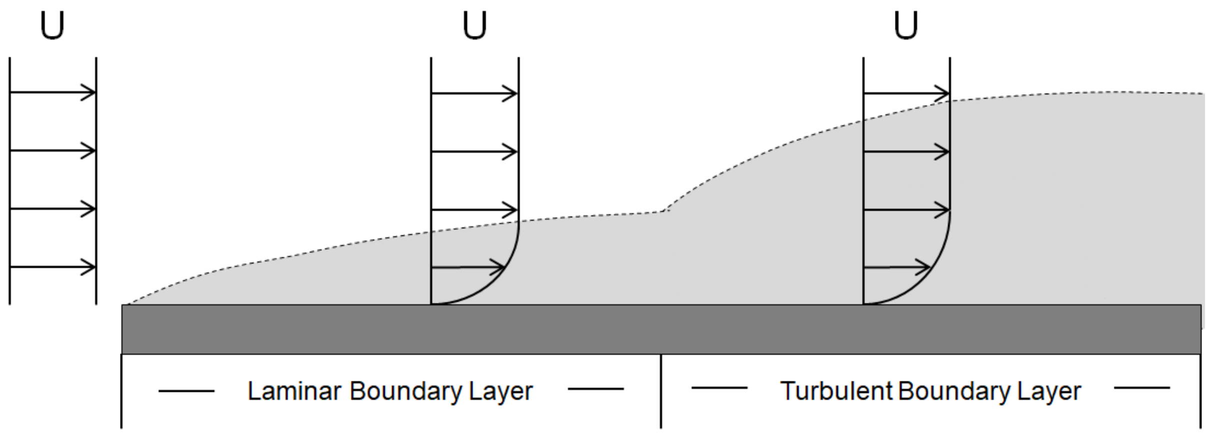

Fig.1: Typical flow regime found on a flat plate

In the context of the overcasting reinforcement process, casting over an aluminum matrix insert, this flow regime was originally believed to be the main driving factor of why different grades were found at various locations along the insert. To appropriately model this it was decided that the use of the (LES) large eddy simulation turbulence model was required. Although the LES turbulence model filters out smaller eddies tracking only the large ones, these larger eddies are the ones that are likely to be driving the adhesion bonding quality, dictated by the geometry of the insert and the surrounding mold.
For modelling near wall effects in the boundary layer the Wall Adapting Local Eddy-viscosity (WALE) model for the LES turbulence solver was chosen.

4 Model Setup

4.1 Thermal Coupling

The running geometry created by Alvant for insert testing was simplified into a 2D model for analysis. Through using a 2D model simulation time was reduced and more suitable for repeated simulations.

Switching to a 2D model there is some loss in effects due to the melt flow over the inserts edges, however as adhesion is typically measured along the inserts centerline, it is an appropriate assumption to create a 2D model for this case.

To enable the ability to capture the effects of temperature on the bonding results a Thermal-Fluid FSI coupled model had to be employed. An insert was created with thermal properties defined with the **`*MAT_THERMAL_ISOTROPIC`** material card. To enable coupling between the insert and the fluid domain the cards **`*CONTROL_SOLUTION`** with solution option set to 2, **`*ICFD_CONTROL_FSI`**, option set to 1 and **`*ICFD_CONTROL_CONJ`** option 0 to enable monolithic coupling of the fluid and thermal solve domains.

For the thermal solve keyword **`*CONTROL_THERMAL_SOLVER`** option 17 was selected, which enables the GMRES solver. The GMRES solver was developed by LSTC and JSOL primarily for fluid-thermal problems.[1] A inlet velocity was applied at the inlet of the insert channel where a filter exists in the system and the aluminum melt was defined as a fully incompresible fluid.

Fig.2: Simplified 2D model setup of the insert and channel

4.2 Mesh Refinement

To choose an appropriate mesh refinement level for the model a sensitivity study was performed. Global mesh sizing was gradually reduced so that the amount of nodes in the freestream channel above the insert varied. All the models were run on 4 cores of Intel i7 4GHz with 64GB of memory.

Model	Mesh CharacteristIc Length	Nodes Across Channel	Total Nodes	Total Elements	Model Runtime / Hours
1	0.550	9	7935	14870	0.4
2	0.367	13	15706	29914	0.6
3	0.275	17	26853	51710	1.2
4	0.220	22	39937	77382	2.2
5	0.183	26	55737	108476	5.1
6	0.157	31	75353	147212	7.2
7	0.138	35	95794	187616	10.8
8	0.122	39	121616	238737	18.1
9	0.110	44	147784	290587	25.1

Table 1: Sensitivity Study

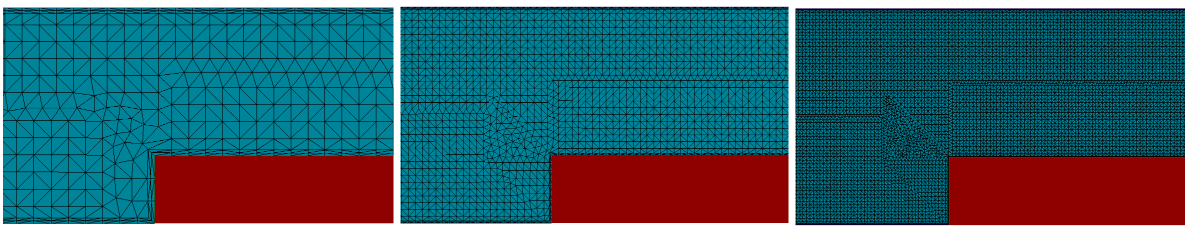

Fig.3: Grid Refinement Level for Models 1, 4 and 9.

Results of the sensitivity study found large differences in values measured up to model 4 with 0.22 mesh sizing giving approximately 22 nodes above the insert, beyond this level there was minimal advantage seen to using a fine mesh sizing. As such it was decided to use this level in the model for mesh sizing around the insert for the study.

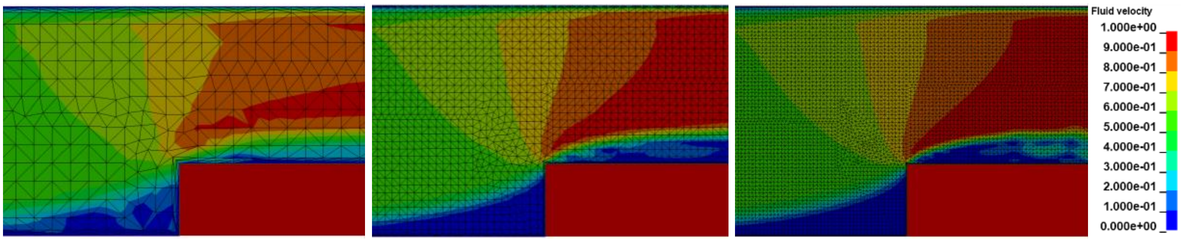

Fig.4: Velocity Contours for Grid Refinement Levels 1, 4 and 9.

Although 0.22 mesh sizing was chosen, it was noted that regions away from the insert did not require this level of refinement as minimal difference was found in the free stream regions and as such a coarser level of 1mm was used in order to improve simulation time further.

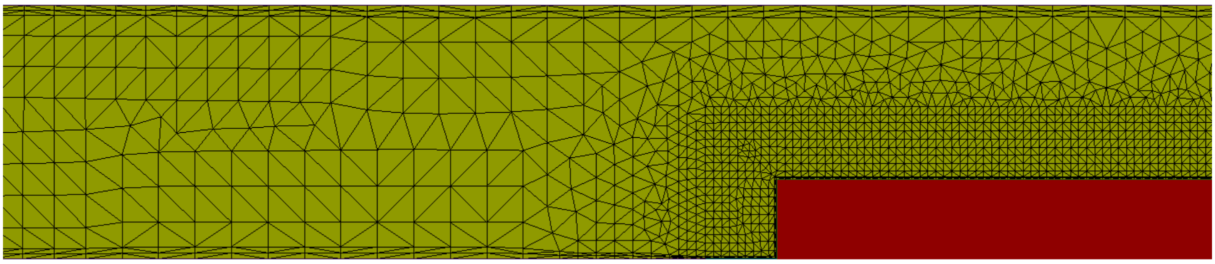

Fig.5: Final Meshing Strategy

In order to create this mesh, mesh boundaries were defined in LS PrePost as beam elements and converted to the appropriate ***MESH_SURFACE_ELEMENT** required by the ICFD solver. The internal automatic volume mesher within LS-DYNA®, was used to create the volume mesh. Care was taken around corners and curved features in order to preserve meshing quality. To prescribe the areas of local mesh refinement internal boundaries were added into the model as ***MESH_INTERF** parts.

5 Results

5.1 Test Replication

Prior to using CFD, investigation 14 tests had been performed by Alvant Ltd on a 10mm long insert with several pours at varied temperatures, mass flow rates and pouring time with bonding grades evaluated at 3 separate positions. Grades are evaluated on a 1-5 scale with a grade 5 indicating a very high quality of adhesion between the melt and the insert.

All these tests were then replicated in the 2D model by varying the inlet parameters upstream of the inlet using the ***ICFD_BOUNDARY_PRESCRIBED_VEL** and ***ICFD_BOUNDARY_PRESCRIBED_TEMP** keywords. Due to the model having FSI coupling, the insert‘s tempertaure could be measured and used in the bonding calculation.

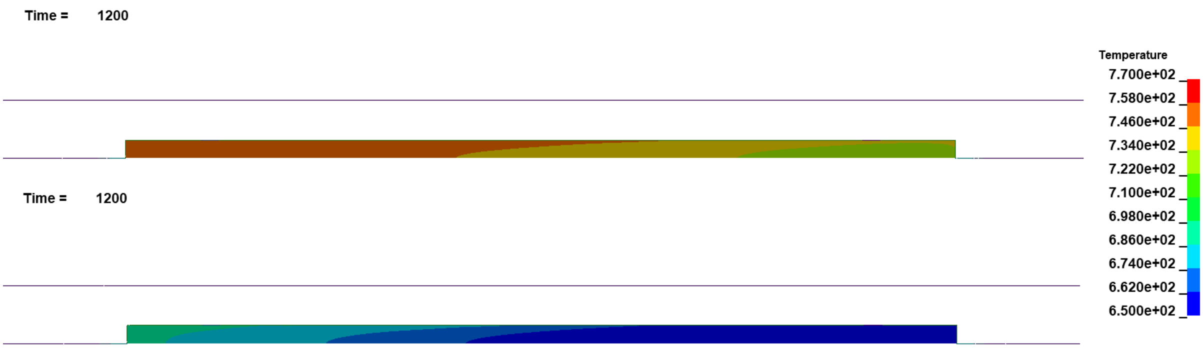

Fig.6: Insert Temperature for tests 2 (top) and 3 (bottom) after 1200ms

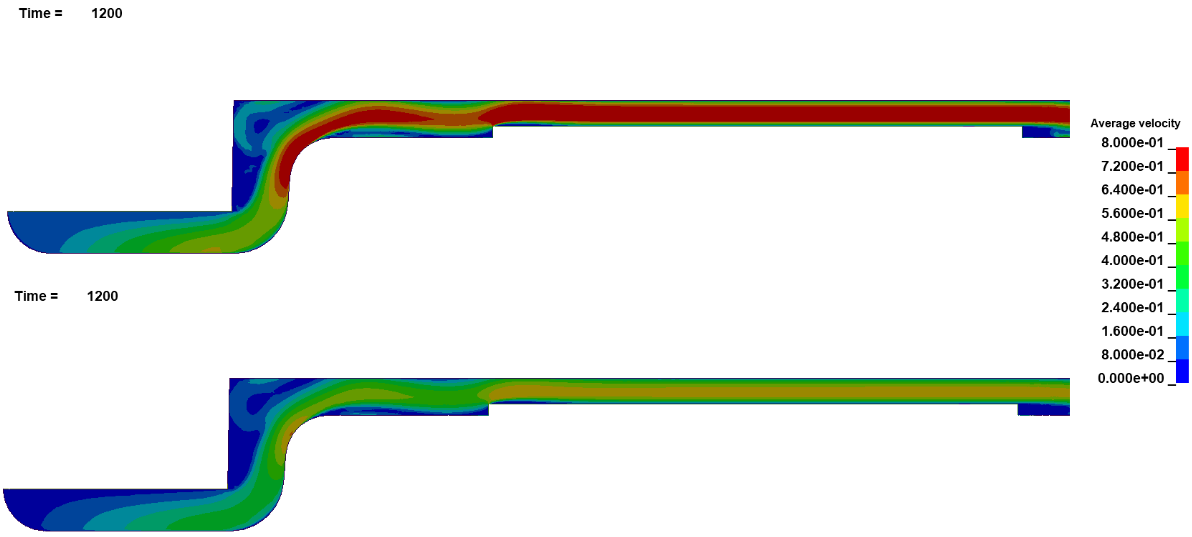

Fig.7: Average velocity for tests 2 (top) and 3 (bottom) after 1200ms

From the models several more metrics were measured in order to create response surfaces that would be later used to estimate bonding quality. Pressure and viscous forces on the fluid to insert boundary were measured from the **`*ICFD_DATABASE_DRAG`** keyword, whereas points measured in the **`*ICFD_DATABASE_POINTOUT`** keyword were used to measure velocities and temperatures in the freestream above the boundary layer.

Using these metrics as input parameters and measured bonding grades as the output parameters a series of response surfaces were created with the response surface tools withing LS-OPT. These response surfaces made up the predictive tool that therfore enabled future tests with alternate geometry to be estimated from simulation within LS-DYNA®.

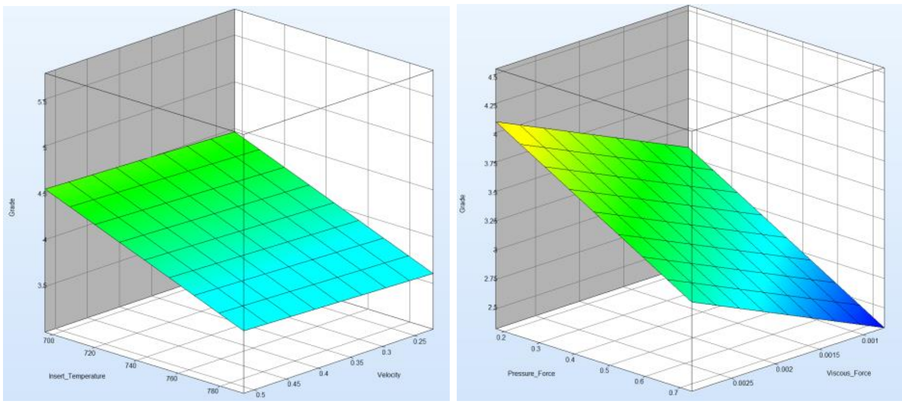

Fig.8: Example Response Surfaces Genergated from the Investigation

A polynominal metamodel was used with a linear order, this enabled an equation to be created that was used for predicting grades in subsequent simulations. Using some more the tools within LS-OPT to interrogate the accuracy of the response surfaces showd that the method gave a resonable accuracy between results that would be predicted by the response surface and those that were created in phyisical test.

The most beneficial knowledge gained by GRM Consulting and Alvant Ltd from using response surface methodology on the investigation has been the ability to identify metrics that are most likely to influence the quality of bonding. Previously the influence each metric had was relatively unknown but through this method the weighting of each factor has been identified. Now for future investigations in it is known where the largest benefits in design or setup changes will heavily influence the quality of manufacture.

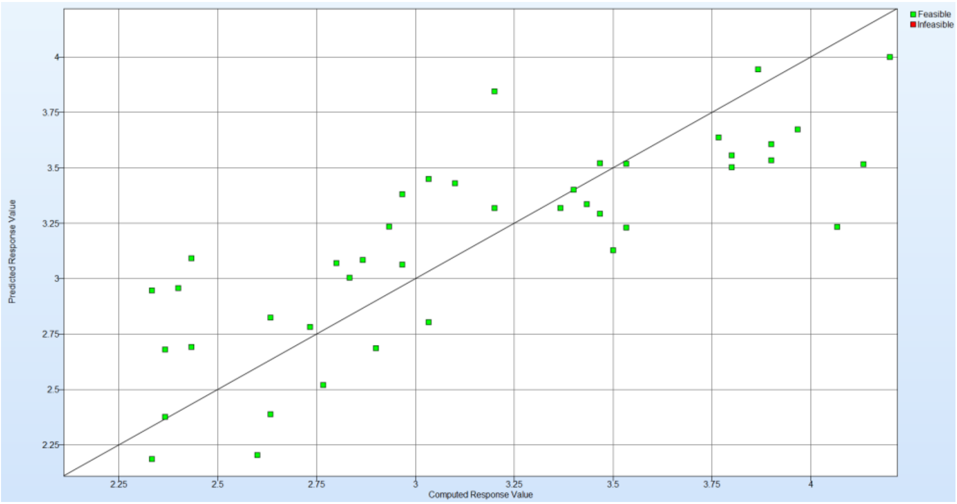

Fig.9: Accuracy Plot of the Generated Response Surfaces

5.2 Alternate Geometry

To test the accuracy and usefulness of the response surfaces created, two separate cases were carried out for physical test and comparison in CFD. The two tests were designed around generating two different flow phenomenon around the insert, resulting in a 'turbulence minimum' and 'turbulence maximum' case, to promote the effect of turbulence on the inserts bonding quality.

Fig.10: Turbulence Minimum (T Min) Test Design

For the turbulence minimum case the geometry was modified to remove features from the inlet and the leading edge of the insert that were observed to generate vortices in simulation. For the turbulence maximum test the geometry was altered to remove the effect of vortices that were observed to dissipate over the insert so a diffuser shaped design was employed to propagate vortices along the inserts length.

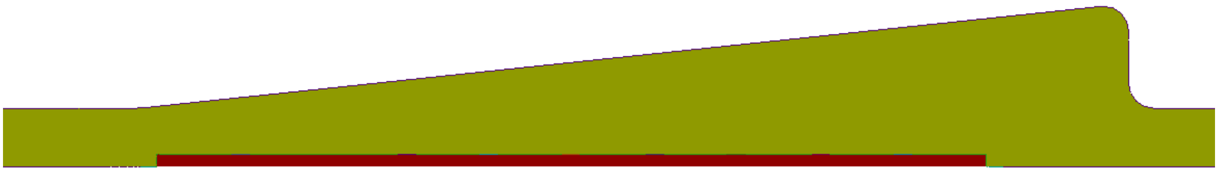

Fig.11: Turbulence Maximum (T Max) Test Design

Due to the methodology used, measuring the quality of adhesion from physical test was limited to just 3 points on the sample. However using simulation to estimate a bonding grade enables the ability to measure in this case 9 multiple locations along the insert, enabling much more trends to be easily observed.

Distance Along Insert (mm)	T Min Variation to Physical Test	T Min Variation to Physical Test
10	1.7	0.4
50	3	-0.3
90	3.4	-0.3

Table 2: Turbulence Min/Max Results Accuracy to physical test

The variance of alternate geometry was found to have a profound impact on the bonding quality as well with the turbulence minimum and turbulence maximum tests producing varied results, along with other input parameters that dictate the bonding quality. Due to the presence of the leading edge of the insert creating turbulence, grades that were evaluated at 10mm along the length were found to vary to grades that were measured further along the insert in the previous test setup. In comparison the variation was much smaller when the leading edge of the insert was removed, showing that the presence of turbulence and its characteristics can have a substantial impact on the quality of the insert adhesion.

6 Summary

The reasoning behind why quality of adhesion from physical tests for the overcasting reinforcement process provided varied results was identified through simulation within LS-DYNA®. By also through using tools in the LS-DYNA® ICFD solver, physical test data and combined with response surface methodology, a method has been developed that enables the ability to predict the quality of adhesion of the overcasting reinforcement process, and identify its largest influencers. This predictive ability will be used further to help guide the design of future more complex components for enhanced quality of manufacture.

Although the results from test for the first time this method was used as a predictive tool were mixed, the tools ability to help guide the design and interrogate the quality of adhesion, is a useful tool for the overcasting reinforcement process. With a greater sample size and results from various cases a more robust predictive modelling tool could be built which would inevitably lead to more accurate results.

7 Literature

[1] Tool cooling simulation for hot forming, T.Kuroiwa "11th European LS-DYNA Conference", 2017,

[2] LS-DYNA Keyword User's Manual Volume III, Livermore Software Technology Corporation , 2017,