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Enhancing Aluminum-Alloy Composites with Interlocking: A Hybrid Casting Approach

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Abstract*: This study explores a hybrid casting technique to reinforce aluminum-alloy composites with interlocking steel inserts. Modified cold rolling creates surface structures facilitating interlocking during solidification. Results demonstrate a 30% increase in compound strength with elevated temperatures. Conversely, reductions in piston position and melt velocity diminish strength by 41% and 30%, respectively. Concerns include the aluminum alloy melt's presolidification and gas entrapment.This research highlights the efficacy of structured cold rolling in high-pressure die casting for aluminum-alloy multi-material components*.

Keywords: interlocking; aluminum-alloy components; structured cold rolling; high-pressure die casting

I. INTRODUCTION

Multi-material design methods are gaining popularity in the automotive industry as a result of the demand for lightweight motor vehicles to satisfy CO2 emission requirements and increase the range of electric vehicles. Combining lightweight components with a foundation material of high strengthaluminum is a particularly useful material because of its favorable strength-to-weight ratiois one efficient approach. However, due to metallurgical differences and the tendency to create brittle intermetallic phases (IMPs), combining aluminum with other materialslike steelpresents difficulties.

Alternative joining techniques based on interlocked connections are gaining interest as a solution to these problems, particularly for structural components with intricate geometries. This study employs aluminum as the main material for examining this kind of method. Particularly, a roof cross member cast in almost series.

II. METHODS AND PROCESSES

This study's first phase was to demonstrate how surface characteristics on aluminum-based sample elements resulted in strength rise. In order to compare unstructured and structural components, a test for fatigue with dynamic loading was designed for the entire component. It has been suggested that the exterior structure would boost the load-bearing capacity and that compound strength would increase correspondingly with broader structures.

The focus then turned to assessing the impact of several process factors in high-pressure die casting (HPDC) as well as treatment actions both upstream and downstream on the strength of the compound. An extreme value analysis was used for assessing the effects of various casting circumstances that are often encountered in the industry. Assuming that during casting, relatively small channels become filled with melt, factors like melt and mold heats as well as melt velocity.

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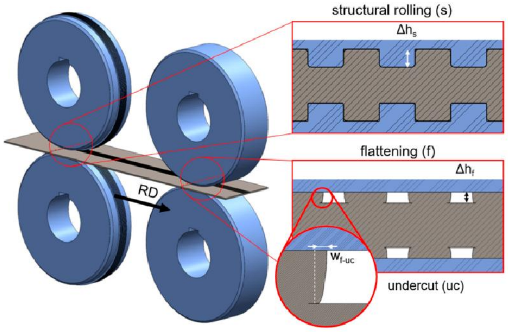

Figure 1. Process scheme of double-sided structural rolling and flattening.

High-Pressure Die Casting of the Hybrid Part

A modified high-pressure die casting tool, originally developed by Joop [16], was employed for the hybrid casting tests. This tool was intended for use with structural castings prevalent in automotive applications, like a roof cross-member profile. Applying casting simulation software (Magmasoft 5.4), the present hole shape has been modified in order to optimize the opportunities for casting a hybrid of both steel and aluminum sheet. The goal of this modification was to reduce the possibility of casting faults by obtaining more consistent die filling (see Figure 2).

Additionally, a design involving an area without a central hole pattern was put into operation for the melt flow in the aluminum insert. Because of its creative layout, negative consequences such melted penetration by the insert was much reduced in interference. In addition, this core region functions.

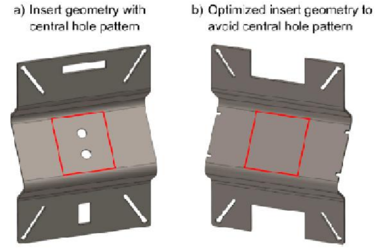
a) Insert geometry with central hole pattern
b) Optimized insert geometry to avoid central hole pattern

Figure 2. Comparison between original insert version (**a**)
[16] and optimized version for the productionof compound test specimens (**b**).

Element Composition of the Aluminum Alloy:

Silicon (Si): 10.5 wt. %
Iron (Fe): 0.20 wt. %
Copper (Cu): <0.02 wt. %
Manganese (Mn): 0.81 wt. %
Magnesium (Mg): 0.42 wt. %
Zinc (Zn): <0.02 wt. %
Titanium (Ti): 0.20 wt. %

Here is the DOE matrix presented in table format:

Run	Melt Temperature (°C)	Die Temperature (°C)	Melt Velocity (m/s)	Changeover Point (mm)	Upstream/Downstream Process
1	650	180	40	265	Air quenching
2	680	200	40	265	Air quenching
3	650	180	20	265	Air quenching
4	650	180	60	265	Air quenching

Run	Melt Temperature (°C)	Die Temperature (°C)	Melt Velocity (m/s)	Changeover Point (mm)	Upstream/Downstream Process
5	650	180	40	240	Air quenching
6	650	180	40	280	Air quenching
7	650	180	40	265	Pre-heating insert
8	650	180	40	265	Water quenching
9	650	180	40	265	T6 heat treatment

This table provides a clear overview of each experimental run and the corresponding values for the melt temperature, die temperature, melt velocity, changeover point, and upstream/downstream process[4].

Here are the tensile test results of the test samples along with the corresponding process parameters and comparison with reference samples:

ID	Process Parameter	Equivalent Stress (MPa)	Reference Comparison
1	Reference—13 mm structure	6.9	-
	Reference—25 mm structure	5.1	-
2	Raised melt/die temperature	6.7	+30% (2)
3	Melt velocity at gate 20 m/s	3.6	-41% (1)
4	Melt velocity at gate 60 m/s	4.9	-17% (1)
5	Changeover point at 240 mm “Chamber Full”	4.1	-30% (1)
6	Changeover point at 280 mm “Metal at Gate”	5.6	-6% (1)
7	Pre-heating insert	6.7	+6% (1)
8	Water quenching	5.8	-3% (1)
9	T6 heat treatment	5.1	-13% (1)

Provide the reference comparison.

- The percentage demonstrates how the equivalent stress has shifted when compared to the reference samples.
- Reference samples: These are typical samples that haven't had any adjustments made to any specific procedure parameter.
- (+) indicates a greater amount of stress in relation to the reference.
- (-) indicates a decrease in stress measured against the reference.
- The number contained within quotes denotes the description of the corresponding process parameter.

III. CONCLUSION

The results of the tensile tests highlight the significant impact of deviations in process parameters on casting defects and subsequent changes in bond strength. From these findings, two main effects were observed, leading to the following conclusions:

Importance of Complete Channel Filling:

Increasing melt and die temperatures reduces the risk of cold flow and enhances the melt's ability to fill the undercut channels, resulting in higher strength during testing.

Lower gate velocities during the mold filling phase and premature changeover points lead to incomplete channel filling and reduced compound strength.

Excessively high gate velocities contribute to decreased compound strength due to increased porosity observed in the channels.

Limited Influence of Upstream and Downstream Processes:

Evaluation of upstream processes such as insert preheating, as well as downstream processes including post-casting water quenching and T6 heat treatment, did not significantly affect test performance. This reinforces the primary conclusion regarding the critical importance of complete channel filling for achieving desired compound strength.

These conclusions underscore the necessity of careful control over process parameters, particularly concerning channel filling, to ensure optimal bond strength in hybrid cast components. Additionally, while upstream and downstream processes may offer potential benefits, their impact appears secondary compared to the critical factor of achieving thorough channel filling during casting.

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