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Opportunities and Challenges for Use of SSM Forming In The Aerospace Industry

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Abstract. SSM is now considered an established technology to produce high integrity near net shape components for the automotive industry in particular. Although it is used extensively in the automotive industry, very little attention has been given to aerospace applications. SSM processing does demonstrate the potential to replace certain hogout components in commercial aircraft with the main aim to reduce costs while maintaining high strength to weight ratios. In order to achieve this it will require developing processes to reliably cast components with consistent properties to meet aerospace requirements. Since SSM forming is a relatively new process, materials properties data bases for components produced using this technique is very limited. One of the major challenges is the generation of a data base of material properties to assist design engineers for design of components, as well to assess the life expectancy and development maintenance schedules.

Introduction

The SSM process inherently offers the opportunity to produce high integrity components. Since its discovery in early 1970s by Spencer et al; a wide spectrum of routes and processes has been developed to produce semi-solid metal slurries [1]. There have been major advances in a wide range of metal alloys. Since the initial activities on lead-tin and aluminium alloys; Mg, Fe, Cu and even superalloys have been successfully processed using the SSM route. However, most of research has been focussed on the aluminium and magnesium alloys with the automotive industry being the main target market because of the trend to produce lighter weight and more fuel efficient vehicles.

There has been very little attention given to applications in the aerospace industry. In the aerospace industry high strength aluminium is used extensively in the heat treated condition to achieve maximum strength to weight ratios. The SSM process offers the opportunity for high pressure die casting of high strength aluminium wrought alloys to manufacture near net shape components. These components can also be heat treated due the low porosity in SSM formed components. Although the volumes of the parts produced are not as large as that required in the automotive industry there is the opportunity to replace certain high cost hogout processes. It is evident with the opportunities comes several challenges. The paper will give an overview of the potential applications of SSM forming in the aerospace industry, what are the challenges and the type of research and data that needs to be generated to realize this potential.

Rationale for considering SSM forming in the aerospace industry

Aluminium alloys are used extensively in the aerospace industry; in the form of cast as well as hogout (machined or forged) components. The alloys used can range from standard casting alloys A356, A357, 201, B201, 206 and modified wrought alloys 7075 and 7050. Most structural components are manufactured using expensive hogout methods. Currently Boeing is considering SSM as a replacement for some of the casting and hogout manufacturing methods with the main aim of reducing costs while maintaining the properties achieved using traditional methods. The components to be replaced are high volume hogout components used in commercial aircraft and certain military applications.

SSM forming offers several advantages that make it competitive with hogout processes:

- Low gas porosity due to laminar filling of dies
- Low solidification porosity because of the high solid fraction present
- Casting of thin walled, complex shaped, near net shaped components with good surface finish.
- Improved die life because of the lower casting temperature
- The components are heat treatable and weldable because of the low porosity present
- The ability to cast alloys that are normally difficult to cast using conventional liquid casting techniques.

Typical Components that may be manufactured using SSM forming

Aircraft structural components can be classified into two major categories, primary and secondary structural components. These components are typically manufactured from aluminium casting or wrought alloys depending on the manufacturing process used. Primary structural components, examples, fuel system drain mast, are typically components with high requirements for resistance to fatigue crack propagation. These components are also thin walled and weight is of critical importance. Typical materials used for these applications are high strength wrought aluminium alloys, eg. 7075. Production methods used are normally machining or forging followed by a heat treatment process to enhance the mechanical properties.

Secondary structural components, examples, interior fittings and brackets, are components which must be light weight with high static tensile properties. Typical production techniques utilized would be hogout processes followed by heat treatments. There is enormous potential to replace the hogout process with SSM forming because of the higher production efficiency and lower cost when compared to hogout processes. Due to lower requirements in terms of fatigue properties in some instances some of the lower specification wrought alloys could be replaced with casting alloys.

The main aluminium alloys of interest are A357, 201 and 206 casting alloys and modified 7075, 7050 and 2024 wrought alloys. These alloys will cover most of the components whether it is for primary or secondary structural components.

Challenges

When switching from a proven manufacturing method to a new untested process there comes many challenges before approval and implementation of the technology. The application of SSM forming has been mainly focused on the automotive industry, hence, most research and development work has concentrated on alloys and properties related to this industry's needs. For SSM to be applied in the aerospace industry the unique requirements for this industry needs to be considered. In general some of the key issues that need to be addressed are listed in Table 1.

Table 1: Issues that need to be addressed for implementation of the SSM processes in the aerospace industry

1.	Process stability
2.	Die design
3.	Casting of thin walled high strength components
4.	SSM processing and casting of high strength wrought alloys
5.	Data base of mechanical properties
6.	Corrosion, corrosion fatigue and stress corrosion cracking (SCC) of SSM formed components.

Process stability. One of the fundamental methods of ensuring that components are produced with consistent mechanical and physical properties whichever SSM technology used must be controlled within tight boundaries. For aerospace applications defect tolerances are much tighter than that which is applied in the automotive industry especially for components exposed to fatigue type loading. A total process control method must be employed starting with foundry practice to the final forming and post production processes. Hence it would be critical to ensure that the quality of the melt used is of a high standard. This implies that the inclusion levels have to be kept within acceptable limits as stipulated by aerospace standards. In recent research on the influence of chemical composition on the SSM process by Kaufman et al, it was shown that for SSM forming it may be necessary to specify smaller ranges for key alloying elements to ensure process stability.

Component and die design. When designing components to be manufactured for semi-solid forming the thixotropic flow behaviour needs to be taken into account. This has a significant influence on component geometry. Although there have been a number of case studies on the manufacture SSM components, there is very little documented literature on the design principles for SSM forming. Modeling for SSM flow behaviour in dies has been developed significantly over the last decade and there are commercially available simulation packages to assist with die design. Although these packages give a good indication of flow behaviour to assist with die design they cannot predict segregation of liquid phase.

Thin walled components. Although SSM casting has demonstrated that it is possible to produce components with varying wall thickness as well as relatively thin walled components this has been evaluated using mainly automotive and consumer products. The wall thickness for aerospace type components is significantly thinner on certain components hence establishing the appropriate processing and casting parameters will be a significant challenge.

SSM processing of high strength alloys. One of the main advantages of the SSM forming technology is the capability to HPDC alloys that are difficult to cast. The alloys of interest are the high strength wrought alloys, 7000 and 2000 series, and the 200 series casting alloys. There have been significant research activities in the thixocasting of these alloys [3,4,5,6] and the results have shown that the strengths achieved in the T6 condition are lower than that achieved for conventional wrought alloys. There has been limited work done using the rheocasting processes. Optimization of the rheocasting process for the 7000 and 2000 series aluminum wrought alloys will need to be addressed. In order to achieve the strengths attained with wrought alloys it may be necessary to modify the existing wrought alloy compositions. There is also the need for development of new alloys for semi-solid metal forming which is receiving increased attention [7,8,9].

Data base of mechanical properties. SSM forming is a relatively new forming technology, hence it would be necessary to develop a reliable database of mechanical properties to assist engineers to design components. Although there are number of reported studies on the mechanical properties of typical casting alloys A356 and A357, these are mainly tensile properties and are generally component specific or results generated from simple castings produced on a laboratory scale. There have been limited reports on fatigue and fracture properties [10,11,12,13,14]. Again these articles mainly evaluate the casting alloys. In order for SSM to be used effectively in the aerospace industry a significant amount of attention must be given to develop a data base of mechanical properties for not just casting alloys but also for modified wrought alloys to be used in the primary structural components. One of the major challenges would be to investigate the fracture toughness and fatigue crack propagation properties and influence of the microstructure and heat treatment on these properties.

Corrosion, corrosion fatigue and stress corrosion cracking (SCC) of SSM formed components. Corrosion and corrosion stress interactions of SSM cast components have not been studied extensively. For aerospace application the SCC and corrosion fatigue of wrought alloys is especially important for structural components.

Conclusions

It is evident that there are a number of areas in terms of SSM processing as well material properties that need to be developed to a level that is acceptable for aerospace applications. In order for SSM processing to be implemented for commercial aircraft components it is essential that reliable processing techniques as well as a comprehensive database on materials properties need to be generated. The main areas of development that need to be addressed is to demonstrate that the technology can process high quality components within the tolerances specified by the aerospace industry and to establish a reliable database of mechanical and corrosion properties for SSM cast alloys. SSM forming has the potential to become an important processing and powerful manufacturing technique for both the current and next generations of commercial aircraft.

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