SQUEEZE CAST AUTOMOTIVE APPLICATIONS AND DESIGN CONSIDERATIONS

Z. Brown, C. Barnes, J. Bigelow , P. Dodd

With an increasing emphasis on vehicle weight reduction, the demand for lighter weight automotive components continues to increase. Squeeze casting is an established shape-casting process that is capable of producing lightweight, high integrity automotive components that can be used for structural applications. In recent years the squeeze casting process has been used with various aluminum alloys to produce near-net shape components requiring high strength, ductility, pressure tightness or high wear resistance [1]. Squeeze casting has proven to be an economical casting process for high volume applications and offers design and materials engineers an alternative to conventional casting processes such as gravity permanent mold (GPM), low pressure die casting (LPDC), sand cast aluminum/ iron, and conventional high pressure die casting (HPDC).

This paper describes Contech's squeeze casting technology (P2000TM) and provides examples of high volume automotive components manufactured at Contech. This paper also includes product design considerations, an overview of process simulation techniques, a comparison of mechanical properties, and case studies for select automotive components.

KEYWORDS: squeeze casting, aluminum, automotive applications, die casting, safety critical

INTRODUCTION

Conventional HPDC is a well-established process for the manufacturing of a wide variety of aluminum automotive components such as engine blocks, pump housings, oil pans, and transmission components. Conventional HPDC has many advantages including near-net shape capability, low manufacturing cost, and excellent dimensional accuracy and repeatability.

Achievable casting performance is limited however, due to defects that emerge during the casting process such as gas and shrink porosity, laminations, and inclusions. In addition, HPDC components are not considered heat treatable, which further limits achievable performance.

For applications that require higher component integrity (high strength and ductility, reduced porosity, uniform microstructure, and ability to heat treat), alternative casting processes such as squeeze casting should be considered. Squeeze casting is an established process that builds upon conventional HPDC practices and is used to manufacture various automotive components that require high strength and ductility, as well as applications that require high pressure tightness or wear resistance. Examples include steering column components, steering knuckles, control arms, suspension links, pump housings, and various powertain components [1]. The squeeze casting process is capable of producing components with dimensional accuracy and near-net shape capability that is equal to conventional HPDC. Unlike HPDC however, the squeeze casting process is capable of producing higher integrity components. As a result, design engineers are able to further optimize current aluminum designs or substitute aluminum in place of heavy materials such as steel and cast iron.

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SQUEEZE CASTING TECHNOLOGY (P2000TM)

Squeeze casting can be divided into two categories; "direct" and "indirect". Direct squeeze casting, often termed "liquid-metal forging", consists of pouring metal into a lower die contained within a hydraulic press. The upper die closes over the lower die and high pressure is applied throughout the entire solidification process. In contrast, indirect squeeze casting consists of pouring molten metal into the cold chamber of a die

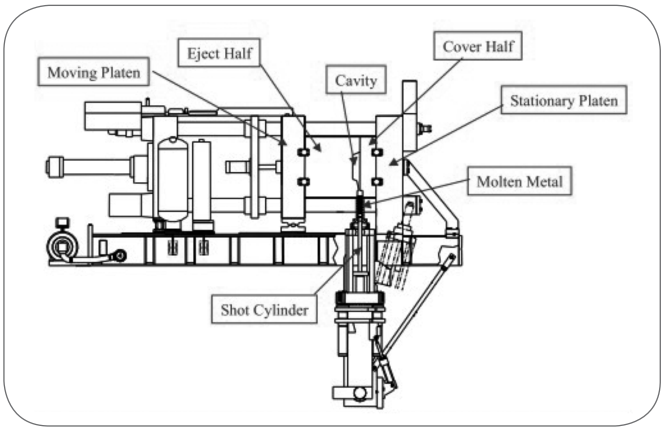

Fig. 1 **Schematic of P2000™ casting machine.**
Schema della macchina di colata P2000™.

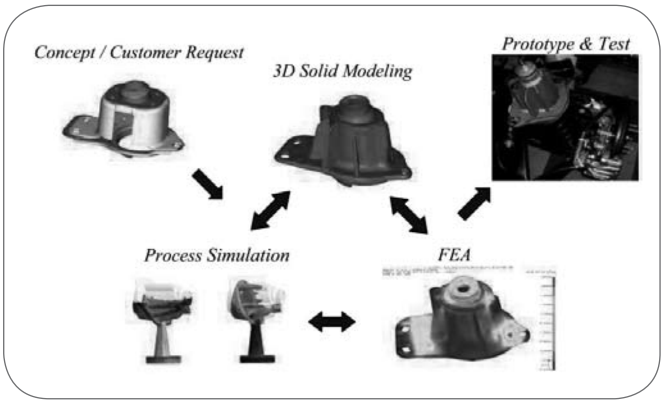

Fig. 2 **Design process for aluminum shock mount.**
Configurazione del processo per la produzione di un supporto anti-urto in alluminio.

casting machine, ejecting the metal into the cavity at relatively slow shot speeds, and applying pressure through the shot system during solidification [2].
Contech's proprietary P2000™ process is considered an indirect squeeze casting process. Fig. 1 shows the schematic of a typical casting machine. The vertical cold chamber is designed to tilt back prior to pouring the metal into the cold chamber. The metal is poured down the sidewall of the cold chamber to minimize turbulence, thereby minimizing porosity and the formation of oxide skins.
This is done outside of the casting cycle during the spraying phase so overall cycle time is minimized. The metal is slowly forced into the preheated die cavity, and pressure is applied throughout solidification. The slow injection speed reduces turbulence resulting in minimal air entrapment. The continuous application of pressure helps minimize shrink porosity and creates rapid heat transfer at the mold/metal interface resulting in a fine microstructure (small dendrite arm spacing (DAS) and fibrous silicon morphology). The reduced amount of shrink and gas porosity, fine microstructure, and ability to heat treat are factors responsible for the improved part integrity [3].
The proprietary CONTECH P2000™ squeeze casting process has been in high-volume production for over 25 years and has been continuously refined throughout this timeframe. As a result, the P2000™ casting process takes into account all factors that can influence the quality of the casting including die cooling systems, gating and venting configurations, casting process parameters, die lube selection and application, alloy selection, metal handling, heat treatment, and secondary operations. If all of these factors are considered during the design and product development phase, components can be optimized to not only meet functional requirements but also manufacturing requirements.

DESIGN CONSIDERATIONS

With ongoing emphasis on weight reduction, designers are challenged with developing components that meet weight and cost targets, while meeting functional and manufacturing requirements.
Examples of functional requirements include strength, durability, stiffness, hardness/wear resistance, surface appearance, and packaging. Manufacturing requirements include castability, dimensional capability, cycle time optimization, tooling reliability, machining stock minimization, and overall casting quality. Determining the proper balance between these factors can be challenging. It is recommend therefore that design engineers collaborate closely with casting engineers as early as possible during the development of a new product.

Design Process

Creating a fully optimized casting design requires multiple design iterations and analysis techniques. Fig. 2 shows an example of the design process that was used to convert a steel stamped shock mount assembly to a single aluminum squeeze casting. Solid modeling software was used to develop the initial casting models. Finite element analysis (FEA) was used to optimize the component geometry and ensure all strength, durability, and stiffness requirements were met.
Process simulation tools were used to ensure manufacturing requirements were met and to indentify potential casting flaws (i.e. porosity, flow related defects, etc.). The final design was validated through component testing of the prototype castings. The aluminum shock mount weighed approximately 30% less than the steel design. The number of individual stamped and welded components was reduced from seven to one.
By using both FEA and process simulation tools simultaneously, design engineers can take advantage of the full material potential, resulting in lighter weight designs. Simulation results can be compared to FEA results to determine if potential casting defects are near high stress regions, potentially resulting in lower than expected casting performance. In addition, specific geometries that improve manufacturability and component integrity can be incorporated into the design in the early stages of development. By using this type of approach, design engineers can take full advantage of the castings true potential.

Process Simulation

Process simulation tools, when used properly, are an effective method of evaluating potential casting integrity, establishing process settings, predicting residual stresses, and determining optimal gating and die cooling configuration.

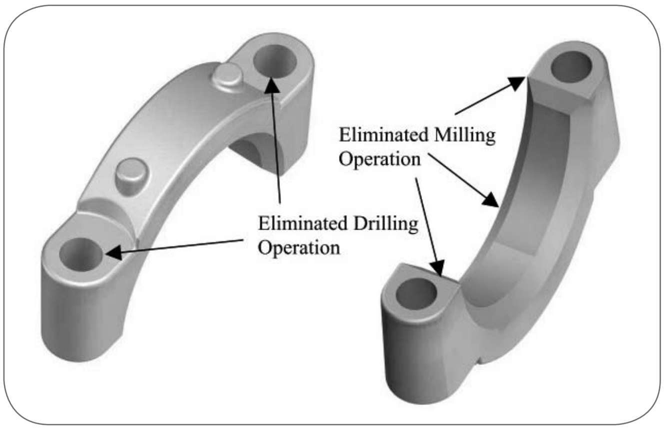

Fig. 3

Example of an aluminum bearing cap that was converted from GPM to the P2000™ squeeze cast process. All secondary machining operations were eliminated.
Esempio di una calotta in alluminio prodotto mediante squeeze casting (P2000™) anzichè in gravità in conchiglia. Tutte le operazioni secondarie di lavorazione sono state eliminate.

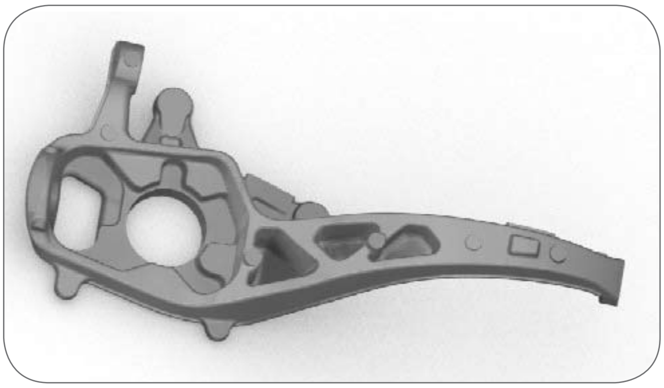

Fig. 4

Example of P2000™ squeeze cast knuckle.
Esempio di snodo prodotto con la tecnica di squeeze castingP2000™.

Solidification simulations are used mainly to predict shrink porosity and evaluate directional solidification. Fill simulations are used to identify potential fill related issues such as laminations due to merging flow fronts, turbulence, and improper venting.
Tooling design engineers rely on these tools when optimizing gating size and location, cooling line placement, cooling media and temperature, die configuration, and process development. New process simulation techniques are now being used to predict the microstructure at various locations throughout the casting. Since strength and ductility are influenced by the microstructure, this tool can be used to predict mechanical properties at various locations throughout the casting. This information can then be used when interpreting FEA results. Other new developments allow for the prediction of residual stresses induced during the casting and heat treating process. Most commercially available FEA software does not consider residual stress. High residual stress can result in lower than expected component performance and dimensional capability.

Design Recommendations

The squeeze casting process is capable of producing complex geometries with high dimensional accuracy and repeatability. This allows designers to create near-net shapes, thus minimizing secondary machining operations. Fig. 3 shows an example of an aluminum bearing cap that was converted from gravity permanent mold to squeeze casting. Due to the near net shape capability of the squeeze casting process, all secondary machine operations were eliminated. The use of precision cores with minimal draft (less than .5° per side) eliminated the need for a secondary drilling operation. The flatness and surface finish requirements were achieved in the as-cast condition, eliminating the milling operation.
For applications that require high mechanical stiffness, design engineers must consider both the modulus of elasticity and section modulus. Modulus of elasticity is a function of the stiffness of the alloy itself and is fairly similar for most aluminum casting alloys. Section modulus is a function of stiffness from the casting geometry. Increasing the section modulus through design can offset issues with a lower modulus of elasticity. Complex geometries such as ribs, pockets, and u-shaped sections can be used to increase section modulus. It is recommended to avoid drastic wall thickness changes and isolated thick sections. By avoiding localized thick sections and drastic wall thickness changes, the tendency to form shrink porosity is greatly reduced. Isolated thick sections can also induce stress concentration points and cause casting defects such as hot tears and heat sinks.

Material Selection

One important advantage of the squeeze casting process is that it is can be used with various alloy/ heat treat combinations that can be tailored to meet design requirements. Primary alloys, such as A356 (AlSi7Mg) are used in the T6 condition for applications that require high strength and ductility such as control arms, steering knuckles, and suspension links. Secondary alloys such as ADC12 (AlSi11Cu3Fe) are used in the as-cast, T5, and T6 conditions for applications that require high strength, pressure tightness, and wear resistance. Typical mechanical properties are shown in Tab. 1.

Alloy-Temper	Yield (MPa)	Tensile (MPa)	% Elongation	Hardness (HBN)
A356- T6	220-260	290-340	9-15	85-100
ADC12-F	140-170	200-270	2-3.5	95-105
ADC12- T5	230-260	280-320	1-3	110-130
ADC12- T6	290-320	344-380	2-5	120-140

Tab. 1

indici di prestazione dei materiali candidati.
Materials indexes for candidate materials.

P2000™ APPLICATIONS

Fig. 4 shows an example of a squeeze cast front steering knuckle. In this

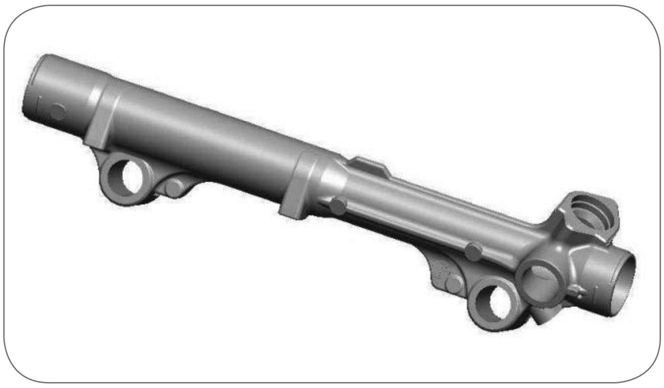

Fig. 5

P2000™ rack & pinion housing for a full size truck application.
Alloggiamento pignone per camion prodotto con la tecnologia P2000™.

application, a direct conversion was made from cast iron to a much lighter-weight, near net-shape aluminium squeeze casting. Since steering knuckles are considered safety critical components, rigorous testing is required prior to shipment. Examples of tests include material property measurements, component strength and fatigue testing, dimensional checks, x-ray, and ultrasonic inspection. The P2000™ squeeze casting process was able to meet, and in some cases, exceeded all customer requirements and expectations with A356.2 alloy and a T6 temper [3]. This high-volume knuckle (120,000 parts annually) has been in production for several years.
Fig. 5 shows an example of a squeeze cast rack and pinion housing for a high-volume full size truck. The integrity of the cast housing is critical to the overall function of the hydraulic steering system. Leakage of hydraulic fluid from any pressurized area of the casting can create a drop in hydraulic pressure, thereby creating a potential malfunction of the vehicle steering system. Through the years rack and pinion housings have primarily been made via the conventional HPDC process. For this particular application, the customer required higher mechanical properties and burst requirements than the HPDC process could deliver. The P2000™ squeeze casing process was ideally suited for this type of component due to the superior physical and mechanical properties, dimensional capabilities, and prior success with similar applications. The annual requirement of 400,000 castings is achieved using a two-cavity die, ADC12 alloy, and a T6 temper.

CONCLUSION

Squeeze casting is an established shape-casting process that is capable of producing lightweight, high integrity, automotive components that can be used for structural applications. The squeeze casting process has many advantages over other casting processes including high mechanical properties, near-net shape capability, minimal gas and shrink porosity, and the ability to heat treat.
Even with the many advantages of the squeeze casting process, desired quality level cannot be guaranteed without proper design and upfront engineering. Carefully planned casting geometries and tooling designs can offset issues with manufacturability and casting performance. Advanced computer aided engineering software such as solid modeling, process simulation, and finite element analysis are powerful tools that can be used to assist with product development, tooling design, and process engineering. The use of these tools, combined with the design and casting engineers knowledge and experience, can result in lighter weight casting designs that meet or exceed all performance and cost targets. The use of lightweight castings will assist the automobile manufacturers in improving fuel economy and reducing vehicle emissions.

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ABSTRACT

APPLICAZIONI DI "SQUEEZE CASTING" NEL SETTORE AUTOMOBILISTICO E CONSIDERAZIONI PER LA PROGETTAZIONE

Parole chiave: alluminio e leghe, pressocolata, processi

Per la crescente enfasi sulla riduzione del peso nei veicoli, continua ad aumentare la domanda di componenti automobilistici più leggeri. Lo "squeeze casting" è un processo che permette di produrre componenti leggeri e ad alta integrità che possono essere impiegati per applicazioni strutturali sugli autoveicoli. Negli ultimi anni il processo di "squeeze casting" è stato utilizzato con varie leghe di alluminio per la produzione di componenti "near-net-shape" che richiedono alta resistenza meccanica, duttilità, tenuta a pressione o alta resistenza all'usura [1]. Il processo di "squeeze casting" si è dimostrato un processo economico per applicazioni ad alti volumi di produzione ed offre ai progettisti una alternativa rispetto ai processi convenzionali, come la colata a gravità in conchiglia (GPM), la colata in bassa pressione (LPDC), la colata in sabbia di alluminio / ghisa, e la pressocolata convenzionale (HPDC).
Il presente documento descrive la tecnologia di squeeze casting (P2000™) sviluppata dalla Contech; fornisce anche esempi di alti volumi di produzione per componenti di autoveicoli fabbricati presso tale azienda. Il documento presenta anche delle considerazioni relative alla progettazione dei prodotti, una panoramica delle tecniche di simulazione del processo, il confronto delle proprietà meccaniche, alcuni studi di casi per componenti automobilistici specifici.