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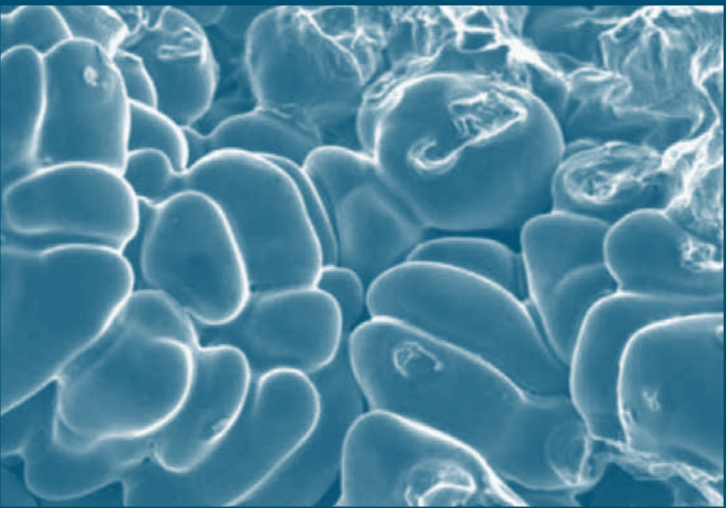
SQUEEZE CASTING: THE FUTURE



Dr Amita Iyer

Skills Victoria/ISS Institute TAFE Fellowship

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Department of Innovation,
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Executive Summary

Squeeze casting is a relatively new casting technology when compared with traditional sand casting, which dates back to between 2000 and 3500 BC. Squeeze casting has number of advantages, including the elimination of gas and shrinkage porosities, the reduction or elimination of metal wastage due to the absence of feeders or risers, and the possibility of the manipulation of processes to achieve the required optimum parameters.

Squeeze casting can be applied to high integrity parts like suspension arms, brake calipers, aluminium wheels, steering knuckles, vanes, ring groove reinforced pistons, connecting rods, rotary compressor vanes and shock absorber cylinders, to name a few.

Squeeze casting is a die casting method based on slower, continuous die filling and high metal pressures. Laminar die filling and squeezing, which is the application of pressure during solidification, ensures that the component is free from blowholes and porosity. This method produces heat-treatable components that can also be used in safety-relevant applications and are characterised by higher strength and ductility than conventional die castings.

The die casting process is the high-speed injection of a molten metal alloy into a steel mould. This alloy then solidifies rapidly (solidification time varying from milliseconds to a few seconds) to form a net shaped component and is then extracted from the mould. During the die casting process the die is filled at high speed, but during squeeze casting the filling process takes longer, from a half-second to three seconds. This slower approach permits a die filling that is virtually free of gas entrapment.

Dr Amita Iyer's current observation of the Australian context suggests that manufacturing industries are still sceptical about the use of squeeze casting; considering it as a relatively new technology when compared to conventional die casting methods.

The aim of the Fellowship was to provide the opportunity for Dr Iyer to develop a comprehensive understanding of how others in the world of the manufacturing industry are embracing squeeze casting and implementing it easily and successfully. The Fellowship itinerary included visits to CONTECH, Ryobi die casting, CWRU University, and NADCA, all in the USA.

The Fellowship provided a valuable opportunity to undertake a comprehensive investigation of the process parameters and skills required to maximise the potential of squeeze casting within the Australian context.

Key areas of study included:

- Identification and assessment of various approaches being employed by the squeeze cast manufacturers, and highlighting those considered to be best practice.
- Visiting professional associations to gauge the status of squeeze casting overseas.
- Collecting, recording and analysing the manufacturing techniques of squeeze casting.
- Identification of any special die requirements for squeeze casting.
- Identification of the difference between standard die casting and squeeze casting methods.
- Identification of post-finish operations on squeeze casting parts, such as machining and/or heat treatment.
- Determining the influence of squeeze casting parameters on mechanical properties and microstructures.
- Identification of the relationship between the design of the part, the process variables and the soundness of the squeeze cast part.

Executive Summary

The overseas Fellowship program was designed to explore the identified skills and knowledge deficiencies and for Dr Iyer to return to Australia equipped with the knowledge and ideas essential to ensuring enhanced teaching practices and content delivery. Offering effective experiences and opportunities for others to maximise their learning will be essential to promoting and improving the overall acceptance of squeeze casting in this country.

The investigation was carried out using the following methods:

- Contacting and interviewing aligned and comparable manufacturing associations, practicing die casters and training providers (researchers).
- Viewing the application and implementation of squeeze casting in production.

In order to meet the Fellowship aims and objectives the following sites were visited:

- CONTECH USA, Pierceton, Indiana
- CONTECH USA, Auburn, Indiana
- CONTECH USA, Portage, Michigan
- Ryobi Die Casting USA Inc., Shelbyville, Indiana
- Case Western Reserve University (CWRU), Cleveland, Ohio
- North American Die Casting Association (NADCA), Wheeling, Illinois

Dr Iyer believes that squeeze casting is one of the most exciting emerging technologies available to the die casting industry. It is essential that the message that squeeze casting is feasible and achievable be delivered to Australian manufacturers. Crucial to ensuring this is the need for engagement with the tertiary sector. Engineering students of TAFE institutes need to be educated about the benefits and feasibility of squeeze casting. Ground-breaking research is being carried out in universities in USA, and financing is provided mainly by industry and government. TAFE institutes in Australia are ideally placed to participate in these kinds of commercial development opportunities or technology diffusion projects, and to benefit from private sector funding. There can be opportunities for Australian Industries to learn from these projects.

Following the International Experience section in this report, a series of findings are made regarding a range of initiatives and activities that Dr Iyer identifies as central to knowledge transfer and furthering opportunities for the squeeze casting industry. The report concludes with a series of recommendations for Government bodies, professional associations, education and training providers, industry and community.

Table of Contents

Abbreviations/Acronyms

µm	Micron
ADCA	Australian Die Casting Association
CAD	Computer-aided design
CAFE	Corporate Average Fuel Economy
CMP	Certified Materials Professional
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CWRU	Case Western Reserve University
DAS	Dendrite Arm Spacing
EPA	Environmental Protection Authority
F	As fabricated
GPM	Gravity Permanent Mould
HPDC	High Pressure Die Casting
HSC	Horizontal Squeeze Casting
HVSC	Horizontal Vertical Squeeze Casting
ISS Institute	International Specialised Skills Institute
MMC	Metal matrix composites
MPa	Megapascal
mpg	Miles per gallon
NADCA	North American Die Casting Association
NHTSA	National Highway Traffic Safety Administration
OEM	Original equipment manufacturer
PPM (wt)	Parts per million, by weight
psi	Pounds per square inch
RMIT	Royal Melbourne Institute of Technology
SAMME	School of Aerospace, Mechanical and Manufacturing Engineering
Si	Silicon
t	Tonnes
VSC	Vertical Squeeze Casting

Definitions

Aluminium (Aluminum) casting alloys in the USA are numbered according to a three-digit (plus decimal) system adopted by the Aluminum Association (AA) in 1954 and approved by the American National Standards Institute in 1957 (ANSI H35.1). The American Society for Testing and Materials (ASTM), the Society of Automotive Engineers (SAE), and the Federal and Military specifications for aluminium castings conform to the AA designation system.

A380, A356, 383F, A356.2 and ADC 12

These are alloys made of aluminium and silicon (Si) that are used for die casting.

319, 380, 383, and 390

Other alloys commonly used with squeeze casting.

7010 Alloy

Wrought aluminium alloy.

800 t clamping force

Clamping force of the die casting machine. They are rated by how much clamping force they can apply. When the die casting machine closes, the two die halves are locked and held together by the machine's hydraulic pressure.

1200 t clamping force

Clamping force of the die casting machine. They are rated by how much clamping force they can apply. When the die casting machine closes, the two die halves are locked and held together by the machine's hydraulic pressure.

Acicular

Having the shape of a needle.[1]

Boss

A protuberant ornament on any work, either of different material from that of the work or of the same.[2]

Bottom gate

A gate located on the bottom side of the mould cavity.

CAFE

Corporate Average Fuel Economy (CAFE) is the sales weighted average fuel economy, expressed in miles per gallon (mpg), of a manufacturer's fleet of passenger cars or light trucks with a gross vehicle weight rating (GVWR) of 8,500 lbs. or less, manufactured for sale in the United States, for any given model year. Fuel economy is defined as the average mileage traveled [sic.] by an automobile per gallon of gasoline (or equivalent amount of other fuel) consumed as measured in accordance with the testing and evaluation protocol set forth by the Environmental Protection Agency (EPA).[3]

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1 http://www.thefreedictionary.com/acicular

2 http://www.hydroponicsearch.com/spelling/simplesearch/query_term-bosses/database-!/strategy-exact

3 http://www.nhtsa.gov/cars/rules/cafe/overview.htm

Dendrite

The treelike structure of the solid that grows when an undercooled liquid solidifies.

Design

Design is problem setting and problem solving. Design is a fundamental economic and business tool. It is embedded in every aspect of commerce and industry and adds high value to any service or product—in business, government, education and training, and the community in general.[4]

Ductility

Ability of a material (such as a metal) to undergo permanent deformation[5] through elongation[6] (reduction[7] in cross-sectional areas) or bending at room temperature[8] without fracturing.

Equiaxed crystals/grain

Equiaxed crystals are crystals that have axes of approximately the same length.[9]

Eutectic

(Chemistry) (of a mixture of substances, esp. an alloy) having the lowest freezing point of all possible mixtures of the substances.[10]

Feeder

Through which the metal is fed into the mould cavity.

Fettling

To remove (excess moulding material and casting irregularities) from a cast component.[11]

Flash

A thin irregular ridge of metal on the outer face of a casting, resulting from seepage of the molten metal into the joint between the separate components of the mould used in its manufacture.[12]

H13 die steel

High-quality tool steel used in the construction of a die-casting die for casting aluminium, magnesium and zinc alloys

Innovation

Creating and meeting new needs with new technical and design styles. (New realities of lifestyle).[13]

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[4] 'Sustainable Policies for a Dynamic Future', Carolynne Bourne AM, ISS Institute 2007.

[5] http://www.businessdictionary.com/definition/deformation.html

[6] http://www.businessdictionary.com/definition/elongation.html

[7] http://www.businessdictionary.com/definition/reduction.html

[8] http://www.businessdictionary.com/definition/temperature.html

[9] http://encyclopedia.thefreedictionary.com/equiaxed

[10] http://www.thefreedictionary.com/eutectic

[11] http://dictionary.reference.com/browse/fettle

[12] http://www.answers.com/topic/casting-flash

[13] 'Sustainable Policies for a Dynamic Future', Carolynne Bourne AM, ISS Institute 2007.

Jetting

Relates to a high speed of metal flow.

Net shape

Part fabrication resulting in final dimensions that do not require machining or cutting.[14]

Near-net shape

Part fabrication resulting in final dimensions that require minimal machining, cutting or other finishing.[15]

Risers

A reservoir in a manufacturing mould.[16]

Skill deficiency

A skill deficiency is where a demand for labour has not been recognised and training is unavailable in Australian education institutions. This arises where skills are acquired on-the-job, gleaned from published material or from working and/or studying overseas.[17]

There may be individuals or individual firms that have these capabilities. However, individuals in the main do not share their capabilities, but rather keep the intellectual property to themselves. Over time these individuals retire and pass away. Firms likewise come and go.

Sustainability

The ISS Institute follows the United Nations for Non-Governmental Organisations' definition on sustainability: *"Sustainable Development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"*.[18]

T

'T' represents the heat treatment process. The wide choice of alloy compositions, solution heat treatment temperatures and times, quench rates from temperature, choice of artificial ageing treatment and degree to which the final product has been deformed permit a wide range of properties to be achieved. A system of standard designations is used, based upon the letter 'T' followed a number after the alloy designation, to describe the various conditions. For example: T4.

T4

Solution heat treated and naturally aged.

T5

Cooled from hot working and artificially aged (at elevated temperature).

T6

Solution heat treated and artificially aged.

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[14] http://www.encyclo.co.uk/define/Net%20shape

[15] http://www.encyclo.co.uk/search.php

[16] http://dictionary.sensagent.com/riser/en-en/

[17] 'Directory of Opportunities. Specialised Courses with Italy. Part 1: Veneto Region', ISS Institute, 1991.

[18] http://www.unngosustainability.org/CSD_Definitions%20SD.htm

Acknowledgements

Dr Amita Iyer would like to thank the following individuals and organisations who gave generously of their time and their expertise to assist, advise and guide her throughout the Fellowship program.

Awarding Body – International Specialised Skills Institute (ISS Institute)

Dr Iyer thanks the staff at ISS Institute for their support, help and guidance, in preparation, development, and during her Fellowship. Specifically, the former CEO Carolynne Bourne AM, Paul Sumner, Ken Greenhill and Katherine Dent.

The International Specialised Skills Institute Inc is an independent, national organisation that for over two decades has worked with Australian governments, industry and education institutions to enable individuals to gain enhanced skills and experience in traditional trades, professions and leading-edge technologies.

At the heart of the ISS Institute are our Fellows. Under the **Overseas Applied Research Fellowship Program** the Fellows travel overseas. Upon their return, they are required to pass on what they have learnt by:

1. Preparing a detailed report for distribution to government departments, industry and educational institutions.
2. Recommending improvements to accredited educational courses.
3. Delivering training activities including workshops, conferences and forums.

Over 180 Australians have received Fellowships, across many industry sectors. In addition, recognised experts from overseas conduct training activities and events. To date, 22 leaders in their field have shared their expertise in Australia.

According to Skills Australia's 'Australian Workforce Futures: A National Workforce Development Strategy 2010':

> Australia requires a highly skilled population to maintain and improve our economic position in the face of increasing global competition, and to have the skills to adapt to the introduction of new technology and rapid change.
>
> International and Australian research indicates we need a deeper level of skills than currently exists in the Australian labour market to lift productivity. We need a workforce in which more people have skills, but also multiple and higher level skills and qualifications. Deepening skills across all occupations is crucial to achieving long-term productivity growth. It also reflects the recent trend for jobs to become more complex and the consequent increased demand for higher level skills. This trend is projected to continue regardless of whether we experience strong or weak economic growth in the future. Future environmental challenges will also create demand for more sustainability related skills across a range of industries and occupations.[19]

In this context, the ISS Institute works with Fellows, industry and government to identify specific skills in Australia that require enhancing, where accredited courses are not available through Australian higher education institutions or other Registered Training Organisations. The Fellows' overseas experience sees them broadening and deepening their own professional practice, which they then share with their peers, industry and government upon their return. This is the focus of the ISS Institute's work.

For further information on our Fellows and our work see www.issinstitute.org.au.

[19] Skills Australia's 'Australian Workforce Futures: A National Workforce Development Strategy 2010', pp. 1-2 http://www.skillsaustralia.gov.au/PDFs_RTFs/WWF_strategy.pdf

Fellowship Sponsor

The Victorian Government, Skills Victoria is responsible for the administration and coordination of programs for the provision of training and further education, adult community education and employment services in Victoria and is a valued sponsor of the ISS Institute. Dr Iyer would like to thank them for providing funding support for this Fellowship.

Employer Support

Dr Iyer would like to acknowledge the support of the School of Engineering at RMIT University (TAFE), for providing the time and the additional resources required to undertake the Fellowship and associated activities.

Supporters

In Australia

- Graham Barrow, Senior Technical officer, Toyota
- John Carriage, Senior Die Casting Specialist, Commonwealth Scientific and Industrial Research Organisation (CSIRO)
- Dr Matt Dargusch, Program Manager, CAST Cooperative Research Centre (CRC) Limited
- Michael AC Delacorn, Vice President, BOSCH
- Phillip Innes, Metallurgist, BOSCH
- Nick Juniper, Industry Liaison Manager, Manufacturing Skills Australia
- Paul Kennett, Executive Director, Manufacturing and Engineering Skills Advisory Board
- Adrian Martin, MAHLE-ACL
- Peter Ryan, Head Of School of Engineering, Royal Melbourne Institute of Technology (RMIT) University (TAFE)
- Professor Aleksandar Subic, Head of School, School of Aerospace, Mechanical and Manufacturing Engineering (SAMME), RMIT University (TAFE)

In The United States of America

CONTECH USA

- Forrester Asher, Plant Manager
- Chuck Barnes, Advanced Engineering Manager
- Curtis French, Director of North American Manufacturing
- Tim Harmeyer, Senior Manufacturing Engineer
- Mick Schieber, Director of Engineering and Technology

Ryobi Die Casting (USA)

- Patrick S Cheng, Senior Research Engineer
- Yeou-Li Chu, Director of Research & Development
- Vivek S Joshi, Director of Quality

Case Western Reserve University

- Professor David Schwam, Case School of Engineering, Department of Materials Science and Engineering

North American Die Casting Association (NADCA)

- Alex Monroe, Project Engineer
- Steve Udvady, Director

Australian Organisations Impacted by the Fellowship

The following industry, government and education sectors have been identified by Dr Iyer as being potential beneficiaries of the findings of the study program:

Aerospace Engineering

The demand from this industry for components and parts that are currently forged may be converted to squeeze cast parts. Research findings may also change the demand for wrought alloys to squeeze cast parts. Lightweight metal matrix composites (MMCs) could have high potential and many applications throughout this industry.

Automotive Engineering

As squeeze cast parts are high quality and lightweight, the automotive industry will greatly benefit from squeeze casting. As the global trend continues to move to lightweight components for fuel economy and sustainability, the market must adapt to squeeze casting.

Education/Training Organisations

The Metal and Engineering Training Package (MEM 05) is relevant to squeeze cast die casting. It is not necessary to heavily modify any units in the courses included in the Training Package since we already cater for training in the different types of die casting processes, but there may be a need to update the current information available in this area.

While the main components of these courses already contain the generic aspects associated with squeeze casting, the particular skills and underpinning knowledge in the techniques, and the applications and benefits of squeeze casting will need to be included.

One training course that would be appropriate for teaching more specific squeeze casting knowledge and skills is the Advanced Diploma in Engineering Technology with particular reference to the Manufacturing Processes and Materials Science units.

About the Fellow

Name: Dr Amita Iyer

Employment

- Senior Educator (Associate Degree in Engineering), School of Engineering, RMIT University (TAFE)

Qualifications

- Graduate Certificate in Industrial Education and Training, RMIT School of Education, Australia, 2007
- Certificate IV Workplace Assessment and Training, RMIT School of Education, Australia, 2005
- Doctor of Philosophy in Metallurgical Engineering, Indian Institute of Technology, Madras, India, 1997
- Bachelor of Engineering in Mechanical Engineering, APS University, Rewa, India, 1997
- Master of Engineering in Mechanical Engineering, Bangalore University, Bangalore, India, 1992

Memberships

- Member, Institution of Engineers (India)
- Certified Materials Professional (CMP) Member, Materials Australia
- Life Member, Indian Institute of Metals
- Member, Institution of Engineers, Australia
- Member, Australian Die Casting Association (ADCA)

Brief Biography

Until recently Dr Amita Iyer had worked in manufacturing Industries. She has almost ten years of experience in the die casting industry. In 2001 she joined the CSIRO as a Research Scientist in the casting division. She has done extensive research in casting in Australia and overseas. Dr Iyer joined RMIT in 2006 where she was developing, directing and administering the Piping Design and mid-level Refrigeration and Air conditioning programs.

Dr Iyer's expertise is Material Science and Engineering, which lead to her teaching students at the Associate Degree level. Her approach to education is to create integrated and holistic models of learning that simulate industry practice. She also uses e-learning paradigms and information to address the learning styles of different individuals.

At the beginning of the Fellowship Dr Iyer started teaching online Advance Diploma students. Currently, she is the Senior Educator for the Associate Degree in Engineering at the School of Engineering, RMIT University (TAFE). In her free time Dr Iyer likes to spend her time with her two daughters and her husband. She also enjoys reading, gardening and watching Bollywood movies.

Aims of the Fellowship Program

The aim of the Fellowship is to identify and acquire the skills and training needed to produce squeeze castings of high density, low porosity and with a good surface finish.

Over the course of her Fellowship, Dr Iyer investigated the following areas:

- Learning about and receiving training in the manufacture of squeeze castings. This included starting from basic metal requirements through to various squeeze casting manufacturing methods.
- Understanding special die requirements, with focus on die steel, heat treatment, special coatings on die for longer die life, and how to solve problems discovered during heat checks.
- Getting the best combination of process parameters such as die temperature, pouring temperature, superheat and applied pressure.
- Understanding the influence of casting parameters on mechanical properties and microstructure.
- Learning about the difference in post-finishing operations between squeeze castings and normal castings, such as fettling, machining and heat treatment.
- The relationship between the design of the part, the squeeze casting system, the processing variables, and the soundness of the squeeze cast part.
- Understanding the squeeze casting machine and identifying the features that are different from a normal casting machine.

The Australian Context

A Brief Description of the Industry

Squeeze casting was introduced by Ube Industries Ltd in 1976. Toyota Motor Corporation Ltd presented their problem to Ube in 1975 because the carmaker was experiencing air leakage in its aluminium wheels. Regardless of the casting process used, the wheels suffered from slow leaking over time because of porosity in the aluminium.

Toyota asked Ube for help to jointly develop an economical casting method by which aluminium wheels could be cast to a density that would prevent leaking and using alloys that were heat-treatable in order to maximise the alloy's physical properties. The squeeze casting machine was the result.

Squeeze casting is now considered a high integrity process because it imparts qualities to a metal that are difficult to achieve with conventional die casting. This includes absence of porosity, improved wear resistance, and the ability to heat treat the component. Products manufactured on a worldwide basis using this method include steering knuckles, pistons, engine mounts and wheels.

What is Squeeze Casting?

Squeeze casting is a die casting method based on slower continuous die filling and high metal pressures. Laminar die filling and squeezing, which is the application of pressure during solidification, ensures that the component is free from blowholes and porosity. This method produces heat-treatable components that can also be used in safety-relevant applications and are characterised by their higher strength and ductility when compared with conventional die cast components.

How is Squeeze Casting Different from the Normal Die Casting Process?

The die casting process is the high-speed injection of a molten metal alloy into a steel mould. This alloy then solidifies rapidly (solidification time varying from milliseconds to a few seconds) to form a net shaped component and is then extracted from the mould. During the die casting process the die is filled at high speed, but during squeeze casting the filling process takes longer, from a half-a-second to three seconds. This slower approach permits a die filling that is virtually free of gas entrapment.

What are the Benefits of Squeeze Casting?

Using this method it is possible to produce heat-treatable castings (not possible in conventional die casting due to air entrapment). It has become known as 'squeeze' casting because the casting is squeezed in a controlled fashion under high pressure to complete the filling of the die.

The applied pressure and instantaneous contact of molten metal with the die surface produces a rapid heat transfer condition that yields a pore-free, fine-grained casting with mechanical properties approaching those of a wrought product. Squeeze casting offers high metal yield, minimum gas or shrinkage, low porosity and an excellent surface finish, combined with lower operating costs.

Squeeze casting decreases the percentage of porosity and increases density as well as grain size. This fine grain size improves the mechanical properties of the squeeze cast component.

Another big advantage of squeeze casting is the possibility of using pre-forms (high-porosity bodies made from specially selected materials). By infiltrating these with molten metal under high pressure it is possible to further improve the properties of the aluminium through composites and, hence, create working surfaces that are extremely hard wearing.

Of the many casting techniques available, squeeze casting has greater potential to create less defective cast components. Since the as-fabricated components can be readily used in service (or require only minor post-fabrication treatment), squeeze casting is regarded as a net or near-net shape fabrication route.

The development of a pore-free casting technology has been a benefit for the metal mould casting process. The aluminium components produced in this process show very high integrity, very low porosity and very good mechanical characteristics, which can be further improved by subsequent heat treatment. The higher properties associated with the squeeze casting are attributed essentially to the lack of porosity in the matrix and refinement of the microstructure.

Where Does Australia Stand in Terms of Squeeze Casting?

Squeeze casting is still not a popular method for casting in Australia. It is still the conventional HPDC or tilt gravity method that is more often used. If Australia is to produce high integrity parts for both domestic and export markets, it has to develop and utilise more expertise in squeeze casting.

SWOT Analysis of the Industry

Strengths

1. Selected institutions within the TAFE sector have a strong focus to promote squeeze casting.
2. Industry engagement can be achieved as more companies obtain squeeze casting machines.
3. Enhanced chances of research and collaboration with a like-minded industry.
4. New product development opportunities in the automotive, building and aerospace industries due to:
   - reduced shrinkage in automotive.
   - improved load bearing capacity in building.
   - improved fatigue life in aerospace.

Weaknesses

1. There is a misconception about die life.
2. There is no sound understanding of what component design features need to be present in a design before squeeze casting.
3. Limited knowledge and training exists for squeeze casting.
4. Cost of new machinery verses existing machinery investment may scare off possible investment.

Opportunities

1. Quality of the product will be improved significantly.
2. There will be huge energy savings.[i]
3. New product development opportunities because the quality will be almost as good as a forged product.
4. Easy adaptability in learning.

Threats

1. Due to higher cost Industry may not like to embrace the idea of squeeze casting.
2. Higher running costs compared to gravity casting.
3. The ongoing conservative mindset about favouring conventional casting methods.
4. The lower costs involved in high pressure die casting.

Identifying the Skills Deficiencies

Identifying and Defining the Deficiencies

Squeeze casting, compared with traditional sand casting (which dates back to between 2000–3500 BC) is a relatively new casting technology. Squeeze casting has a number of advantages; these include the elimination of gas and shrinkage porosities; the reduction or elimination of metal wastage, due to the absence of feeders or risers; the possibility of manipulation of processes to achieve the required optimum parameters.

Overseas organisations were approached as part of the Fellowship. Knowledge areas relevant to the process are listed below:

1. Collect, record and analyse the manufacturing technique of squeeze casting.

Analyse the machine parameters, alloy composition, die temperature, pouring temperature, super heat, solidification time and applied pressure. Analyse and record the information sourced via observation and interviews with the production department and quality control shop personnel in order to get the best combination of process parameters, such as die temperature, pouring temperature, super heat and applied pressure.

Action: To become skilled in understanding the manufacturing technique of squeeze casting and understanding how process parameters affect the casting's soundness.

2. Identify the special die requirements for squeeze casting.

Conduct analysis of the die history to gain knowledge of die requirements, with a particular focus on the steel used for making dies, heat treatment, die lubricant, special coatings on the die for longer die life, and how to solve problems with heat checks.

Action: To become skilled in die selection criteria and the ability to achieve longer die life with squeeze casting manufacturing method.

3. Identify the difference between standard die casting and squeeze casting methods.

Observe and inspect machine features, and interview people involved. Study the features of the squeeze casting machine and how they differ from the standard die casting machine. Differentiate between these different features and the different methods used.

Action: To become skilled in identifying the different features of squeeze casting machine.

4. Identify post-finishing operations on squeeze casting parts like machining and/or heat treatment.

Observe and conduct interviews and record data relating to post-finishing operations in squeeze casting, such as fettling, machining and heat treatment.

Action: To gain an understanding of the post-finishing methods of squeeze casting, and to determine if there is a difference between these and the standard die casting post-finishing methods.

5. Determine the influence of the squeeze casting parameters on the mechanical properties and the microstructure of parts.

Conduct microstructural analysis of the parts and conduct some mechanical testing on the squeeze cast parts to determine how the process parameters can affect the microstructure and mechanical properties resulting in sound casting.

Action: To gain an understanding of how different casting parameters affect the mechanical properties of the squeeze cast part.

6. Identify the relationship between the design of the part, the process variables and the soundness of the squeeze cast part.

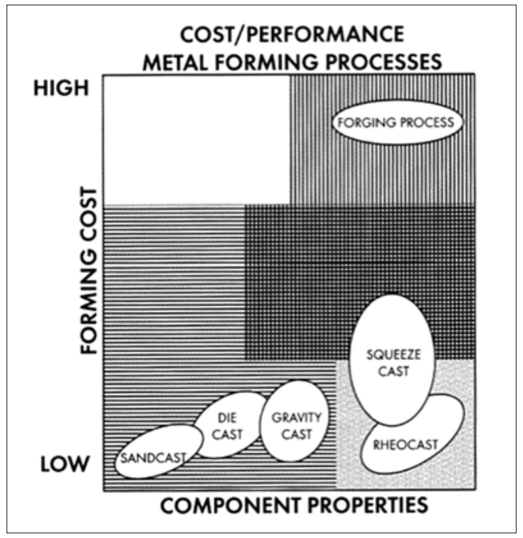
Conduct interviews with the design department, production shop and quality department personnel to determine the impact of squeeze cast part design on the soundness of the part.

Action: To gain understanding of the design of the part and the role played by squeeze casting in successful production of the component.

Why it Needs to be Addressed

Squeeze casting can be applied to high integrity parts like suspension arms, brake callipers, aluminium wheels, steering knuckles, vanes, ring groove reinforced pistons, connecting rods, rotary compressor vanes and shock absorber cylinders.

Cost/Performance of Metal Forming Process



In the design of automotive vehicles there is a strong move towards reducing the weight of components, driven by a range of environmental and social pressures. This trend is a consequence of the overall objective in the automotive industry: to reduce fuel consumption of vehicles.

Besides the enormous cost savings that result from lower fuel consumption, environmental benefits due to a decrease in pollution are also important.

Weight reduction in cars, in many cases, is most effectively achieved by replacing the traditional iron or steel used with lighter materials such as aluminium alloy. With an advanced manufacturing method like squeeze casting the mechanical properties of the lighter metal can be comparable to iron or steel.

With regard to Australia:

- Skills training in this field is not available at any TAFE college or University. One training course that would be appropriate for teaching more specific squeeze casting knowledge and skills is the Advanced Diploma of Engineering Technology and particularly the Manufacturing Processes and Materials units of this Diploma.
- Car manufacturers in Australia may ultimately change their cast iron parts to lighter metals such as aluminium produced with advanced manufacturing methods like squeeze casting to get the comparable mechanical properties.
- Squeeze casting is now the most popular fabrication route for MMC parts. An annual growth of 12–15 per cent in the usage of MMCs is predicted in automotive, aerospace and other industries, such as sport and leisure goods.[ii] This is a clear indication that Australia has to roll up its sleeves and acquire the capability to process advanced materials by more demanding manufacturing processes.

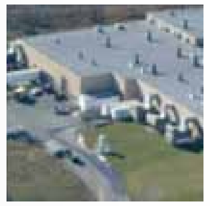
The International Experience

The overseas Fellowship program was designed to explore the identified skills and knowledge deficiencies and for Dr Iyer to return to Australia equipped with the knowledge and ideas essential to ensuring enhanced teaching practices and content delivery. Offering effective experiences and opportunities for others to maximise their learning will be essential to promoting and improving the overall acceptance of squeeze casting in this country.

In almost every case, the organisations and locations visited did not permit photographs to be taken. Diagrams and photographs included in this report have been gained from references or the Internet, with permission.

CONTECH USA, Pierceton, Indiana

Reference: www.contech-global.com



CONTECH USA is well known in die casting technology, and offers a full range of high integrity casting processes, both thin and thick wall, using aluminium and magnesium.

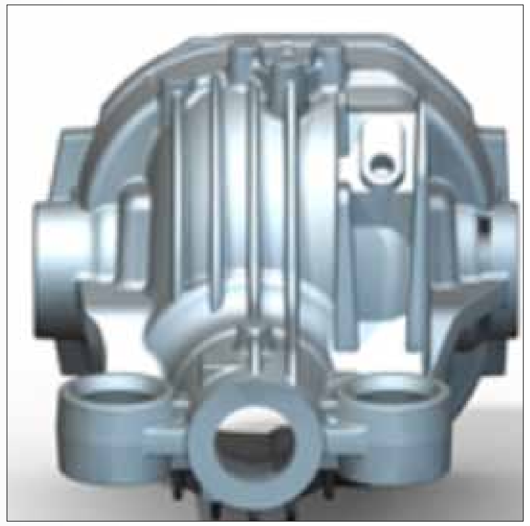
Materials, along with heat treatment, are tailored to deliver strength and elongation to meet customers' requirements. These parts are produced as high-pressure die castings or squeeze castings.

CONTECH USA's cast and machined products are routinely offered to customers as fully tested sub-assemblies. A variety of pins, bushings, bolts, gaskets, and other components are assembled by CONTECH USA and subsequently subjected to leak testing and other performance and quality related tests.

The CONTECH USA facility at Pierceton, Indiana has around sixteen squeeze casting machines.

Examples of selected automotive components manufactured at CONTECH USA are:

- Axle carriers, requiring high strength, with a yield strength greater than 280 megapascals (MPa) and a tensile strength greater than 350 MPa, and high levels of stiffness.
- Axle covers, requiring pressure tightness.



Axle carrier

Axle cover

- Valve housings, requiring pressure tightness (must not leak when pressurised at 10.69 MPa) and high burst pressure between 9 and 20.69 MPa).
- Steering column housings, requiring high impact strength (with a yield strength of 250 MPa and elongation greater than five per cent).

Valve housing

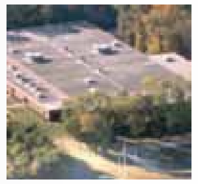
Steering column housing

The Key contact person in CONTECH USA, Pierceton, Indiana was Mike Schieber. The following points were discussed during the visit to the plant:

- It is not as difficult to produce parts by squeeze casting as the conventional die casting industry believe.
- There is not much difference in the cost of the component produced by conventional high-pressure die-cast route rather than the squeeze cast route.
- Weight reduction is an engineering requirement in today's market. Squeeze casting can produce components with reduced weight. The knuckles previously being made in cast iron are now made by squeeze cast aluminium giving significant reduction in weight in these automotive parts.
- Energy saving can be huge with squeeze casting. Iron and steel components can be converted to lightweight metals such as aluminium and magnesium. As the melting temperature of iron and steel is high, the energy consumption required to melt these alloys is really high. Squeeze castings have a low melting point; hence, there can be huge saving in energy.
- One very false notion among companies is that squeeze casting is more costly. The costs of squeeze casting remain higher at the moment as there are no competitors seriously developing this process.
- There is an increase in cycle time as the piston moves slowly for filling the cavity and more metal melting due to larger gating. Both of these factors will only marginally add to the cost.
- The squeeze casting machine, Horizontal Vertical Squeeze Casting (HVSC) is more expensive than conventional High Pressure Die Casting (HPDC); however, it is not significantly so. But, compared to a gravity die casting machine, the squeeze casting machine cost is significant.
- A HPDC machine can be used as a squeeze casting machine with slight modifications.

- Compared to the conventional gravity process, the squeeze casting machine stock is less. It is possible to get near a net shape in squeeze casting. When compared with HPDC, squeeze casting material property is good; hence, less material needs to be used in the process. It is about getting a high integrity part so that it can be heat treated. Fine grain structure, and less shrinkage porosity means that T4, T5 and T6 heat treatment can be done.
- Soldering is not a major problem. It is the same as casting by any other method. Die spraying after every shot and die lubrication helps soldering.
- Dry ice is used to clean the die surface, as it will loosen the material sticking to the die surface.
- The reject rate is part specific. Squeeze casting demands tighter control over the process parameters.
- There are chances of a huge scrap rate if simulations are not done prior to actual production. Incorrect tool design and not tightly controlling the process can cause increased reject rate.
- Heat treatment can be done in a much shorter cycle time compared to gravity casting, due to the finer structure of the squeeze cast part.
- Gate design should be such that it is big enough to fill in laminar fashion.
- Beryllium copper inserts can be used near the surface to get directional solidification. The flow rate of water in cooling lines should be monitored. Bubblers or percolators can also be used.
- Simulation is very important for directional solidification. A shot monitoring system is very important for tighter process control.
- Metal temperature is more or less the same as HPDC. Die lube has insulating properties; hence, there is no need to superheat the metal. A modifier also increases the fluidity of the metal.
- One very important discussion was that die life is much the same with squeeze casting as it is with conventional die casting. Die material is also the same at premium H13 die steel. Internal preheating helps in increasing die life.

CONTECH USA, Auburn, Indiana



The CONTECH USA Auburn plant is located in Auburn, Indiana. It has around 22 machines ranging from an 800 t clamping force to a 1200 t clamping force. Alloys used are ADC 12 and A380 aluminium alloy. Decades of experience in die casting ensures that components are manufactured to exact specifications. Advanced machining capabilities and assembly processes allow complete control of the process from start to finish.

The Auburn plant is 100 per cent focused on producing rack and pinion housings and is recognised as North America's leading producer of one-piece rack and pinion housings.

Using enhanced high-pressure die cast machines the Auburn facility also die casts one-, two- and three-piece rack and pinion housings. Auburn also offers precision machining of parts to the customer's most exacting specifications.

The key contact people in the Auburn plant were Forrester Asher, Plant Manager and Curtis French, Director of North American Manufacturing. The points focused on during the discussion were as follows:

- A key attribute of the squeeze casting process is directional solidification. The ideal squeeze casting process would yield a part that completely solidifies at one end, and still remains liquid at the other. In this process, as the molten metal cools and becomes semi-solid, continuous high pressure can be maintained to the 'liquid-end' of the part in order to feed the gradual shrink, until the entire part is completely solidified.

This yields a cast part that is 99.97 per cent solid, with virtually no residual shrink porosity. Since squeeze cast parts are virtually porosity free, they can be T4 heat treated without the danger of excessive blisters. Hence, squeeze casting offers a near-net shape (95–98 per cent) aluminium component that can be aircraft-grade heat treated for high integrity, high strength and pressure tight applications.

- There is less flash produced in squeeze. Hence, there are considerable savings regarding metal loss.
- Though a lot more process control is needed in squeeze casting, once the process parameters are established, squeeze casting is more consistent than gravity die casting.
- Complex part geometry can reduce die life.

CONTECH USA, Portage, Michigan

CONTECH USA makes extensive use of a simulation tool throughout the entire product launch phase and validation phase to minimise defects and predict mechanical properties for the squeeze casting process.

The key contact person in Michigan was Chuck Barnes, Advanced Engineering Manager. During discussion he emphasised following points:

- The squeeze casting process is considered by a high integrity process that is capable of producing near-net shape products that can be heat treated. Even with the many advantages of the squeeze casting process, the desired level of quality cannot be guaranteed. Therefore, prior to casting development trials, the use of simulation software and advanced modelling tools are needed to assist with optimising the die design. In addition, simulation tools can be used to predict part integrity. As a result, this information can be used to assist with product design and optimisation.
- Neglect of optimised gating design and process control will not make a good casting even with the squeeze casting process. For example, both poor design and poor process control can contribute to defects in squeeze castings. Typically, there can be many problems observed, such as metal stream jetting from an unbalanced runner and gate design, wrong casting layout in the die, shrinkage porosity from solidification, lack of fill from improper temperature distribution and/or blisters from interrupted heat transfer.
- If the customer has close interactions with the die caster the chances of success are greater.
- Stress analysis of the part should be done prior to the squeeze casting process using computer-aided design (CAD) software. Higher stress areas should be cooled faster. Hence, lubricant and placement of cooling lines are very important to successful squeeze casting.
- Average flow simulation is about seven to eight times greater for squeeze casting parts. Occasionally it can get to 30 times greater before you achieve a successful casting.

Ryobi Die Casting USA Inc., Shelbyville, Indiana

Reference: http://www.ryobidiecasting.com/

The following information has been taken directly from the Ryobi website:

Ryobi is located in Shelbyville, Indiana (20 miles southeast of Indianapolis). Their facilities include two die casting plants and a machining facility encompassing 560,000 square feet of manufacturing space. Established in 1985 as a subsidiary of Ryobi Limited (Japan), which has die casting facilities in Japan, China, Northern Ireland, and the United States. The Ryobi Group of companies makes products that are used in a number of industries.

Ryobi is leading the industry in high-pressure aluminium die castings. Products include transmission cases, housings, engine parts, and most recently, structural parts. Parts are used in a number of Ford, GM, and Toyota vehicles. In addition, they also manufacture smaller parts for Tuff Torq Corporation, utilised in the lawn and garden industry.

The company prides itself on utilising best practices and giving employees the tools they need to do the job right.

Ryobi offers full service die cast solutions. Their strengths include die design and die making capabilities within the Ryobi Group, melting and alloying in-house, casting, finishing, machining, and assembly.

Their die cast machine sizes range from 500 ton to 3,500 ton and their casting weights range from three pounds to 40 pounds. Their product range varies from small ladder brackets to large transmission cases and engine blocks. They melt over 170 million pounds of aluminium per year.

Ryobi does not produce parts with squeeze casting. Dr Iyer visited the Ryobi plant to see what opinions HPDC manufacturers have about squeeze casting and how it is perceived by them.

The main contact in Ryobi was Yeou-Li Chu, Director of Research and Development. In summary the observations made by Dr Iyer during discussion with Chu were as follows:

- Squeeze casting die life is short.
- Cycle time is longer with squeeze casting process.
- Squeeze casting machinery is more expensive.
- Selling price is more when utilising squeeze casting. Quality of the squeeze cast parts is higher when compared to HPDC and gravity mould casting.
- Squeeze casting is a costly process because of short die life and costly machinery.
- The squeeze casting process can produce a near-net shape.
- Ryobi is only doing T5 heat treatment. T5 heat treatment is done for dimensional stability: for high strength T6 heat treatment is needed.
- HPDC does not look very promising when it comes to producing composite parts.
- There will be greater emphasis in the future to reduce fuel consumption. This can be done in two ways: either increase the efficiency of the car or reduce the weight of the car.
- Thermal shock can spoil die life in HPDC. Bottom pouring and the slow movement of metal in the squeeze casting process will result in less thermal shock, affecting die life.
- Thermal shock is a surface phenomenon. It has more to do with cooling than heating. Die spray and die lubricant will have more chances of creating thermal shock.

Dr Iyer also had a good discussion with Patrick S. Cheng, Sr. Research Engineer. He had previously worked with squeeze casting manufacturers. His views follow:

- Cost in squeeze casting is high as the quality requires high inspection, and 100 per cent X-ray testing is needed, as well as mechanical tests.
- Melt quality is kept high in squeeze casting, and the Hydrogen level is checked regularly.
- The maintenance required for the squeeze casting machine is high.
- The most popular lube for squeeze casting is graphite lube that can become dirty at times.

- Die design is very complicated in squeeze casting compared to other casting methods. To achieve directional solidification, a lot of control is needed with cooling lines and die temperatures. Die cracks can occur due to wrong die design and improper heat transfer.
- One important point discussed was that people have misunderstood squeeze casting. They think squeeze casting should be porosity free. If casting has shrink porosity it is not a problem in heat treatment. Die casters also scrap shrinkage porosity; hence, squeeze casting is more costly.

Case Western Reserve University (CWRU), Cleveland, Ohio

Reference: http://www.case.edu/

The following information has been taken directly from the CWRU website:

The Department of Materials Science and Engineering (DMSE) at CWRU is a research centred educational institute whose mission is to enhance the productivity, quality, and benefit of materials-related learning to its students, faculty, and the community. DMSE has a commitment to the improvement of materials technology as an advantaged academic unit equipped with state-of-the-art facilities in areas of materials surface analysis, mechanical characterization, and an extensive suite of advanced electron microscopy instrumentation that act in synergy to consistently thrust them among the top tiers of materials research institutions in the nation.

Their Department carries with it a world-renowned reputation for cutting-edge research that leads to revolutionary discoveries in areas ranging all the way from metallic glasses to advanced semiconductor development.

The key contact person at CWRU was Professor David Schwam, the Research Professor in the Department of Materials Science and Engineering at CWRU and Director of Case Metal Processing Laboratory. He has more than 30 years of experience in theoretical and experimental investigations related to casting and solidification, heat treating and squeeze casting.

A summary of the points discussed with Professor David Schwam are as follows:

- The mass production of squeeze casings has become a very competitive casting process in the automotive industry because of its advantages over other casting processes. Even with the many advantages of squeeze casting, the process is still sensitive to process control and gating geometry.
- Casting defects can occur from the beginning of fill through to part extraction. These casting defects can be directly attributed to non-optimised processing parameters, or lack of control in the following areas: metal filling velocity, metal and die temperature, dwell time, cooling pattern, casting design. The casting defects can be eliminated or reduced ahead of time by optimising the process parameters with simulation tools.
- As a result of the large, bottom gates and the slower, non-turbulent fill, it is possible to produce a single, continuous metal front during cavity filling. The metal front is the boundary between the molten metal and the air in the cavity and can be a major source of oxide formation during the casting process. A 'quite' metal front produces fewer oxides because there is less interaction between the molten metal and the air in the cavity.
- It is a high cost machine compared to a tilt pour gravity casting machine. It was noted, however, that a tilt pour gravity machine can have multiple cavities.
- Squeeze casting parts can be used for high integrity components subject to fatigue loading that were originally made from cast iron, such as brake rotors and steering knuckles. Automotive component manufacturers are now able to replace ferrous metals with aluminium.

- Heavier metals can now be replaced by lighter metals due to the squeeze casting process. Aluminium has replaced cast iron in engine block manufacture.
- Manufacturers are very sensitive to cost. They will opt for the lowest cost processes that produce the desired properties. No manufacturer wants to pay more just because part quality is better.
- The use of composites is increasing. There is a fairly strong push from the automotive industry to make vehicles lightweight to satisfy environmental pressure. This has resulted in the demand for lightweight metal increasing.
- Regardless of whatever the power source, such as hydrogen, electrical, a hybrid lightweight vehicle will be needed. According to Professor Dr Schwam, *"Weight is going to be critical. Making composites out of aluminium and magnesium will become high priority. That is where squeeze casting will shine."*
- If the cost of energy goes up we will see resulting changes in technology.
- Vehicle manufacturers in the USA are bound by Corporate Average Fuel Economy (CAFE) regulations, defined to improve automobile efficiency, with standards for passenger cars and light trucks. CAFE is the sales weighted average fuel economy expressed in miles per gallon (mpg) of a manufacturer's fleet of passenger cars or light trucks with a gross vehicle rating of 8,500 pounds or less, manufactured for sale in the united states, for any given model year. Fuel economy is defined as the average mileage travelled by an automobile per gallon of gasoline (or equivalent amount of other fuel) measured in accordance with the testing and evaluation protocol set forth by the Environment Protection Agency (EPA). From early 2004, the average for cars must exceed 27.5 mpg, and for light trucks must exceed 20.7 mpg.
- It is hard to beat squeeze casting for high viscosity alloys and composites. Wrought alloys have high viscosity. Forging alloys like 2000 and 7000 series are used for pressure application can be used for squeeze casting.
- Any alloy that is hard to cast with gravity die casting may be easier to cast with the squeeze casting process due to pressure available.
- High-pressure gas cylinders are used in the aerospace industry. Hydrogen when used as fuel in automobiles will be carried in lightweight gas cylinders. The squeeze casting process can prove to be a very effective method for high-pressure gas cylinders as welding can prove very effective. Squeeze casting can be very effective when used for these applications.
- The die life of a squeeze casting die is short. Die life depends upon the amount of heat it extracts from the components being produced; therefore, if part is thicker more heat will be injected into the die. Die temperature goes up when metal is injected. When a part is chunky a lot of heat goes into the die. When lubricant is then sprayed the die cools and, hence, the cycle is severe. All parts in squeeze casting are chunky with the result that the die is always operating under demanding conditions.
- Die life is part specific, whether it is HPDC or squeeze casting. It is important not to focus on the process, but to concentrate on part geometry and surface to volume ratio. Cross sections of squeeze cast parts are thicker and cycle time is longer; hence, temperature extremes will be larger in squeeze casting.
- In the squeeze casting process the lubricants used should have more insulating properties because to avoid premature solidification during slower filling process. Graphite is used as a die lubricant.
- Molten metal temperature and die temperature are also part specific. Parts with thin-walled sections may require higher melt temperatures and a good insulating coating to avoid premature solidification.

- The microstructure of squeeze cast parts is similar to high-pressure die cast parts. Dendrite Arm Spacing (DAS) is a strong indicator of the cooling rate. The cooling rate is the same (more or less) for both; hence, the HPDC has the same microstructure. Due to a slower filling rate there will be little or no porosity in squeeze casting. However, when squeeze cast parts are compared to gravity cast parts there will be a difference in microstructure.
- Yield is greater with squeeze casting than with gravity casting. Gravity casting has big runners and risers; however, the yield from squeeze casting is the same as HPDC. Though the gates are bigger, cores can be put in squeeze casting; hence, machining is reduced.

North American Die Casting Association (NADCA), Wheeling, Illinois

Reference: http://www.diecasting.org/

The following ha been taken directly from the NADCA website:

NADCA was founded in 1989 through the merger of the American Die Casting Institute (ADCI, founded in 1928) and the Society of Die Casting Engineers (SDCE, founded in 1957).

NADCA represents the voice of the die casting industry and is committed to promoting industry awareness, domestic growth in the global marketplace and member exposure. Headquartered in Wheeling, Illinois, the association is comprised of both individual members and corporate members located throughout the United States of America, Canada and Mexico.

Members of NADCA receive monthly magazines and e-Newsletters on industry events and technical updates, die casting design assistance, discounts on publications and services, access to sales leads and exposure to Original equipment manufacturer (OEM)s. Most recently, NADCA has completed a searchable die caster database, containing more than 500 domestic die casters that can be filtered by name, region, materials and casting sizes.

Below is a summary of NADCA activities, industry involvement and advocacy.

Research and Development: NADCA is heavily involved in identifying industry needs, expanding funding sources and dispelling myths associated with die casting techniques. Indeed, NADCA has an entire technical archive and library dedicated to improving the flow of information on die cast part quality and repeatability. Industry research projects and findings are disseminated through books, CDs and software, as well as being published in its two bi-monthly magazines — Die Casting Engineer and its corporate members-only publication LINKS.

Marketing: NADCA brings business and engineering focus to die casting as the process of choice.

Meetings and Expositions: NADCA hosts member, OEM and supplier trade shows, with events including the Metalcasting Congress annually and CastExpo, the world's largest exposition of metalcasting technology, every three years. Both bring industry members together in one forum, providing public and networking opportunities that develop customer relations, and position attendees as leaders in die casting. Other annual events include the Executive and Plant Management conferences.

Education: NADCA offers more than 30 industry training programs annually, both at its Wheeling, Illinois, headquarters and on-site at die cast plants and OEM facilities. All NADCA's education resources are centered on presenting industry knowledge, improving die cast part quality and production techniques.

Design Assistance: As a recent addition to the association's educational offerings, NADCA has created www.diecastingdesign.org. As an online resource, the Web site is available to help designers and specifiers of die castings optimise die cast parts and processes. In-plant presentations are also available.

Government Affairs: NADCA is a strong advocate in Washington, fostering strategic alliances and developing grassroots efforts to effectively bring industry matters before Congress and key federal agencies. Members are continually alerted on legislative matters and have the opportunity to meet with federal lawmakers each year at the Government Affairs Briefing.

Chapter Relations: NADCA currently has 15 chapters nationwide serving local die casters, communities and industry. Monthly events and meetings help foster community and local business relations, provide networking opportunities and allow for discussions on developments in the industry.

The key contact person in NADCA was Alex Monroe, Project Engineer. The following points were raised during discussion:

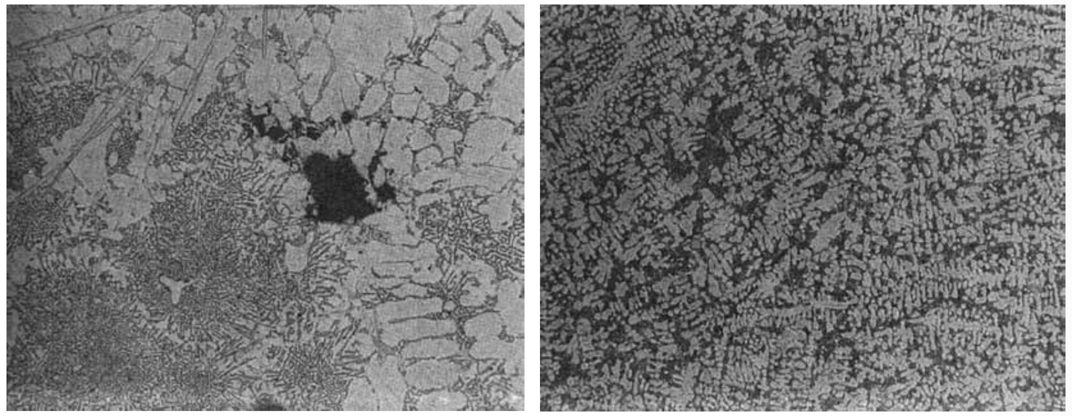
- A sound casting made with the proper squeeze process must follow a scientific method. All process parameters should be under control. High pressure must be applied to the casting in order to squeeze 'gas' out and to pack the material tightly. Care is needed to ensure the high pressure does not create metal flow jetting when it is forced into the small in-gate area. The runner in-gate should be big enough to allow for intensification pressure (to the cavity), but the molten metals' gravity may lead to open gate shrinkage. Metal temperature should be kept high to assist metal fluidity, but high metal temperature may also produce blister defects. When these parameters are dealt with, an overall process control plan should be applied.
- Recycling of flash will still equate to some metal loss. Flash is only 20 per cent recoverable.[iii] As flash is absent in squeeze casting, metal loss will be less when utilising this casting technique.
- The energy saving is quite high when squeeze casting. Reduced scrap is an enormous energy saver. Scrap is reduced by almost 15 per cent in squeeze casting.[iv]
- Graphite is used in a shot sleeve. If over lubricated it will flow too quickly and mix in with the casting.
- Dies experience extreme thermal shock due to the application of high pressure. New die materials are emerging that are much harder and tougher, and capable of withstanding high cracking.
- The squeeze casting process is generally reserved for heavier sections. Thin parts are generally not suitable for squeeze cast parts.
- Cost of the part will be similar to a part cast using the HPDC method. There can be a slight increase in cost due to large in-gates as these may then have to be cut off.
- Filling is slower, and large gates may distort the part.
- Composites are very expensive. Another factor to consider is adhesion of particles in MMCs. NADCA is undertaking a project to find a less expensive way of doing it.
- The NHTSA standards for CAFE are expected to rise to 35 mpg in the future. As this standard becomes higher car parts and total car weight will need to be lighter to achieve this rating.
- At present, there are few industries where the squeeze casting process can be used due to excessive re-tooling issues. There is an opportunity in the marine industry where internal combustion engines are being used. Renewable energy is expected to be the future development area. Wind generated power equipment, such as frame hold, internal rotating turbine components and wind turbine blades, can be manufactured using squeeze casting.
- Reject rate is low in squeeze casting.
- There is a misunderstanding of the particular applications that are best suited to squeeze casting.

Outcomes

Products manufactured worldwide using the squeeze casting process include cross members (produced using Vertical Squeeze Casting [VSC]), control arms (produced using HVSC), steering knuckles (produced using VSC and HVSC), pistons (produced using VSC), engine mount (produced using HVSC), scroll compressors (produced using VSC), and wheels (produced using VSC).

Automotive industry downsizing has led to increased attention being paid to relatively new aluminium casting technologies, and specifically squeeze casting. Although there have been failures, there have been many success in meeting specially targeted goals and costs utilising this alternative process. The successes stem from an understanding of the particular process being used and designing a casting that can benefit from the features of squeeze casting. In the main, the failures have resulted from an inadequate familiarity with the process, lack of appropriate data at the very first design stage, and a wrongful application of the process to meet part cost and function goals.

The higher ductility of squeeze cast components is due to the lack of porosity (due to the higher solidification rate) in the matrix and a more refined microstructure, due to reduction in DAS.



(a) **(b)**

Comparison of a permanent mould cast (a) and a squeeze cast (b) of aluminium alloy. The microstructure shown in (a) is coarse dendrite; that in (b) is preferred ultrafine dendrite. Both are shown at 80 times magnification.[v]

The reduction in porosity and the refinement of the microstructure of the cast product are responsible for the higher tensile properties of the product when produced using squeeze casting.

The rapid growth in the market for safety-critical, high performance components that require superior mechanical properties, will lead to a corresponding rapid growth in improved and advanced automotive casting.

Castings that have exceptional as-cast mechanical properties and are solution heat treatable have one thing in common: they have virtually no porosity. Porosity in castings is primarily caused by two issues that occur during solidification:

1) Shrinkage of the metal. Shrinkage occurs as the metal undergoes the phase change from liquid to solid.
2) Entrapment of gas in the casting. Gas entrapment can occur during the filling of the die or as a result of dissolved hydrogen in the melt coming out of the solution during solidification.

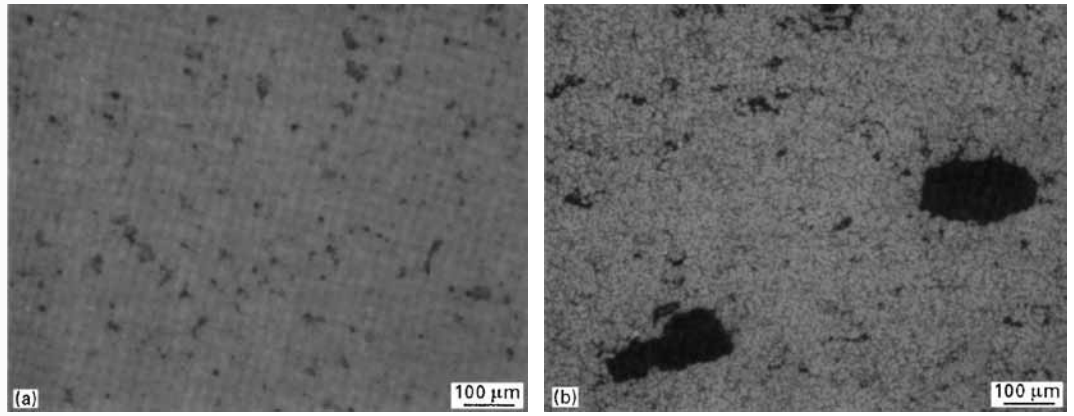
In conventional die casting, after the cavity is full, the gates quickly freeze off. The metal in the die undergoes a density increase during solidification, which translates into a contraction of the casting. Because the metal in the gate has solidified, liquid from the runners cannot compensate for the contraction. In addition, because of the high filling velocities, air can be entrapped.

The International Experience

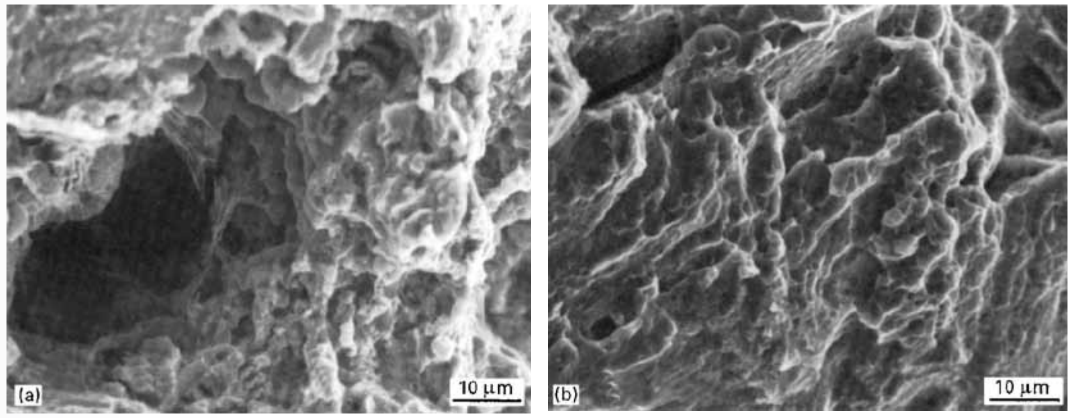
The squeeze casting process eliminates both types of porosity. Shrinkage porosity is eliminated by using a relatively large gating area. After the cavity is full, the gate can continue to feed liquid metal into the casting. During the intensification phase (after the cavity is full), plunger motion can be detected for several seconds while liquid is in the gate. Air entrapment is avoided by using a relatively slow in-gate velocity, maintaining a planar front filling of the die. The other form of gas entrapment is from dissolved hydrogen, and this can be reduced using a conventional degassing technique.

To compound the situation, many inquirers ask producers of each process to quote the same part, making a judgement on cost factors alone, without taking into consideration the inherent benefits of each process.

The goal of the squeeze casting process is to provide a net shape with minimum porosity to allow for a multitude of secondary processes that may be porosity sensitive, such as solution heat treating, plating, and welding. The definition, accepted by all major casting associations, contains three major conditions: slow cavity fill, high pressure during solidification, and the potential for solution heat treating.



Optical micrographs showing microstructure of (a) a squeeze cast part, and (b) a die cast part, both in the as-cast condition [vi]



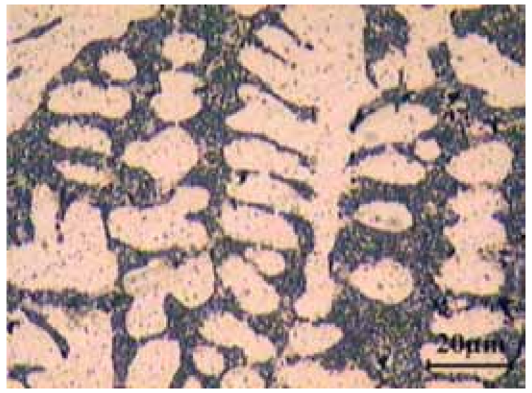
SEM fractographs of (a) a die cast part, and (b) a squeeze cast part [vii]

It is important that these potential mechanical and physical benefits are taken advantage of by the industry.

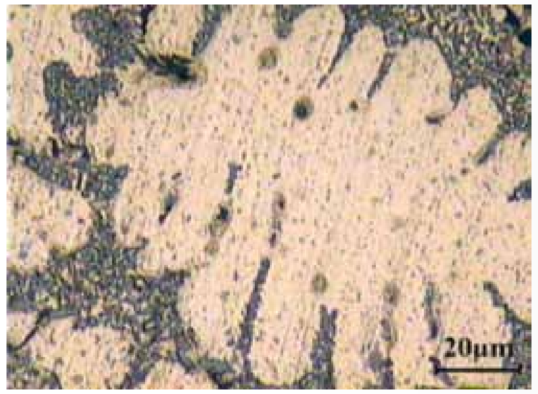
The squeeze casting of aluminium alloy and to a lesser extent magnesium alloys, is a process that offers the potential of producing high-quality, sound castings with reproducible properties. This process can produce near-net shape castings that are essentially free of pores.

This allows both the solution heat treatment and the welding of the castings without resulting in gassing or blistering. The squeeze casting process is best adopted to structural types of light metal castings that are fairly chunky in shape rather than castings of a rangy shape with thin sections.

The squeeze casting process employs larger in-gates and considerably lower molten metal velocities than conventional pressure die casting. With the proper location of the in-gates and maintaining high pressure on the molten alloy during solidification, it is possible to avoid nearly all shrinkage and gas porosity. In some cases, it is necessary to employ pressure pins in selected parts of the casting. The high pressure on the molten metal maintained during solidification, keeps the surface of the casting in direct contact with the die surface, resulting in rapid solidification and a fine, secondary DAS. This structure provides excellent properties with only a small amount of variation from one casting to another.



(a)



(b)

As-cast microstructure of (a) squeeze cast specimen (b) gravity cast specimen [viii]

Although the squeeze casting process has many advantages in producing parts of light metals that can be utilised in structural applications, the full potential can only be realised once the process has been optimised. A number of factors can influence casting quality including in-gate velocity, design and location of in-gate, optimum filling time for the casting, pressure used in filling and molten metal and die temperatures.

Gating and Runner Design

One of the characteristics that distinguishes squeeze casting from HPDC is the size of in-gates. HPDC gate thickness is typically in the range of one to three millimetres. This results in very high gate velocities, cavity fill times measured in milliseconds, and turbulent flow during cavity fill.

Squeeze casting takes advantage of very large in-gates and slow fill rates to promote non-turbulent, laminar flow during cavity fill. Typically, gate thickness is in the range of 0.25 to 1.5 inches, depending on the wall thickness of the casting. Recommended gate velocities are below 20 inches per second, and cavity fill times are often in the range of two to five seconds.

Large gates allow the metal in the gate area to remain molten during casting solidification, so that pressure can be maintained while the casting solidifies. This greatly reduces the development of shrink porosity. Placing gates in the thickest regions of the casting also ensures that the gates are placed at the last regions to solidify, which is important for continued ‘feeding’ during solidification. Ideally, the gates and runner should solidify after all other areas of the casting so that pressure can be maintained.

The in-gate size is an important consideration since it must remain open until the casting is solidified and pressure is maintained on the solidifying casting. The volume of the metal entering the die cavity has to be sufficient to fill the cavity before localised solidification occurs.

This is best accomplished with a larger in-gate to attain rapid filling without excessive velocity. The fan type of in-gate helps to accomplish this rapid fill without high velocities.

Higher metal pressure provides a more complete fill of the die including improved compensation for solidification concentration.

When the proper filling pattern, in-gates, overflows and die temperature is attained for a given die, very good tensile properties can be attained on the squeeze casting.

The main benefit of a squeeze casting process is the ability to produce high integrity castings with minimal porosity. This benefit is realised by minimising turbulence during filling of the cavities, and by ensuring directional solidification towards the gates.

Process simulation can be utilised to optimise gate and runner design, to develop a shot velocity profile that minimises turbulence, and to ensure directional solidification through the determination of the best placement of gates and cooling channels.

Process simulation allows for the correct determination of many of the crucial squeeze cast process parameters, such as metal velocity, temperature, pressure and cycle time. A key advantage of this simulation is that it allows for the visualisation of metal pressure, velocity, and the temperature changes that occur during filling. It also ensures that a suitable gating design and die design has been developed.

Designing for directional solidification guarantees that liquid metal is able to feed the shrinkage areas during solidification. Factors that influence directional solidification include gating and runner design, die cooling/heating configuration, metal pressure, alloy type and temperature, and die temperature.

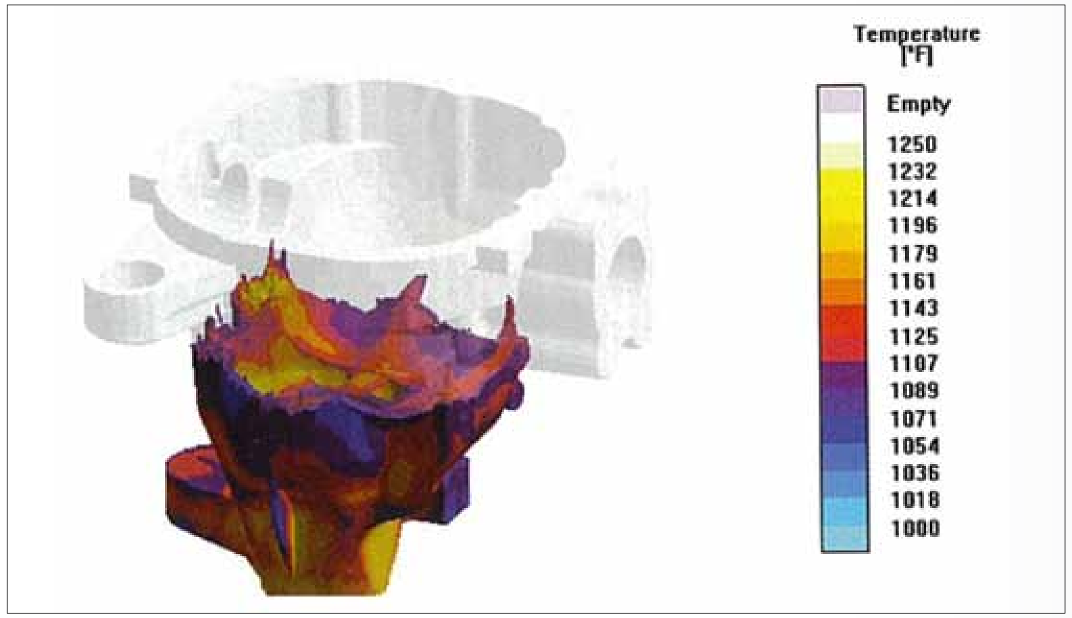
To achieve directional solidification or the desired solidification pattern, various simulation techniques can be used. Some of the traditional techniques that are being used include: localised squeeze pins, isolated cooling, and alternative die materials.

Shrinkage porosity is a casting defect that normally occurs in thick cross sections often isolated by thinner cross sections. The goal of a successful process and die design is to either eliminate the shrink porosity or relocate the shrink porosity to other unimportant locations. These areas could be locations that are not machined, have no surface finish requirements, or where high mechanical properties are not required. Using a localised squeeze pin is one example of an effective way to accomplish this goal. Squeeze pins are used to push semi-solid metal into the cavity during the solidification process. As a result, shrink porosity in the surrounding area is minimised. New simulation techniques are being used to optimise the use of squeeze pins. Process parameters such as squeeze pin travel, velocity, timing, and pressure can all be simulated. The results can then be used to optimise the design and process parameters.

Another method that is used to reduce shrink porosity is through the use of spot solidification techniques. This method can be achieved by using certain high thermal conductivity tools and materials such as baffles, bubblers and super cools along with alternative die materials to create a spot of local cooling. ‘Super cooling’ exists when water is controlled in a way that it is changed to steam in order to increase the thermal transfer coefficient due to a phase change.

The gate must be large enough to remain open during the solidification of the casting in order to obtain satisfactory quality. When the in-gate is not thick enough to match the thickness of the casting, the results are poor.

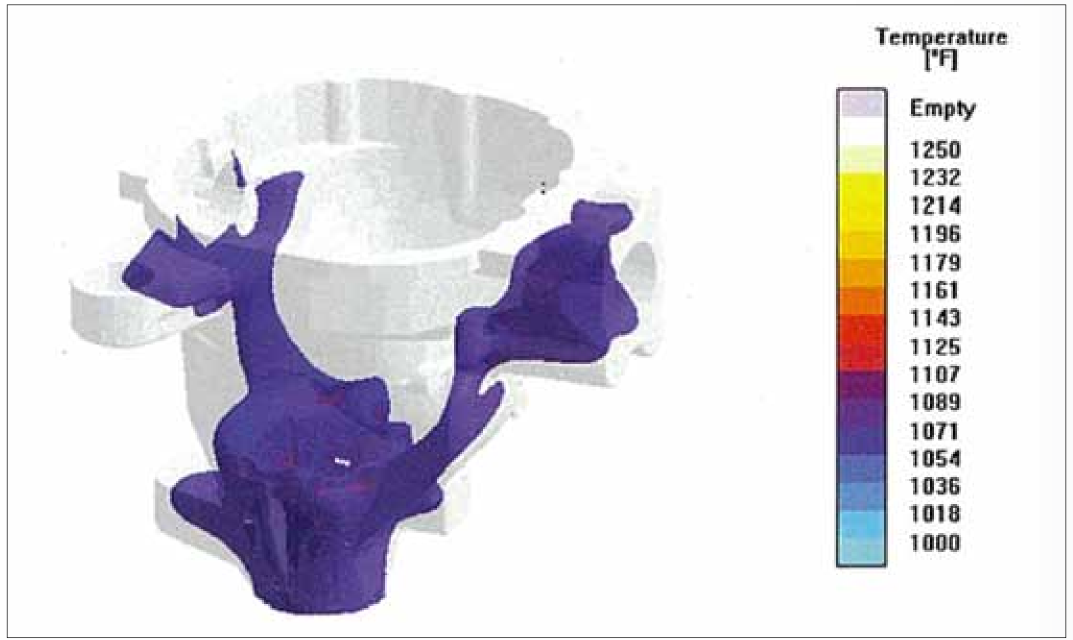
Process simulation provides a power tool to assist runner and gating design. Temperature, velocity and the pressure distribution pattern should all be used to optimise the gating system. In order to minimise filling defects, some techniques can be applied such as natural geometry gate, short distance gate, simultaneous multiple gate, sound runner to in-gate transition design, ring gate etc. When casting has very complex geometry with many cores, slides and pins, a group of simulations with different designs should be used to get the optimised design.



Mould filling simulation (HVSC process) [ix]

Mould Filling Simulation (HVSC process)

Process simulation is a powerful tool: one that is based on the fluid mechanics mathematical model. However, it cannot reflect the actual die casting process to 100 per cent accuracy. It is not necessary to solve all die casting process defects and problems automatically. The automotive casting engineer must combine a 'castable' design, gating/runner design, process control experience and fluid flow knowledge in the die casting production.



Process simulation was used to evaluate the runner design and ensure adequate directional solidification was achieved [x]

Metal flow temperature, velocity and pressure distribution composed all criteria for quality casting production. A good gating design should make metal flow have the lowest temperature, velocity and pressure loss. Attention should be paid not only at in-gate, but also at the end of flow filling velocity, which is even more important in some cases. Higher velocity will lead to lower pressure; therefore, proper balance selection between the two is critical in casting gate design. Gate position considerations are either short path, natural geometry path, or positions that provide an easy way to delivery and avoid any obstacles. When these principles conflict with each other, process simulation is used to compare and decide the best option.

If possible, squeeze casting should be bottom gated. This means that the casting or castings are oriented in the die so that the gates are at or near the bottom of the cavity. This reduces or eliminates cascading of the molten metal during cavity filling, which is undesirable because it can lead to the entrapment of gas and the formation of oxides.

Bottom gating also ensures a bottom to top filling pattern that, along with a well designed vent system, acts to evacuate as much air from the cavity as possible during cavity filling.

Die

The squeeze casting process needs very high quality filling to produce a non-turbulent flow. The casting layout in the die becomes a critical factor and must apply the pressure directly to the molten metal without creating jetting and separation. Flow should be stable and reduce heat loss. Necessary process modelling should be tried first before the real die is cut.

The squeeze casting process is very demanding on a die surface. It is characterised by low fill velocities and high injection pressures to enable a superior quality casting to be produced. Typically, squeeze cast parts are those that require high structural endurance and better surface finish. The low cycle time of squeeze casting increases the strain on the die component. Analytical studies have shown that during the injection stage and during die spray, die stresses constantly exceed the yield stress of the die material.

Onset of heat checking and the progression of heat cracks become a major issue in the production of cosmetic components like wheels. Due to this heat, actual tempering back of the steel can occur, steel may loose yield strength and ductility may be reduced.

The key characteristics for an improved die material for this application are thermal fatigue resistance, ductility and temper resistance. Thermal fatigue, or heat checking, is a gradual growth of fine cracks on the die surface due to the continuous temperature cycling between the surface and the core of the tool. Loads become so high that the result will be a strain or creep during each cycle. It is the accumulation of this strain that leads to thermal fatigue.

How much strain can a die surface have before a ductile crack is initiated? This depends on the ductility of the steel, as well as its ability to maintain its strength at elevated temperature, or temper resistance. Once a crack is present, the rate of crack propagation is critical. The rate of crack propagation will depend upon the toughness of the steel. The toughness of the overall die is related to many factors, some of those being steel quality, the heat treatment process and die hardness.

The latest hot work alloy type is low Si, high molybdenum variants. As hardness increases the crack depth is reduced. That means gross cracking resistance is not sacrificed while substantially improving heat checking resistance. The heat transfer across die surfaces increases in squeeze casting because the applied pressure eliminates the air gap at the liquid metal/mould interface.

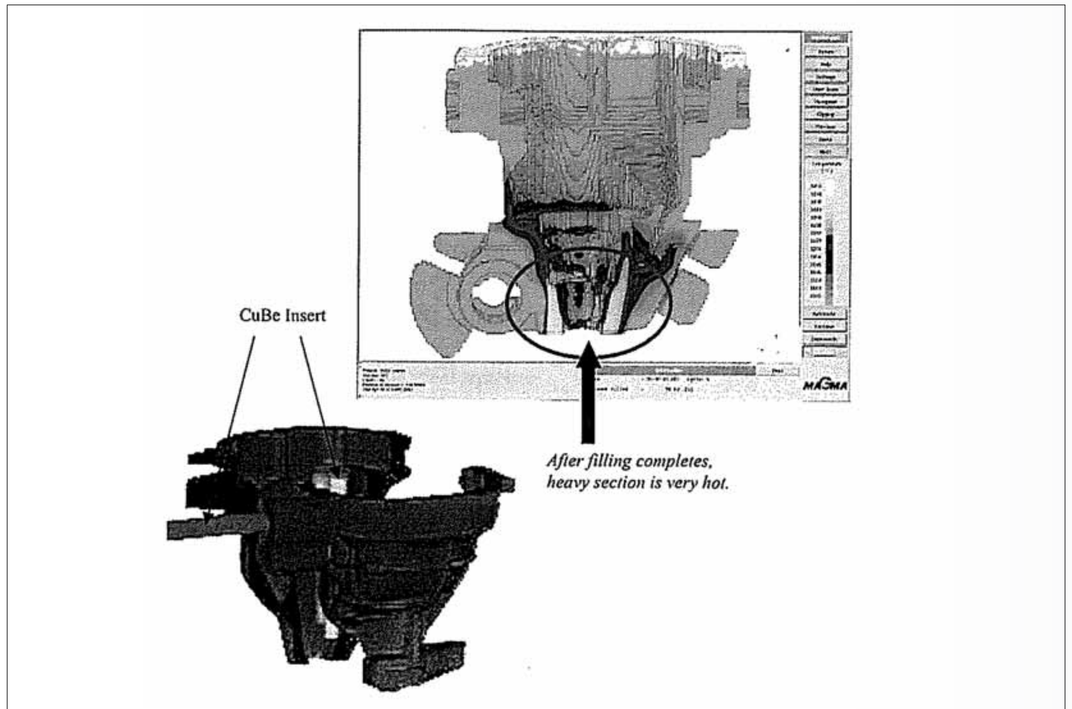
It has been reported that there was an increase in the cooling rate from 11 degrees Celsius per second from a permanent mould casting to approximately 282 degrees Celsius per second with squeeze casting.[xi] Solidification times are reported as one half the time in the gravity die castings. Furthermore, the heat transfer coefficient is four times greater in squeeze casting than in gravity die casting.[xii]

Squeeze casting is widely used for the thick-walled casting. The process generates a lot of heat during die filling and solidification. Since a regular die surface cannot extract the heat away in a given time, defects such as shrinkage porosity, warping, die heat checking and soldering often occur. Thus, high thermal conductivity materials are often used to provide the rapid and uniform heat removal from the parts. The cooler material establishes a cooling channel. This kind of channel can absorb heat from the die to reduce the local heat and decrease cycle time. It can also setup local directional solidification, which actually extends the feeding distance and reduces the volumetric shrinkage defect.

An ideal solidification pattern leaves no isolated liquid or semi-solid regions in the casting. Pressure from the shot piston can then be applied during the entire solidification step, resulting in a very dense casting. This can be readily achieved when casting geometry is simple and when gates can be placed in the thickest section of the casting. Complex casting designs with several thick areas separated by thinner walls will decrease the ability to achieve directional solidification. In such instances, other means to achieve a high integrity casting must be employed.

The proper use of high thermal conductivity material is a good way to setup local directional solidification. This cooling channel can absorb the heat and actually extend feeding distance effectively. It is used to combat defects such as volumetric shrinkage, die heat check and soldering. Proper application can also reduce the total cycle time.

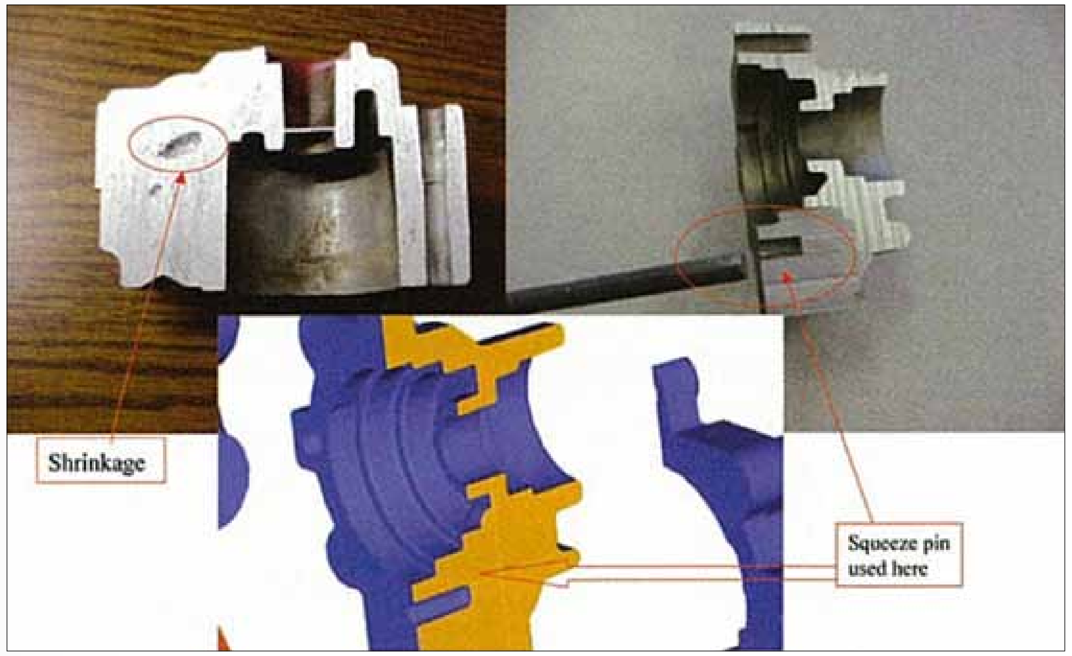
It should be noted that a material with higher thermal conductivity has higher heat flow rate. It does not necessarily mean that it is able to transfer heat rapidly to transient surrounding areas unless the material has a small heat capacity. It is somewhat like a reservoir that can receive and hold large amounts of water, but this does not mean it delivers water to other places quickly. In a certain time period, the greater the amount of heat a material can absorb, the smaller the thermal gradient that exists throughout the material. Therefore, the heat transfer occurs slowly. For this reason the heat taken by the high conductivity material should be removed or transferred by fluids (water or oil) to set up continuous thermal gradients. For better control of the process, attention should be paid to the size and length of the thermal pin. Proper selection of the insert material is critical for the casting process.



High thermal conductivity insert used for heat transfer [xiii]

When volumetric shrinkage occurs, squeeze pins can be used. The use of squeeze pins depends on the shrinkage position, size and the tooling condition. Normally, the volumetric shrinkage for aluminium is about three to six per cent. Squeeze pin size should provide enough metal to feed these shrinkage areas. In the squeeze casting process, the cavity metal gets the pressure directly from the plunger. Because the die continuously extracts the heat from the metal, a shell or skin forms immediately after the filling process. This shell grows towards the centre of the casting.

Before the casting centre starts to solidify, an efficient molten metal channel must be kept open so that the pressure is able to ‘push’ the molten metal to fill the cavity. However, the casting geometry, timing, and the metal temperature limit this pressure loading. In those cases, squeeze pins are used to help punch the molten metal to fill those critical areas. Therefore, squeeze pin size, movement timing, velocity, and punch position all need to be designed precisely. Squeeze holes actually reduce the effective cross section area of the casting. Therefore they are not allowed to be at those critical positions. The principle is to punch at a non-critical place, and to cause action at critical places. It is no coincidence that some squeeze pins are punched at the runner area.



Squeeze pin usage to cure shrinkage [xiv]

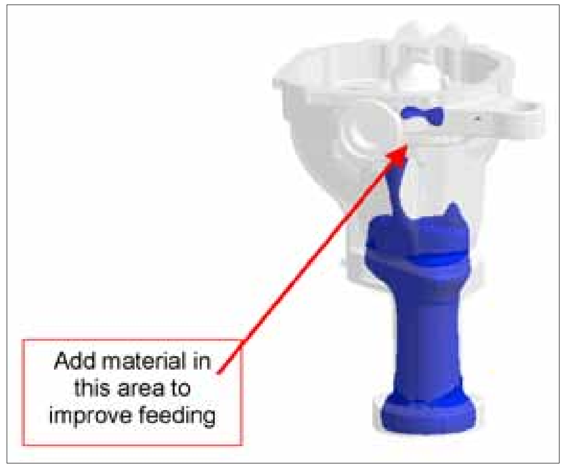
When the pin enters the casting cavity, the metal should be at mush stage with a certain percentage of solid fraction. If the metal has too greater amount of liquid, the squeeze is not effective. On the other hand, if the metal has too much solid fraction, the pin will meet a strong resistance, which will make the pin bend. Therefore, the timing is very important. Because the pin is applying pressure to the contracting high temperature metal, the pin will expand in size. If the velocity is not controlled, the pin will bring the mush metal back into the pin bushing and sticking will occur. Therefore the clearance and pin moving velocity need to be calculated precisely.

Squeeze pin usage must be carefully calculated on position, size, timing, velocity and pressure. The safe way is to ensure the shrinkage volume and to locate the squeeze position (as discussed previously this may be away from the shrinkage area). This then improves squeeze effectiveness by ensuring the molten metal feeds the shrinkage areas.

No matter how good the design is, shrinkage will happen. The squeeze pin just moves the shrinkage from one place to another non-critical place.

Product Design

Like any other casting process, squeeze casting components can also benefit from shape improvements. This is largely due to the fact that sharp corners and drastic changes in cross-sectional areas can be detrimental to directional solidification. Sharp corners induce turbulence and cause the formation of poor fill. Erosion in these areas can also occur. Thus, it is important to carefully consider the product design when a squeeze casting is designed.



Proper use of casting simulation tools can be of great benefit during the design of squeeze cast dies and can assist in placement and orientation of castings [xvi]

The single most important factor influencing feeding during solidification is the geometry of the component being cast. Thick areas of a casting, including bosses and rib intersections that are connected with thinner walls will always have the potential to generate shrink porosity: even with well-engineered runner, gating, and cooling systems in the die, perfect directional solidification is rarely achieved.

As Yun Xia and Chuck Barnes report, casting redesign is very crucial in the squeeze casting process. The flow and heat transfer pattern can be changed by the redesign. Redesign work should be done with consultation with the customer and should get better castability results without losing casting strength or increasing casting weight.[xv]

Heat Treatment and Alloy

An important advantage of the squeeze casting process is that it can be used with various alloy/heat treatment combinations that can be tailored to balance mechanical properties or performance with cost. Primary alloys A356 (AlSi7Mg) are used in the T6 heat treatment for applications that require high strength and ductility such as control arms, steering knuckles, and suspension links. Secondary alloys such as ADC 12 (AlSi11Cu3Fe) are used in the as-cast condition. T5, and T6 heat treatments are used for applications that require high strength, pressure tightness, and wear resistance. Other alloys commonly used with squeeze casting include 319, 380, 383, and 390.

The A356 aluminium alloy is widely used as an important silicon-based aluminium casting alloy. It provides an attractive combination of excellent castability, corrosion and wear resistance, pressure tightness and particularly high strength-to-weight ratio. The microstructure and mechanical properties of this alloy greatly depend on the composition, melt treatment, efficiency of feeding system, cooling rate and heat treatment.

In general, mechanical properties are controlled by cast structure. The mechanical properties of A356 are governed by casting soundness, the amount, size and morphology of the consecutive phases, such as alpha-aluminium (Al) phase, eutectic silicon (Si) particles, and the distribution of microporosity. These factors are influenced by how the Al-Si binary eutectic nucleates and forms during solidification and by the heat treatment process.

The rapid cooling rates of squeeze cast parts greatly refine the microstructure from the plate or needle shape to a fibrous morphology during the Si phase. The rapid cooling is a potent Si-modifier, equal to Si-modification by additives during melting.

The International Experience

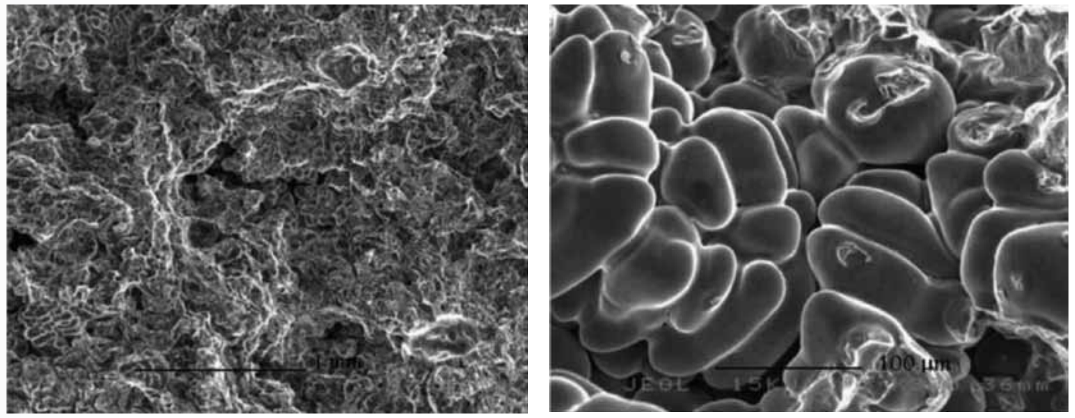
The fine and fibrous particles in squeeze casting need shorter times to dissolve. In contrast, the coarse flakes or plates of Si in permanent mould cast bars are inherently more resistant and need a longer time to dissolve and to segment. These particles have a shorter time to spheroidise, so morphological changes beyond an increased degree of roundness are less evident after heat treatment in comparison with that of the squeeze cast parts.

A lot of work is done by Professor David Schwam of CWRU regarding the heat treatment of squeeze casting. He explains that the structural differences between squeeze casting and Gravity Permanent Mould (GPM) casting, before and after heat treatment, originate from their distribution during the Si phase. In the process of spheroidisation of eutectic material, the Si particles can be divided into two stages, the dissolution and segmentation of the eutectic Si particles, and the spheroidisation and coarsening of the segments.

The solubility of Si in solid aluminium at the solution temperature (540 degrees Celsius) is about 1.25 per cent, while at room temperature it is only 0.05 per cent. Therefore, during solution treatment some Si atoms from the eutectic Si phase will dissolve into the aluminium solution. The driving force for the spheroidising and coarsening of the Si phases is the reduction in the surface area between the Si particles and the aluminium solid matrix. Components produced by squeeze casting can be heat treated without any blister defects. Alloys made by squeeze casting show much better mechanical properties, not only in as-cast condition but also in T4 and T6 heat treatment condition.

The microstructure is determined by how the Al-Si binary eutectic nucleates and grows during solidification and by the heat treatment process. It was established that the lower UTS, elongation, impact strength and quality index of GPM cast parts result from a less favourable microstructure.[xvii] The permanent mould castings have large DAS, coarser acicular Si phases and higher porosity in the as-cast condition. They also have larger size and lower roundness of the Si particles and a higher porosity rating in the T4 and T6 heat treatment.

The sharp edges of the coarse acicular Si phase promote crack initiation and result in lower mechanical properties because of the stress concentration at the sharp edges during plastic deformation. Mechanical properties, especially ductility and toughness, are improved distinctly by squeeze casting. This process reduces the size and aspect ratio of Si particles by increasing the cooling rate. It almost removes the macroporosity and microporosity by pressure application.



(a) **(b)**

SEM micrograph showing (a) a typical fracture surface of gravity cast samples and (b) the typical shrinkage porosity within the dendrites structure [xviii]

If porosity is present in the sample, the fracture will occur more readily because the porous regions yield first, due to the reduced load bearing area. This results in a high concentration of strain near the voids. The concentration of the strain accelerates further damage in the porous region, causing premature fracture. The improvement of mechanical properties by the squeeze casting process can be easily explained by the improvement in the microstructure.

The smaller DAS, finer Si particles and low porosity of squeeze castings in the as-cast condition make the Si particles more difficult to crack. The micro cracks have more difficulty forming and propagating; this retards final fracture and enhances the tensile strength, ductility and toughness.

Squeeze casting also provides better microstructure with finer and rounder Si particles and almost no porosity in the T4 and T6 heat treatment, offering higher mechanical properties. The particle cracking is determined by the plastic flow of the matrix around the hard particles. When the matrix is deformed, particles with large aspect ratios interact more than rounder ones and increase the strain hardening rate at low strains. This leads to higher stresses in the particles that consequently crack more readily. The larger particles are in the same situation as the elongated ones and are more prone to cracking than the smaller ones.

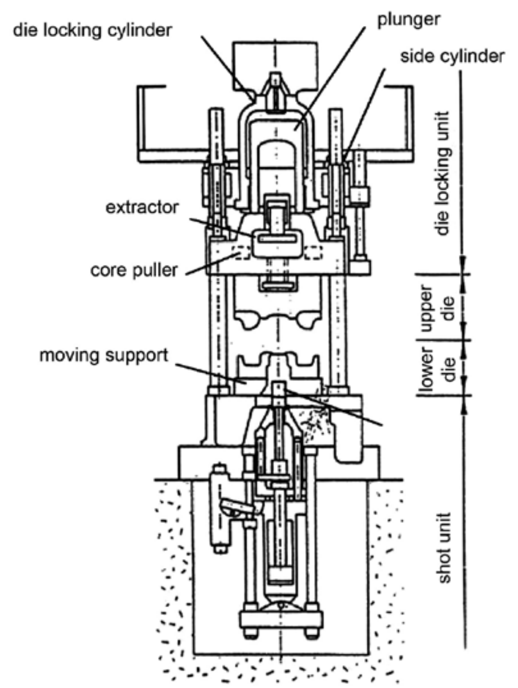
Squeeze Casting Machines

Professor Schwam and Zhu explained that the earliest reports on squeeze casting originated in 1878 Russian literature, the reports suggested pressure should be applied to molten metal while it solidifies in a mould. The commercial development of squeeze casting began to take place in Europe, North America and Japan only after 1960. Two types of squeeze casting technology have evolved based on different approaches to metal metering and metal movement during die filling. These have been named direct and indirect squeeze casting.

In the case of direct squeeze casting, the melt is poured directly into an open die, and a hydraulic ram is moved down into the melt to apply the pressure. The biggest advantage of the direct squeeze casting process is that the pressure is applied to the entire surface of the liquid metal during freezing, producing a casting of full density. This technique, inevitably, gives the most rapid heat transfer, yielding the finest grain structure, but it does not control the die filling stage.

This leads to turbulent flow and the entrapment of brittle surface oxide films. The inherent time delay occurring after the metal is poured and prior to pressurisation with the ram leads to premature solidification. A highly accurate metering system is needed to control the dimensions of the casting.

In comparison, when using the indirect squeeze casting process the pressure is more difficult to apply. The melt is injected into the bottom of the cavity with a hydraulic ram. The metal flow can be controlled via the injection speed, and pressure application begins as soon as the die is filled. The casting forms inside a closed die cavity, and the dimensions of the casting are easier to control.



VSC: Indirect Vertical Squeeze casting machine with vertical shot unit and hydraulic vertical clamping unit (courtesy of UBE Machinery Inc)

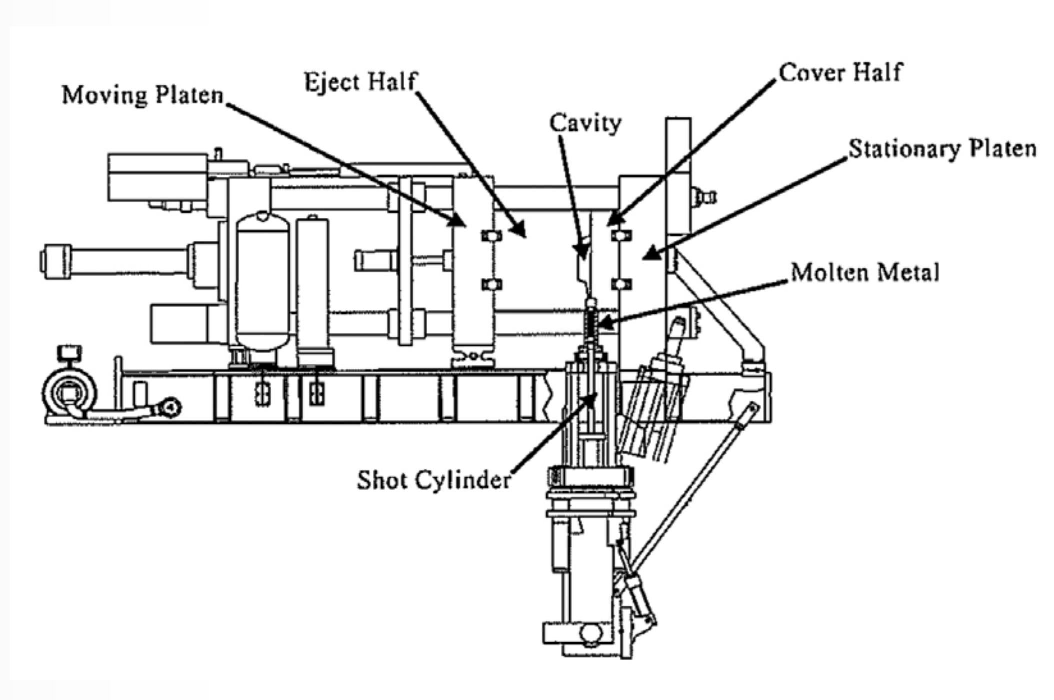
Two types of squeeze cast machines are available at the present time - Vertical Squeeze Cast (VSC) and HVSC.

The squeeze casting process can be divided into various categories in terms of parting line orientation and the way liquid metal is introduced into the cavity. One of these is vertical die opening with vertical shot casting system.

A second system is the HVSC system: a horizontal die opening with vertical shot system. The squeeze casting process consists of pouring metal into chamber (shot sleeve), slowly forcing metal into a preheated cavity, and applying pressure throughout the solidification process. The slow injection speed minimises turbulence during the fill process, thus reducing amount of entrapped air. The continuous application of pressure during solidification, along with rapid solidification rates, help reduce shrink porosity.

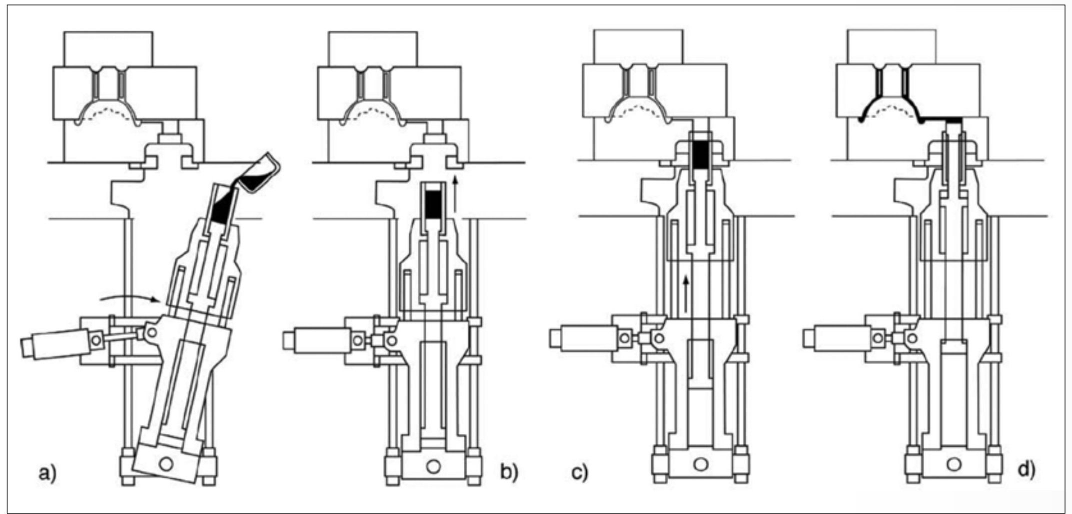
The typical features of the HVSC machine include:

- Horizontal die clamping: the horizontal clamp increases the number of potential parts produced with the machine, making castings that are gated both symmetrically and non-symmetrically.
- Vertical high-pressure delivery: the vertical shot sleeve helps maintain molten metal temperature, and high pressure over 69 MPa is applied to liquid metal in the die cavity to minimise shrinkage porosity and to promote rapid solidification.
- Tilt-docking injection: this involves die closure, pouring of molten metal, tilting of the shot sleeve to the injection position, docking of the shot sleeve and the injection of molten metal into the die cavity.



Squeeze casting machine schematic (courtesy of IdraPrince)

HVSC machines have a distinct advantage, due to the configuration of the vertical shot system. During the pouring process, the shot sleeve tilts out, allowing the metal to be poured down the sidewall of the cold chamber. As a result, turbulence, which often contributes to the formation of porosity and oxide skins, is minimised.



Squeeze casting process cycle and die arrangement for (a) ladling of melt into the inclined sleeve; (b) tilting of the sleeve into vertical position; followed by (c) docking to the bottom of the lower die, before the plunger moves upwards and pushes the melt into the die cavity and applies the solidification pressure (d) (courtesy of UBE Machinery Inc)

Modifiers/Alloys

Among all of the casting defects, porosity and weak microstructure are two of the major concerns. Porosity affects the strength and leaking of functional components while beta intermetallic microstructure affects the ductability and impacts the strength of aluminium silicon casting. Strontium, an alloy modifier has been reported to be useful in refining the microstructure in grain size and reducing porosity for aluminium alloy.

It is reported that increasing the structure level from 200 PPM (wt) to up to 600 PPM (wt) reduces the amount of porosity by about 45 per cent and reduces the size of the iron bearing intermetallic particles by about 30 per cent.[xix]

Strontium had a positive effect in the forming of porosity, but somewhat minimal effects in significantly reducing the quantity of visual porosity. As the squeeze casting process produces very little porosity, the difference in area percentage porosity is too insignificant to be of any note. The addition of strontium had insignificant effects in the formation of porosity in the squeeze die cast process.

It is clear that castings without a strontium modifier contain a fine fibrous Si eutectic phase, while castings with a strontium modifier contain a fine fibrous Si eutectic phase. These results were similar to the findings regarding the conventional die casting process. The beneficial effects of strontium on the microstructure in A380 die castings produced were significant. The A380 with strontium produced a better microstructure than the A380 castings without strontium when using the squeeze diecast process.

Process Parameters and Microstructure

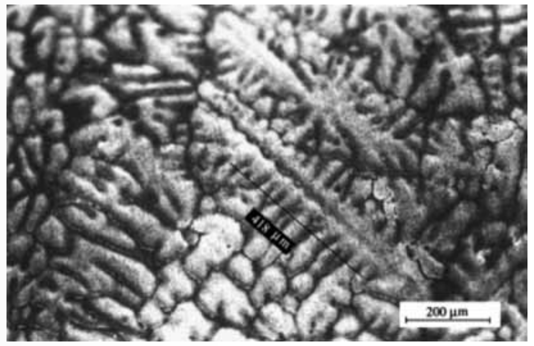
In squeeze casting the close contact with the die surface during solidification results in rapid solidification of the casting. This rapid solidification produces fine secondary arm spacing in the castings, so that good strength and ductility can be attained. These excellent properties are relatively high in the as-cast condition and are enhanced further by heat-treatable alloys and their excellent response to solution heat treatment.

Since the process minimises both gas porosity and shrinkage cavities, excellent properties are attained. These properties have been shown to be equivalent to wrought alloys in many instances.

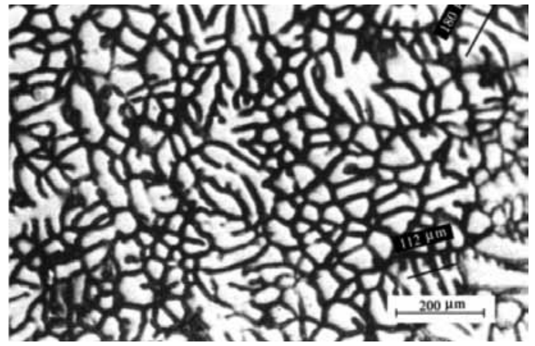
The DAS provides a convenient means of linking the mechanical properties to the solidification conditions. The dendritic structure obtained with pressure solidification is more uniform than with atmospheric solidification.

DAS values were found to be larger in the centre than at the edge of the cross section due to the different cooling rates. The improvement of thermal contact between the melt and the mould surface increases the cooling rate and decreases solidification time at the edge.

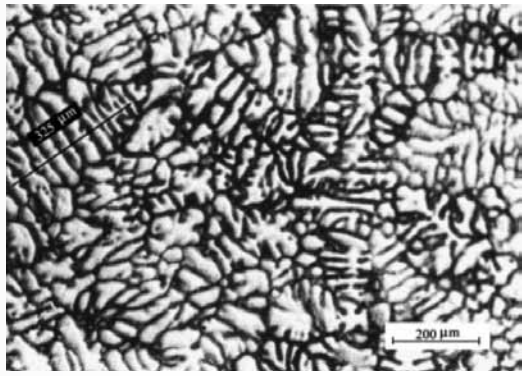
Previous experiments tell us that by increasing the pressure, the difference between the DAS at the edge and in the centre of the casting is reduced.[xx] At a pressure level of 350 MPa the range of the DAS change would be between 10 and 15 microns. In the absence of pressure in the gravity casting, the divergence of the DAS would be greater and be between 15 and 90 microns.



Micrograph of a typical gravity cast sample [xxi]



(a)

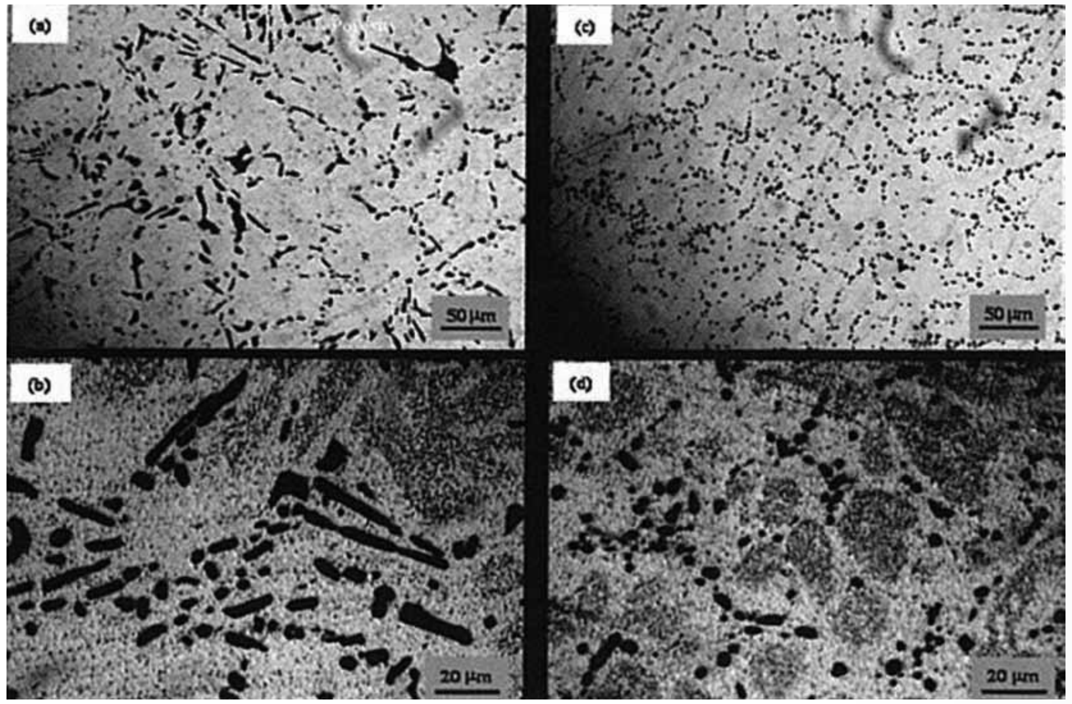


(b) **(c)**

Micrograph of the squeeze cast samples (a) 30 MPa (b) 50 MPa (c) 70 MPa applied pressure [xxii]

The high pressure applied in the squeeze casting process can help to overcome some of the tendency for shrink porosity to form in heavy sections. Metal pressures in the range of 10,000 psi to 20,000 psi are fairly common in the squeeze casting process.

Microscopic examination reveals that application of the squeeze pressure during solidification of this alloy affects the microstructure in the as-cast condition and T4 and T6 heat treatment conditions. In the as-cast condition, squeeze casting refines the primary alpha phase and the eutectic Si phase, and Si gets fibrous morphology; whereas, in a permanent mould, Si has a plate or needle shape.



Shows the microstructure of permanent mould and squeeze casting in the T4 heat treatment condition: (a) and (b) are made from permanent mould casting; (c) and (d) are made from squeeze casting [xxiii]

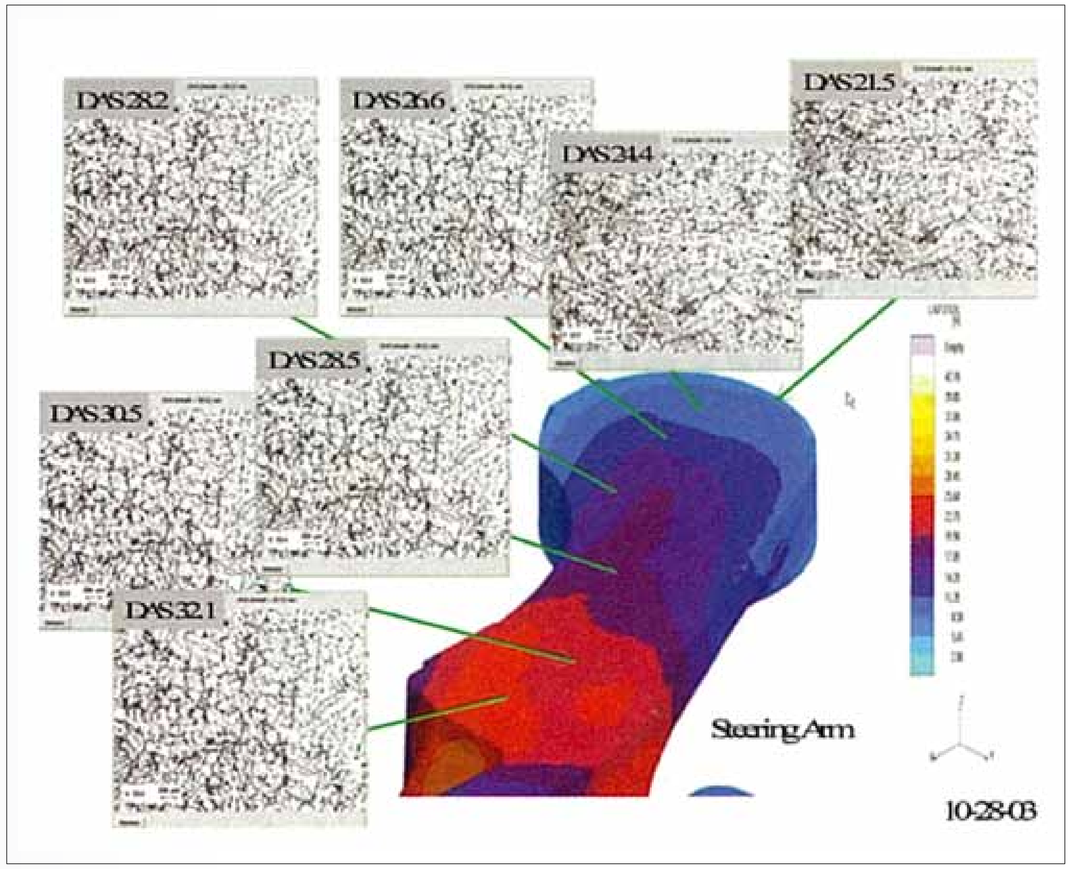
Research done by Professor Schwam and Zhu indicates the difference in the microstructure of squeeze cast part and GPM cast result indirectly from the applied pressure. When the die is made of metal, the die/casting interface becomes the greatest resistance to heat transfer. Due to the contraction of most metals and expansion of the mould during solidification, detachment of the casting from the die wall takes place once the initial solid shell of the casting has sufficient strength to hold the remaining molten metal. Consequently, an air gap is formed between the die walls and the casting, which considerably increases resistance to heat transfer.

In squeeze casting, the applied pressure of about 70 MPa on the casting forces the initial solid shell to remain in contact with the die. The intimate metal-die contact is maintained by the plastic deformation of the casting throughout solidification. This leads to very fast heat transfer rates, high cooling rates and increased temperature gradients in the casting. The cooling rate in squeeze casting, therefore, can be much faster than that of GPM castings, depending on applied pressure, die preheat temperature, cooling line location, casting thickness, die lubricant and other factors.

Another important benefit of high metal pressure during solidification is that the interface between the casting and the cavity is kept tight for a longer period of time, ensuring high heat transfer from the casting to the cavity. The high cooling rate results in very fine secondary DAS (< 20 micron) near the casting surface, which increases mechanical properties and can improve fatigue performance of the cast component. Although the mechanical properties near the surface are elevated, squeeze castings also have more uniform mechanical properties, from the surface to the interior, than castings from some other processes; particularly HPDC. The more uniform distribution can be utilised during product development to yield more optimised product designs.

The low pouring temperature that is utilised for squeeze casting, accompanied with pressure effects, lead to the formation of equiaxed grain structure with final isotropic properties.

New simulation techniques are now being used to predict the microstructure at various locations throughout the casting. CONTECH USA has done lot of work in squeeze cast microstructure simulation. The diagram below shows the cross section of a steering arm from an aluminium (A356.2) squeeze cast knuckle.



Cross section of steering arm [xxiv]

The microstructure, along with the corresponding mechanical properties, may vary considerably throughout the casting due to varying solidification conditions. Factors that influence solidification rates include wall thickness, alloy composition, die temperatures and metal pressure. The microstructure simulation tool enables the user to predict localised material properties that can be used to assist with product design and optimisation.

Chuck Barnes of CONTECH USA explained that the formula to calculate the pressure required for squeeze casting is different from conventional die casting because it considers the rod pressure, which applies opposite pressure during the plunger moving to fill the cavity. Hydraulic pressure pushes the shot cylinder to work. But the rod pressure will be a resistant force and will push back.

Generally speaking, a squeeze casting machine will have less metal pressure shock impact than a conventional HPDC machine, because it generates a rod pressure to resist the intensified shock. It acts like a brake used in a fast moving car before it runs into an obstacle. Thus for a similar sized machine, squeeze casting will provide higher locking force than a conventional die casting machine, thus enabling larger castings to be made.

Lubricant

The squeeze casting process maintains a high pressure on the molten aluminium alloy in the die throughout most of its solidification period.

It has been stated that the squeeze casting process requires some form of insulating film from the die lubricant.[xxv] However, this is not the only critical property for a die lubricant. In addition to providing some insulation for the die steel, the lubricant film must also provide a barrier to prevent soldering and form a lubricating film to allow good metal flow.

Why Squeeze Casting

There have been constant demands and a need to make automobiles lighter and more fuel efficient while, at the same time, increase passenger comforts in vehicles. Automobile manufacturers have sought ways to maintain or reduce the mass of vehicles. This has caused die casting manufacturers to find ways to produce new parts that were previously iron castings or stamped steel assemblies, as well as provide die castings that are stronger and suitable for welding and painting.

Squeeze casting is often called a 'high integrity' process, because it imparts qualities to the metal that are difficult to achieve with GPM casting and conventional die casting. These improved qualities are: reduced porosity in the metal matrix, higher mechanical properties and enhanced wear resistance. In addition, squeeze castings can be heat treated, which is not possible with conventional die castings.

Thicker runner systems and particularly, large in-gates are used compared to conventional die castings. The proper location of the in-gates and maintaining high pressure on the molten alloys, as well as the use of pressure pins (when needed) during solidification permit the casting to be solidified under significant pressure to avoid nearly all shrinkage. The high pressure during solidification keeps the molten metal in direct contact with the die surface providing true-to-die dimensions in the casting. The filling speeds, or in-gate velocities, are relatively low so that entrapped gas in the casting can usually be avoided with proper venting. The net result is a pore-free or nearly pore-free part.

Squeeze casting is a process that combines in a single operation the desired features of both casting and forging. The major attractions of the process are the potential cost reduction when compared with forging and the metallurgical advantages obtained when compared with other manufacturing techniques.

It has been shown that the squeeze casting process could produce sound and fine equiaxed grain structures with most of the conventionally used cast alloys, and even with those compositions normally restricted to use in the wrought form. This sound cast structure is bound to give the material isotropic properties.

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 minimising secondary machining operations. Much effort goes into the improvement of the efficiency and function of automobiles. These improvements often bring about an increase in the weight of vehicles and the decrease of engine performance, which results in poor fuel consumption. In the meantime, the demands for reducing the weight and poor fuel consumption of vehicles continues to increase to cope with global environmental issues.

Replacing steel with aluminium is one of the valid means of meeting these demands. Aluminium die casting products are mainly used for structural parts, such as engine blocks and transmission cases. The use of die casting products is now spreading into the area of critical safety parts, such as suspension and space frames, where high degree of strength, elongation and yield strength are required.

The squeeze casting process is widely used to make thick-walled aluminium casting components with sound mechanical properties. Because the high pressure, high velocity die casting process tends to entrap gas, due to turbulent metal flow, squeeze casting becomes a natural option for those applications requiring high quality castings.

Challenges for Squeeze Casting

The NADCA publication #404 High Integrity Die Casting (Sound, Reliable & Heat Treatable) states that the challenges faced by the squeeze casting process are as follows:

Cavity Count Limitation

Due to the metal pressures that are achieved during squeeze casting, attention must be given to cavity count limitation during the design of the squeeze casting die. The number of cavities must be limited so that the force generated does not exceed the locking force of the squeeze casting machine. The total projected area of the cavities, runner system, overflows, and vent system must be calculated. The metal pressure required to produce sound castings must be estimated and multiplied by the projected area to make sure the locking force is not exceeded. Simpler casting designs can often be produced with lower metal pressure, so they can sometimes have a higher number of cavities than similar sized, complex designs.

Cavity Orientation for Bottom Filling

The ideal location for in-gates in the squeeze casting process is at the bottom of the casting. In some cases, arranging the castings in the die to achieve bottom filling can limit the cavity count in the die.

Minimum Section Thickness

Due to the relatively slow shot speeds and long cavity fill times of the squeeze casting process, heat loss during filling can be significant, which can lead to casting defects such as poor-fill, lamination and laps. Therefore, a minimum wall thickness in the range of 4 mm to 5 mm is generally recommended for squeeze casting. Thinner walls can successfully be cast by increasing shot speed or metal temperature, but this increases turbulence and increases the likelihood of entrapped gas and oxide defects.

Trimming

One disadvantage of the large gates associated with squeeze casting is that the runner system cannot be easily removed from the castings. The runners must be removed using a saw incorporated in the trim die, or in a secondary operation. This adds complexity to die trim, resulting in higher costs, increased maintenance and potential for increased downtime.

Yield

Yield is a term used to describe the ratio of usable casting weight to total shot weight. Due to the large runner systems required, the squeeze casting process often produces lower yields than HPDC. This means that more metal needs to be melted for a given casting weight, which reduces efficiency.

Limited Die life

The lifespan of cavities used in the squeeze casting process is often somewhat shorter than the lifespan of cavities used in other casting processes, such as HPDC. Several factors contribute to shorter cavity life.

In squeeze casting, higher molten metal temperatures are often needed to accommodate slower cavity fill times, so that premature solidification does not occur. Many squeeze castings have very thick walls (one inch thick or more) that take much longer to solidify, so longer dwell times are needed.

The combined effect is that a tremendous amount of energy must be transferred from the cast material through the cavity steel with each shot. This heat needs to be removed from the cavity as quickly as possible to help minimise cycle time, so the squeeze casting cavity tends to have more cooling channels and larger cooling channels when compared with other casting processes.

Higher thermal gradients result in higher thermal stresses. Thermal loads, combined with the cyclic nature of the casting process, produce a challenging environment for tool steels. Significant stress from the clamping pressure of the machine and from the metal pressure only adds to the problem. Particular attention must be given during die design to minimise stress and reduce the potential for premature failure. Also, because some alloys used in squeeze casting have low iron content, die soldering can be an issue. All of these factors contribute to lower cavity life, which can be less than 10,000 shots even when constructed of premium tool steels, such as H-13. For non-premium tool steels, cavity life can be significantly less.

Future

With the current emphasis on reducing materials consumption through near-net shape processing and the demand for both higher strength and high ductility parts, the emergence of squeeze casting as a production process has provided a solution to these requirements. In recent years, squeeze casting has found production application in the USA, United Kingdom and Japan.

Industry experience with squeeze casting is growing rapidly. Squeeze casting was initially marketed for components that were experiencing problems as conventional castings. This might have been because of design limitations, new applications resulting in higher loads, increased requirements for pressure tightness or the desire for improved reliability at the customer end. Following this initial thrust in the market, the next growth areas were replacements for aluminium forgings or as conversions from ferrous castings, such as ductile iron.

While smaller tonnage machines are often used in Japan, with perhaps a more diverse customer base, the primary applications for squeeze castings in the USA are automotive. These applications are motivated by the need for weight reduction in vehicles. This need results in conversions from iron to aluminium and the need for reduced cost and this, in turn, results in the conversion of existing processes such as forging and permanent mould to new processes. The automotive products are predominantly steering and suspension components, like steering knuckles and control arms, and air conditioning parts. Where fatigue and ductility are the important component characteristics, squeeze casting is the preferred process.

As experience with squeeze casting in the industry is augmented with technical knowledge, there is a tremendous opportunity for the growth for squeeze castings. In the past, the process has been applied to improper parts or inadequate designs and the results have been very disappointing. However, as a better understanding of the capabilities of the process is developed, and technically sound models and algorithms are created for optimising squeeze casting, new applications will meet or exceed expectations every time.

Squeeze casting parts and components can replace conventional automobile parts made of cast iron and pressed steel.

It was stated at the *Indirect Squeeze Casting: The HotShot Process*, NADCA 1995 conference that the mechanical properties of the squeeze cast 7010 Alloy have been comparable to wrought alloys.[xxvi] Increasing the pressure above the critical value reduced casting defects, such as shrinkage and gas porosities. Additionally, the increase in pressure results in structural refinements, which allow the tensile properties to be comparable with wrought aluminium.

The squeeze casting process is one of the methods of producing castings that has the ability to make a sound casting that can be heat treated and welded. However, this requires that the process be able to produce a casting without defects that has a sound structure. It will require the control of many features including the in-gating, the fill time, the pressure and the quality of the metal produced.

As pointed out by Alex Monroe of NADCA that Horizontal Squeeze Casting (HSC) machines have a horizontal die clamping arrangement. The shot system can have a horizontal or vertical orientation and this defines the HSC process and HVSC process. The HSC process is often used due to the similarities between conventional HPDC and HSC machines. Conventional HPDC machines can be converted to HSC machines by slightly modifying the shot system. This is often the desirable option since purchasing new die cast machines is often avoided when it can be.

When near-net shape capabilities of the squeeze casting process are exploited, considerable cost savings can be realised.

Automakers throughout the world are urgently redesigning and retooling to produce smaller, lighter vehicles that will cost less and use less fuel. The fact that if the weight of a vehicle is reduced by 10 per cent, the fuel consumption is reduced by six to eight per cent, means that the strength-to-weight ratio of steel, plastic and aluminium for every component of these new models is now being carefully compared. This will inevitably results in an increased demand for die cast aluminium products.

A lighter car using less fuel and producing less greenhouse gas emissions is almost as important as its reduced cost of operation. Also, the recyclable potential of aluminium products is attractive.

Success Story of Squeeze Casting

Examples of squeeze casting—where it was applied with success. The following successes were listed by William A. Butler in Die Casting Engineer an an article called *Research in Action: Squeeze casting and Semi-solid Metal Processing.*[xxvii]

- *Crankshaft Hub: Converted from cast iron to reduce weight. Cast in A390 alloy with T6 heat treatment. Customer requirements include requirements for no blisters and uniform distribution of primary silicon particles.*
- *Lower Control arm: Converted from ductile cast iron to reduce weight. Cast in A356 alloy with T6 heat treatment. Customer requirements were material strength, impact and fatigue performance equal to the previous ductile iron part.*
- *Steering Column Housings: Converted from conventional 380 aluminium and zinc die castings to reduce weight and improve impact strength.*
- *Hydraulic System Housings: Converted from cast iron to reduce weight. Cast in modified 383F aluminium with T6 temper. Customer expectations were no blisters, pressure tight, uniform hardness and good machinability.*

Dr Iyer believes that these success stories will encourage Australian die casters and car manufacturers to adapt squeeze casting process on a larger scale.

Knowledge Transfer: Applying the Outcomes

Primarily, what comes to mind is the continuing problem of ‘technology transfer’ or the ‘resistance to change’ challenge.

The challenge will be to establish, develop and implement a model of training that will be best practice and produce world standard graduates who will be both experts and leaders in using squeeze casting technology.

- Development for manufacturing courses at TAFE/VET institutes and promote and deliver professional development training for practitioners in industry. Cooperation may be needed with the relevant Industry Skills Councils.
- Lobby for the development of a research practicum laboratory to further investigate and develop best practice for squeeze casting.
- Participate in national forums exploring squeeze casting technology for the die casting industries.
- Provide short courses tailored to the die casting industries.

Distribution of this Report

The report will be sent to Manufacturing Skills Australia (MSA), Manufacturing and Industry skills advisory board (MESAB), Australian Die Casting Association (ADCA), CAST CRC, die casting industries and other government, industry and education stakeholders. Dr Iyer will be available to further discussion the issues highlighted in this report. This report will also be available through both ISS Institute and RMIT, which will facilitate the sharing of information with a broad audience.

Workshops and Conferences

There will be presentation at future ADCA meetings. Dr Iyer will also be organising a presentation for RMIT TAFE teaching staff. As RMIT is opening an Advance Manufacturing centre in the near future, this presentation will timely.

Teaching

The entire Fellowship experience has greatly influenced Dr Iyer and she is planning to share the skills and knowledge gained with students studying in the Manufacturing Technology area. These TAFE students will be taught squeeze casting processes in detail within the appropriate Manufacturing subjects, increasing their employability.

Dr Iyer is actively seeking speaking engagements with industry associations and educator networks in order to promote the development of squeeze casting in Australia.

Recommendations

Government

Government can play an integral part in the development and transformation of the die casting industry. This can be realised in number of ways:

- Provide funding for research on squeeze casting to be done in partnership between die casting industries, the CSIRO and educational Institutes.
- Assist educational institutions to set up research facilities in squeeze casting.
- Actively encourage industry to take up squeeze casting technology, so that it can become internationally competitive.

The lack of squeeze casting research in Australia is due to a lack of applied research in general, as emphasis is more on commercial research for specific companies.

Industry

- Invest in squeeze casting technology, to enable international competitiveness.
- Invest in research into squeeze casting technology to create new composite materials.
- Conduct research into the development of parts created using squeeze casting.
- Conduct research into converting automotive parts from iron and steel to lightweight aluminium.
- Apply this new technology in new fields.
- Die casting companies need to upgrade their internal technical expertise to meet these challenges.
- Conduct research into using this technology with wrought alloys. This would then lead to parts produced by squeeze casting having same properties as forged parts.
- Work with the educational establishments and the CSIRO for future research, to provide equipment for education and research, and to train personnel ready for industry.
- Industry and TAFE institutes need to work together so that the training that takes place at the TAFE institutes is relevant to the requirements of industry.
- Future Fellowships and joint collaborative projects to be organised through the ISS Institute. Business and training contacts have now been made in the USA that could be developed further.

Professional Associations

- Develop a proactive approach to squeeze casting technology.
- Encourage industry and Local, State and Federal Governments to take up the challenge of squeeze casting technology.
- Assist when the Training Packages are up for amendments and require squeeze casting technology to be written into the package as mandatory competency units.

Education and Training

- Education and training institutes have an important responsibility to be at the forefront of innovation and development. This Fellowship is a testament to the commitment to continue to research and work towards bringing innovation into the hands of future graduates.

  Consequently, based on the results of this research and investigation, Dr Iyer recommends that the squeeze casting process becomes part of the considerations in curriculum development for advanced manufacturing program enhancement.

- The TAFE system Training Package MEM05 regarding Metals and Engineering, has the following units of competency suitable for modification:
  – VBP 250 Set up Manufacturing Processes for Engineering Applications
  – Under section 5.1 of the competency ‘Required skill and knowledge’ in the Training Package MEM05, the engineering process should include the words ‘squeeze casting’.
- The office of the Curriculum Maintenance Manager to provide for a presentation on squeeze castingat one of the annual Engineering Senate conventions so that TAFE engineering teachers are aware of squeeze casting and how it compares with other manufacturing processes.

Dr Iyer will be available to meet and speak with representatives of Industry Skills Councils to take their findings into the curriculum at TAFE.

Business

RMIT is setting up an Advanced Manufacturing Centre that will open in 2010. This centre can play a role in facilitating the interaction between die casters whether they are in Australia or overseas. The Advanced Manufacturing Centre can procure or hire squeeze casting machines for facilitating research projects while building training capacity in TAFE at the same time.

Paul Robbins from CASTOOL stated, *“Today the product must be cheaper and better. In today’s business climate it is good to embrace the innovative technology absolutely necessary to compete with the overseas market.”*

Ways in Which the ISS Institute can be Involved

The International Specialised Skills Institute has the potential to utilise its many contacts to attract funding and work with government agencies, universities, TAFEs and professional associations to assist the growth of specialist skill development in this area.

Further Skill Deficiencies

Squeeze casting still has a long way to go and the immediate step will be to further investigate forging alloys and wrought alloys to be used by this method. Australian die casters can be ahead of other countries by researching and developing new components and using composites that will have far superior properties.

International exchange opportunities are open for further development by both business and education training institutions.

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