Institution: Queen's University, Belfast

Unit of Assessment: 12

Title of case study: New Method for Die Casting of Automotive Components Saves Energy and Material

1. Summary of the impact (indicative maximum 100 words)

Die Casting is one of the most widely used production processes for aluminium automotive components with examples including engine blocks and gear-box casings. **Ryobi Ltd** is the **world's leading die casting manufacturer.**

Researchers at QUB have developed a modified casting process with an optimised start-up procedure. Ryobi has implemented the new method across its entire UK facility's die casting machines **resulting in total yearly savings of approximately £1,000,000, 742 GJ energy** (enough to power 50 domestic homes) **and nearly 60 tonnes of aluminium.** This demonstrates clear economic and environmental benefits, which have further potential for global impact.

2. Underpinning research (indicative maximum 500 words)

Ryobi approached Queen's university for help in 2000 as they wished to gain a better understanding of die heat check cracking (low-cycle fatigue failure) with the objective of extending die life. At that time, the university had limited expertise in this area**. Dr Thornhill took the lead in establishing a research program with Ryobi.** Prior to academia he had been a designer in industry and had extensive experience of designing cast components and working with aluminium alloy foundries on new products and troubleshooting existing ones. **Professor Armstrong provided valuable support through his expertise in numerical simulation.** He has an international reputation for his work in computer aided engineering and in particular finite element analysis. He was also co-author of the standard undergraduate text "Mechanics of Engineering Materials".

Initial experimental research was carried out by Makoto Kurokawa, Ryobi plant manager, under the guidance of Thornhill and Armstrong. It was clear, however, that to make real progress a dedicated research associate was required. With funding from INI and Ryobi, Alastair Long joined the team in 2005. Long was a graduate of Queen's University but subsequent to his degree had spent six years in industry with another large foundry, Montupet, gaining significant expertise in computer simulation of the casting process.

A thermal fatigue test rig, designed by Thornhill and developed by Long, demonstrated that the dominant cause of die failure was the difference in temperature between the high point in the cycle and the low point. Computer simulation of the casting process using MAGMA casting simulation software predicted that the temperature differences were greatest when a die is first put into operation [1,2]. This was validated by instrumented production dies with thermocouples implanted close to the dies surface and strain gauges in pockets machined into the back of the die. It was demonstrated that it could take between twelve and fifteen casting cycles for the process to normalise and the corresponding fatigue loading to minimise [3,4].

David Watson took over as Ryobi plant manager in 2007 and facilitated experimental work on a

production casting machine that allowed Long to reduce the number of casting start-up cycles before the process normalises down to as few as five by management of the die cooling system during this crucial period [5].

3. References to the research (indicative maximum of six references)

Research outputs

1. Investigation of thermally induced die cracking for H13 High Pressure Casting dies using simulation methods. Long, Alastair; Thornhill, David; Armstrong, Cecil; Kurokawa, Makoto; Hendry, Arthur. Society of Automotive Engineers, 2007-31-0100.

2. *Determination of the heat transfer coefficient at the metal–die interface for high pressure die cast AlSi9Cu3Fe. Long, Alastair; Thornhill, David; Armstrong, Cecil; Watson, D. Applied Thermal Engineering , Vol. 31, 12.2011, p. 3996-4006. DOI: 10.1016/j.applthermaleng.2011.07.052

3. *Predicting die life from die temperature for high pressure dies casting. Long, Alastair; Thornhill, David; Armstrong, Cecil; Watson, David. Applied Thermal Engineering , Vol. 44, 2012, p. 100-107. ISSN: 1359-4311. DOI: 10.1016/j.applthermaleng.2012.03.045.

4. Stress correlation between instrumentation and simulation analysis of the die for high pressure die casting. Thornhill, David; Long, Alastair; Armstrong, Cecil; Watson, David. International Journal of Metalcasting , Vol. 7, No. 2, 2013, p. 27-41.

5. *The Impact of Die Start-Up Procedure for High Pressure Die Casting, Long, A., Thornhill, D., Armstrong, C., Watson, D., SAE Int. J. Mater. Manf. 6(3):2013, DOI: 10.4271/2013-01-0829

*Best three outputs

Grants

- **Original project (11/10/2005):**
  Extending die life of high pressure die casting dies, £1220k project, £418k to QUB (Thornhill, D; Armstrong, C), Direct industrial finding- Ryobi
- **Follow up project (19/10/2010):**
  Reducing part cost of aluminium die castings by minimising gate size, £1541k, £434k to QUB (Thornhill, D; Armstrong, C), Direct industrial finding- Ryobi

4. Details of the impact (indicative maximum 750 words)

The collaboration between Ryobi Aluminium Casting and QUB has enabled the company to develop knowledge and expertise in new areas which will have long-term benefits. John Hughes, managing director of Ryobi Aluminium Casting has stated "***The enhancements we've made to our processes as a result of this research and development project have not only created cost savings but put us in a stronger, more competitive position to target higher volume and longer term projects across Europe.***"

The extension to die life due to managing the thermally induced low cycle fatigue through die start up is between 20% and 50%. This manifests itself as less frequent die repair and a longer overall die life before it is considered non-viable. The reduced frequency of die repair will directly impact the overall equipment efficiency (OEE) of the die casting machine, though this will also be

influenced by reducing the number of scrap castings.

As castings produced during die warm up are of inferior quality they are scrapped. **The revised start-up procedure reduces the number of castings scrapped by as many as ten castings per die start up.** Although scrap castings are recycled, each time the metal is remelted up to 8% of the material is lost as it oxidises and forms dross. Additionally, it takes approximately 1 MJ/kg to melt aluminium so there is a significant energy saving from remelting less scrap castings.

The revised start-up cycle was tested at the start of June 2009 resulting in an immediate impact on scrap and the overall equipment efficiency (OEE) of the casting machine. The impact on production before and after its introduction is illustrated in Table 1.

Table 1, Summary of the changes due to the modified die start-up.

	OEE %	Scrap %	Parts cast	Part cost
Jan – April 09	66.62	11.5	34,871	£5.22
June – Oct 09	74.59	7	43,711	£4.57

The casting used for illustration in Table 1 has a production cycle time of 75 seconds and a production volume of 250,000 parts per year, on two casting machines. **Therefore the saving due to the reduction in part cost alone is equivalent to £81,250 per year per casting machine.**

The 4.5% reduced scrap rate increases the number of good castings that can be produced from the die within its normal working life. As a typical die life, before it is considered uneconomical to repair, is 100,000 parts and the manufacturing cost is of the order of £200,000 this represents **an additional saving per year per casting machine of £13,675.** This does not include savings made by extending the die life due to reducing the thermally induced fatigue stress.

The shot weight per casting is approximately 12kg. As there is 4.5% less scrap this represents 67.5 tonnes of metal per casting machine per year that isn't remelted, saving 67.5 GJ of energy and potentially 5.4 tonnes of material saved due to reduced dross loss.

Since 2009, Ryobi has rolled out the new casting start-up method across the Carrickfergus factory's eleven die casting machines. **Assuming similar savings on all casting machines, this represents total savings of approximately £1,000,000 per year, 742 GJ energy saving and nearly 60 tonnes of aluminium alloy not reduced to dross.** At the same time there is a small but useful increase in factory capacity due to the increased OEE.

5. Sources to corroborate the impact (indicative maximum of 10 references)

1. Belfast Telegraph Newspaper article (10th July 2013): http://www.belfasttelegraph.co.uk/business/business-news/japanese-companys-links-with-queens-university-pays-off-29408160.html

2. Plant Manager
RYOBI Aluminium Casting (UK) Limited, Carrickfergus

3. SAE Paper 2013, The Impact of Die Start-Up Procedure for High Pressure Die Casting (joint QUB/Ryobi publication http://papers.sae.org/2013-01-0829/

4. Invest NI press release (9th July 2013): http://www.investni.com/newsstory.htm?newsid=18246