A LIFE CYCLE INVENTORY OF ALUMINIUM DIE CASTING

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As part of an ongoing project, a life cycle inventory (LCI) of aluminium high pressure die casting (HPDC) has been collected. This has been conducted from the view of an individual product and also the entire process. The objective of the study was to analyse the process and suggest changes to reduce environmental impacts. One modern aluminium high pressure die casting plant located in Victoria, Australia was evaluated and modelled. Site specific data on energy and materials was gathered and the process was modelled using a typical automotive component. The paper also presents our experience and methodology used in this inventory data collection process from the real industry for LCA purposes. The inventory data collected itself reveals that the HPDC process is energy intensive and as such the major emissions were from the use of natural gas fired furnaces and from the brown coal derived electricity. It is also found the large environmental benefits of using secondary aluminium over primary aluminium in the HPDC process. A detailed LCA is being carried out based on the inventory obtained.

1 Introduction

Aluminium die casting is a manufacturing process used to form complex shapes in which molten aluminium is fed into a steel die to solidify. These castings can have a variety of uses from automotive engine blocks to electronic components. Four million tonnes of aluminium is high pressure die cast each year globally with the industry growing world wide.

Whilst a lot is known and researched about the die casting process itself, very little is known about the environmental consequences of the process. How much aluminium die casting contributes to global warming is a question which is increasingly becoming more important. Life-cycle Assessment (LCA) is a technique that has become common in assessing the environmental impact a product or process. By detailing all of the inputs and outputs to the process or product, a value can be placed on the environmental impact of the process or product. By doing this type of analysis it can also be seen where improvements can be made to lessen the environmental load created by the manufacture of the product.

This paper describes the intermediate phase of an LCA, the Life-cycle Inventory (LCI). This is the collection of all of the data without the full analysis of normalisation and weighting. An LCI allows the amounts of each of the inputs and outputs of a process to be shown in a raw form. This enables only a rough analysis but is useful to show high usage or wastage as is the case with this study.

2 Methods

This study was performed in accordance with the ISO14040 series of standards for LCA[1]. Site specific data was gathered from the site of one aluminium die casting plant. As many inputs as data was available for have been used in this study and all emissions have been included from the site where possible.

2.1 Site - High Pressure Die Casting Plant

The site where all of the data was collected is located in Victoria, Australia. All of the die castings made in the plant are for automotive use. The site has an annual production of 7000 tonnes of aluminium per year and all of the data collected for this study was for the year 2001.

2.2 *Process - High Pressure Die Casting*

The high pressure die casting (HPDC) process was chosen as it is one of the major casting processes used by the automotive industry to manufacture aluminium components. The HPDC process as used at this site has been broken down into seven major parts as can be seen from Figure 1.

The 'ingot' phase consists of aluminium ingots or molten aluminium delivered to the plant and for this study includes the secondary aluminium supplier. The 'melting' of the ingots or storage of the molten aluminium in the second phase of the process, was accomplished in natural gas fired reverberation furnaces. It will be raked and cleaned to remove the dirty metal and dross. A fork truck was used to move the metal from the reverberatory furnace to the holding furnace at the machine. The metal was cleaned between these two furnaces using a flux and nitrogen gas and the metal was held at the machine in a natural gas fired crucible furnace. A robotic arm with a ladle attached transfers the metal from the furnace to the shot sleeve of the die casting machine.

During the casting phase a piston moves behind the metal that has been poured into the shot sleeve, forcing the metal into the die at very high pressure. After the metal solidifies the pressure is released and the die opens. The part is ejected and removed from the die and the die faces sprayed with a release agent generally known as die lubricant so as the aluminium will not stick to the die. The number of finishing operations available to a die casting is very extensive but nearly all die castings will be trimmed to remove the biscuit and runners that are then recycled within the plant. From here the casting can go through common operations such as fettling and shotblasting to remove sharp edges and loose aluminium. All castings are packed in or on something to be shipped to the customer.

For this study an automotive transmission cover manufactured at the site was followed through the high pressure die casting process. The casting selected was cast in a twin cavity die and had a shipped weight is less than 1 kg.

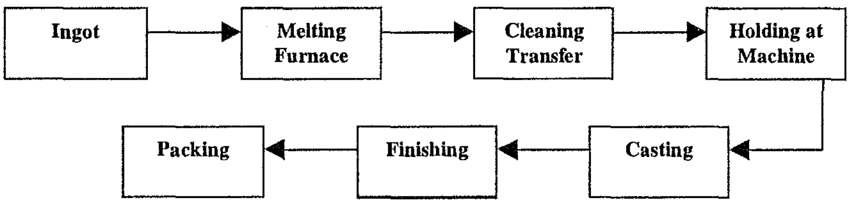

Figure 1. Die casting process

2.3 *Functional Unit and System Boundary*

The functional unit for this study was per 1 kilogram of aluminium shipped. This unit broadly describes the process and all data was scaled to fit this unit.

The system boundary for this study was considered to be the plant / site boundary. Transport of all inputs into the process has not been considered and also transport of the finished product to the customer has not been considered. All activities within the site have been considered. Capital equipment has also not been studied. Where data has been available, the system boundary has been extended to cover energy sources and materials such as the secondary aluminium used at the site.

2.4 *Data Collection*

The process was broadly described and then detailed so as not to exclude any items that were used in the plant or in the manufacture of the component under study. The process was broken down into its individual components as described earlier. By analysing each of these units separately, all of the inputs and outputs were captured.

Data capture is the most time consuming part of any life cycle inventory. As the data will vary for different localities, time must be taken to ensure that the data used is relevant. Site specific data was captured by collecting all data from the stores. This ensured that all items used in the plant could be captured. Of the 3000 items listed in the stores only approximately 250 were considered for the study because of other processes used at the site and also items that were of low volumes were also discarded or grouped together. This data was then compared with knowledge from the personnel at site for consistency. Any data that conflicted has been adjusted as per the site's internal standards.

All electricity, natural gas and water use was collected for the plant. Furnaces were monitored where possible and meters placed on equipment to determine exact energy usage. Where this was not possible estimates have been used based on equipment ratings, motor sizes, burner sizes and old data. Any extra data that is not generally found was also collected. Major repairs to capital equipment was also collected such as furnace refractory replacement.

All of this data was sorted and entered firstly into a spreadsheet and then into GaBi3v2 [2] life cycle software. Using this software and it's associated database enabled the inputs and outputs from the process to be effectively grouped and overall results gathered.

2.5 *Allocation*

A specific component was followed through the process so as all inputs and outputs could be allocated to the functional unit. An activity based allocation method has been used with actual amounts of all inputs measured. Where possible outputs were also measured but it was more common to calculate these from the inputs. Where measurement was not practical, amounts were allocated by the functional unit in relation to the rest of the plant.

3 Results

When recyclable metals are removed, all other outputs from the process go to waste (landfill, air and water emissions, etc.). For each kg of aluminium shipped, 8.6 MJ of natural gas and 5.8 MJ of electricity is consumed in the plant. This is broken down according to Tables 1 & 2.

Table 1. Natural Gas Use per Casting

Process	MJ
Holding of Molten Metal	1.174
Remelt of Scrap	5.194
Holding at Machine	2.048
Other	0.184
Total	8.600

Table 2. Electricity Use per Casting

Process	MJ
Casting Machine	1.843
Air Compressors	0.999
Cooling Water	0.646
Heat Treatment	1.548
Other	0.796
Total	5.832

For this study the results were broken up into many categories. The results for the categories of Global Warming Potential Over 100 years (GWP 100) and Human Toxicity Potential (HTP) are presented in Table 3.

Table 3. Global Warming Potential and Human Toxicity Potential Results

	GWP 100 (CO_2 Equivalent)	HTP (DCB Equivalent)
Electricity	0.8181	0.004541
Natural Gas	1.1451	0.002651
LPG	0.0191	0.001391
Aluminium Supply	1.0629	0.003157
Other	0.0040	0.000155
Total	3.0492	0.011895

The GWP results are all emissions to air and are all from energy production and use. The large amount of natural gas used is because of a cost advantage over electricity. All electricity used is considered to be from base load power that is generated by brown coal fired power stations in Victoria. The HTP results are a combination of releases of substances such as heavy metals into the air, water and to land. These are also generally released from energy production and use. Other items considered for the study such as Acidification Potential also showed a relationship to energy. The large amount of water used in the process is the only result that was high and not directly related to energy production or use.

4 Discussions

4.1 Methodological Considerations

The LCI methodology requires everything to be allocated by the functional unit. By using the functional unit of per kilogram of aluminium shipped for the study has introduced a large variation that makes the study an inaccurate generalisation for the process.

Using this functional unit does imply correctly that for every kilogram of aluminium shipped there is more than one kilogram of aluminium melted and used. Metal losses such as dross will vary according to how much aluminium is melted and cast. Although these have been allowed for in the study, actual results will vary from cast product to product. The yield of the casting (how much is shipped divided by how much is cast) changes from casting to casting and this has been found to create a large variable in the results.

4.2 Process Variations

The Aluminium HPDC process itself has approximately 200 variables that can be modified and will have an affect on the outcome of the LCI. From the results it was found that the amount of scrap that was remelted from each casting is the variable that had the single biggest affect on any of the categories measured. This can vary by up to 10% for each individual casting produced at the site. A 10mm increase in scrap length will result in a 1% increase in CO_2 emissions. The variation within the process itself, the range of suppliers of materials to the site, all the way to energy used at the site and its variability make it erroneous to take absolute numbers from the results. The numbers will not be repeatable and will vary from casting to casting and site to site.

4.3 Data Accuracy

The most important area of a LCI is the data. Access to 'real' data makes this study more accurate than otherwise possible. Actual usage of all major materials, reliable data from energy sources local to the plant and reliable data from the secondary aluminium supplier is the strength of this study. A reliance on LCA data with unknown origins is the weakness of this study and the LCA technique.

Any study is only as good as the data used. For most of the materials entering the site actual data was not available and estimations from available databases have been made. When available, data is in aggregated or disaggregated form. If aggregated the user has no knowledge of the data except for the end result. This data, although not preferred, must sometimes be used and will lead to inaccuracies with any LCI or LCA study. With data being variable in areas such as location, time, method of collection and storage it will continue to be the weakest link in the LCA area of study. Within the Life Cycle Assessment scientific community this is a known challenge and is being confronted by a United Nations initiative.

5 Conclusion

A Life-cycle Inventory is a useful tool to determine the environmental consequences of a product. In the case of this study it has been applied to an individual component with an accurate result. The further Life-cycle Assessment will further reveal the environmental impacts of the inventory. When the results from an LCI or LCA are taken from one product and applied to the process used to manufacture the product the results can be flawed. To generalise the HPDC process by studying one component will lead to incorrect findings.

By analysing the findings for the one component can lead to improvements to the process as used to manufacture this one component. It can be seen from the LCI that wastage is high in the process and this is one area for improvement. Energy usage is also high and the majority if the inventory comes from this area and any improvement will reduce the impact this product has on the environment.

An LCI and LCA when conducted on aluminium high pressure die casting should not be used as an absolute tool but should be used as a comparative tool concentrating on the individual product and not trying to generalise the process by which it is made.

Further work in this study will be the LCA of this component with the addition of cost into the assessment as this is one of the biggest driving factors for improvement for the site where this work was conducted.

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