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# COMPARISON OF THE ENVIROMENTAL IMPACT OF THE CRIMSON PROCESS WITH NORMAL SAND CASTING PROCESS

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## ABSTRACT

The CRIMSON process is an alternative process to conventional casting that can be used for small to medium batch sizes. The aim of this process are to improve the casting quality and reduce the energy consumption within light-metal casting industry. Nowadays, the energy efficiency becomes more and more important. This is not only about the cost of the production, but also about the environmental effect. In this paper, the CRIMSON process will be compared with the conventional sand casting process. The Life cycle assessment (LCA) method will be used to assess the environmental impact of both casting processes.

**Keyword**: CRIMSON, casting, energy saving, Life Cycle Assessment

## 1 INTRODUCTION

The CRIMSON (Constrained Rapid Induction Melting Single Shot Up–Casting) process has been invented by the researchers and engineers from both Cranfield University and a UK company, N-Tec Ltd. The philosophy of the CRIMSON process is to melt just enough mass of alloy in a closed crucible of an induction furnace and to use a counter-gravity filling method to fill a single mould and thus ensure smooth liquid alloy flow behaviour and at the same time avoid unnecessary energy consumption. The process features rapid melting, minimal holding time and counter-gravity filling hence reducing the opportunity for hydrogen absorption and generation and entrainment of surface oxide films. This is a relatively new technology, and thus no previous studies have been reported on the Life Cycle Assessment (LCA) of the process. In this paper, the authors will compare the environmental impact of the CRIMSON process and the conventional sand casting process through LCA simulation.

## 2 LIFE CYCLE STUDY

### 2.1 Goal and scope

The principal goal of the LCA study is to assess the environmental performance of the CRIMSON process and the conventional casting process. In contributing to this goal, a tensile test bar is used to assess the envirmental performance of both casting processes. The life cycle of the production system of the tensile test bar is a collection of the three life cycle stages which includes: raw material production, manufacturing, and recycling. Because same product is produced by both casting process, the use phase of the tensile test bar is not included in this LCA. Three impact assessment methods are considered in this study, Gas Protocol, Eco-indicator and Eco-points. All of impact categories are used to assess the environmental impact over the total life cycle.

## 2.2 System boundaries

In order to provide a clear impact comparison of the CRIMSON process and the conventional process, the system boundaries have been defined for both casting processes. For both casting processes, the material and energy required for each operation were involved. However, due to complexity of the mould making process, the embedded energy was adopted to represent mould making process.

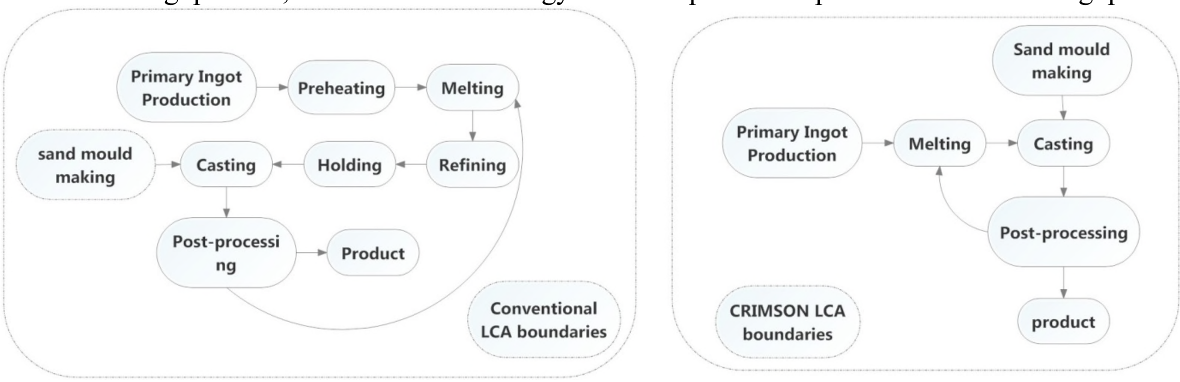


Figure 1 System boundaries for both casting process

## 2.3 Inventory data collection

Inventory data collection requires production data from cradle to grave. It is the most intensive and demanding task in the LCA. Taking into consideration the system boundaries, the required data for LCA can be identified and collected. The energy and material consumption for primary ingot production were hard to reach. Therefore, the existing LCA simulation package inventory database was used as a source. For sand mould making process, a spreadsheet was developed to measure and estimate the embedded energy Besides the energy consumption, the spreadsheet also estimates the quantity of the material going through every single process.

# 3 SIMAPRO SIMULATION

SimaPro is Life cycle assessment software, which is the leading LCA software chosen by industry, research institutes, and consultants (PRe). It has the most complete life cycle inventory database for different industry sectors. For casting foundry sector, following data is available: caustic soda, limestone consumption during alumina extraction; anode, cathode carbon, and aluminium fluoride consumption during electrolysis; inert gas and aluminium additive consumption during ingot casting; energy consumption during entire process and emissions (IAI, 2007). A LCA simulation forms by the assembly and waste scenario. Assembly deals with production stage of the products. It should include all the resources, parts / components and processes to make products. The waste scenario is the use phase and end life of the products. It includes different scenarios such as landfill, recycle, incineration and so on.

## 3.1 Data input for simulation

The purpose of the analysis is to compare the environmental impact for different casting process. There are four types of models need to be investigated. First model is the conventional tensile test bar casting without recycling, the second model is the CRIMSON tensile test bar casting without recycling, the third model is the conventional tensile test bar casting with recycle, and the last model is the CRIMSON tensile test bar casting with recycle. For non-recycle models, the primary aluminium ingot inventory data was used as metal input; for recycle models, the secondary aluminium ingot from automotive scrap inventory data was used as input.

### 3.2 Simulation setup

For normal approach, the impact assessment is used to assess the production, use phase, and end life environmental impact of the product. In other word, the normal approach assesses the impacts only related to final products. Clearly, the recycling in this study refers to reuse the high energy content metal removed from fettling, machining, and scrap. It is not simple as reuse the tensile test bar during a end life phase. Therefore, a special LCA model was developed in SimaPro in order to assess the environmental cost of raw material extraction, production, and in-house recycling.

In order to redefine the definition of recycle in SimaPro, a complex model needs to be developed. There are two difficulties to develop such model in SimaPro. First issue is to separate recycled, non-recycled material, and other material. In the normal approach, all material pass through process without any classification. In fact, the material is composed by recyclable material, non-recycle material and others. The second issue is to make SIMAPRO understand each material has a different waste scenario. Once separated the material into different categories, these categories have to be defined with an associated waste scenario. In SimaPro, one assembly has only one corresponding waste scenario. In order to define the different waste scenario to different categories, multiple assemblies are needed.

According to literature (Jolly, 2010), the metal loss during the casting process has been presented in Table 1. The loss in melting, holding, and degassing operations are oxidation and impurities loss. It can be treated as permanent loss. The metal loss during fettling, machining, and inspection are high energy content scrap metal. They can be recycled to reduce the virgin aluminium requirement. Therefore, the raw aluminium input can be divided into three categories: permanent loss, scrapped, and final product, which refers to non-recycle, recyclable, and others.

Table 1: Metal loss during each step of casting operation for the CRIMSON and the conventional casting process

| | CRIMSON test bar | | Conventional test bar | | Loss type |
|---|---|---|---|---|---|
| | Weight loss % | weight remain (kg) | Weight loss % | weight remain (kg) | |
| raw material | 0 | 6.53 | 0 | 12.68 | Permanent, can be disposed |
| melting | 0.5 | 6.53 | 2 | 12.68 | Permanent, can be disposed |
| holding | 0 | 6.49 | 2 | 12.43 | Permanent, can be disposed |
| degassing | 0 | 6.49 | 5 | 12.18 | Scraped, can be recycled |
| fettling | 60 | 6.49 | 77.5 | 11.57 | Scraped, can be recycled |
| machining | 25 | 2.6 | 25 | 2.6 | Scraped, can be recycled |
| scrap | 10 | 1.95 | 20 | 1.95 | NA |
| good casting | NA | 1.56 | NA | 1.56 | |
| OME | 0.24 | | 0.12 | | |

Beside the metal input, sand is also used to make test bar. Assuming the metal and sand ratio is 1:6 for the tensile test bar sand casting. The sand required for sand mould is 40 kg for the CRIMSON test bar, and 76 kg for conventional test bar. The material input for sand mould also split into two categories: sand can be recycled and sand can be disposed. According to research, 90% of the sand can go back to the process and 10% can be disposed to landfill. Assuming the metal and sand ratio is 1:6 for the tensile test bar sand casting. Based on table 1, the total material input to make casting test bar for both casting process can be categorised as shown in table 2.

Table 2: Total aluminium used to produce the test bar

| | CRIMSON Test bar | Gravity test bar |
|---|---|---|
| permanent loss (kg) | 0.03 | 1.12 |
| scraped (kg) | 4.94 | 10.01 |
| Tensile test bar (kg) | 1.56 | 1.56 |
| Sand will dispose 10% (kg) | 3.92 | 7.61 |
| Sand will recycle 90% (kg) | 35.26 | 68.53 |
| Total Metal(kg) | 6.53 | 12.69 |
| Total Sand(kg) | 39.18 | 76.14 |

### 3.3 The layout of the simulation

After splitting the material flow into different assemblies, the process flow for each assembly can be set up. For permanent loss metal, the process starts from raw material extraction and finish at holding process. For scrapped metal, the process starts from raw material extraction and end at finish process. For tensile test bar, it is the only assembly that goes through whole casting operation from raw material extraction to final shipment. Similarly, the process flow of the sand can be determined. Figure below shows the mind mapping of the simulation.

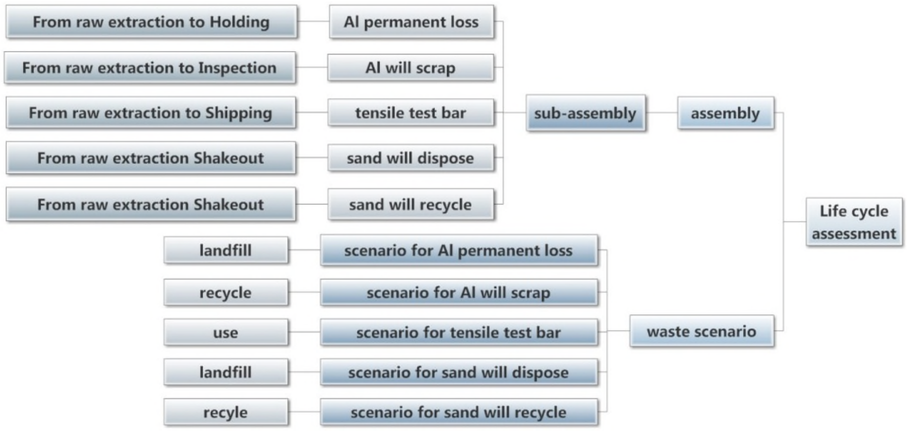


Figure 2: flow chart of new simulation

## 4 LIFE CYCLE IMPACT ASSESSMENT

### 4.1 Greenhouse Gas Protocol

The first impact assessment was focused on green house gasses (GHG). The methodology called Greenhouse Gas Protocol has been used to check CO2 emissions. Table 3 shows the GHG emission to make one set of tensile test bar. Table 3 also shows the emission results calculated from the author's spreadsheet. Ignoring the limitation of the spreadsheet (lack of data about early raw material extraction, therefore embedded energy was used), the spreadsheet results and the simulation results are considerably close.

Table 3: the CO2 emission result from the simulation and the spreadsheet.

| process | | spreadsheet (kg) | simulation (kg) |
|---|---|---|---|
| non-recycle | CRIMOSN | 88 | 108 |
| | Conventional | 172 | 210 |
| recycle | CRIMSON | 25 | 33 |
| | Conventional | 53 | 62 |

### 4.2 ECO-indicator

Besides the CO2 emission assessment, various environment impact assessments can be achieved by using SimaPro simulation package. In this project, two more LCA methodologies have been used for comparing the environmental impact of the conventional casting process and the CRIMSON casting process. ECO-indicator 99 HA was the first method adopted to assess the life cycle impact. It expresses the emissions and resource extractions in 11 different impact categories (Salonitis et al, 2006) and (Drakopoulos et al, 2009).

Total cumulative impact results are shown in figure 3. From the figure, the total environmental effect for each casting scenario can be seen. First of all, recycle sand and metal can reduce the environmental impact for casting process. 62% of impact can be reduced after recycling for the CRIMSON process, and 60% of impact can be reduced for the conventional process. Besides the influence of the recycle activity, the main purpose of the simulation is the comparison of the

CRIMSON process and the conventional cast process. From the result, no matter recycle activity applied or not, the CRIMSON process has less impact than the conventional casting process. 49% and 47% of impact can be reduced for non-recycle and recycle activity respectively.

The impact caused by individual process such as sand mould making and casting production also can be seen from the simulation result. Right side of Figure 3 is the environment impact contribution for each production processes.

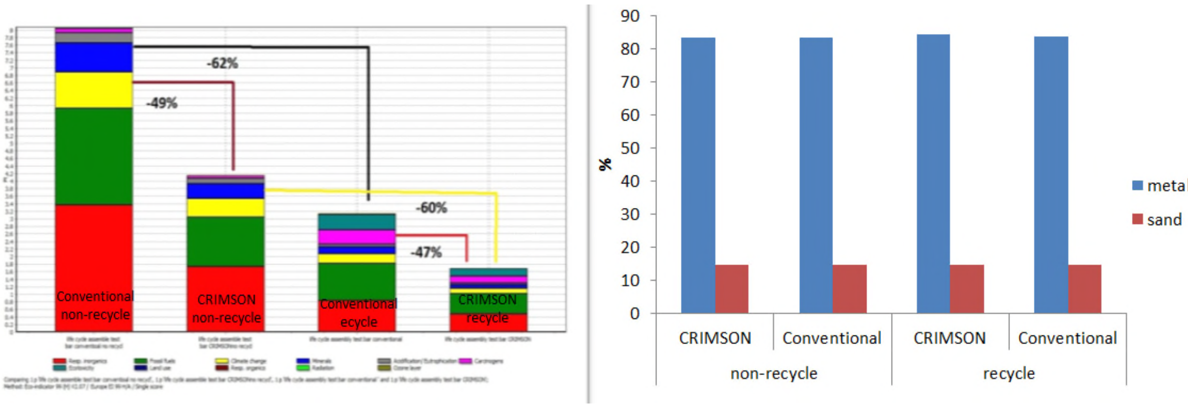


Figure 3: ECO-indicator single score results for four casting scenario

### 4.3 ECO-points 97

The ECO-Points 97 is the second method used in impact assessment. It is based on actual pollution and on critical targets that are derived from Swiss policy (SimaPro). This means that the emission results are compared with the target values set by government (Konstantinos Salonitis, 2006). After the weighting factor is applied, the comparison of the CRIMSON process and the conventional casting process is shown as below. From the table 6, it can be seen that the major contributor the environmental pollution are the NOx, the SOx, NMVOC, the NH3, Dust PM10, and CO2. Furthermore, these gases are the resource for global warming.

Left side of Figure 4 is the single score for four casting scenarios. Again, the recycle activity reduces the environmental pollution about 55%. As it can be seen for the comparison between the CRIMSON Process and the conventional casting process, it has similar results like ECO-indicator. Same as ECO-indicator, the impact caused by individual process such as sand mould making and casting production also can be seen from the simulation result. Right side of the Figure 4 is the environment impact contribution for each production processes.

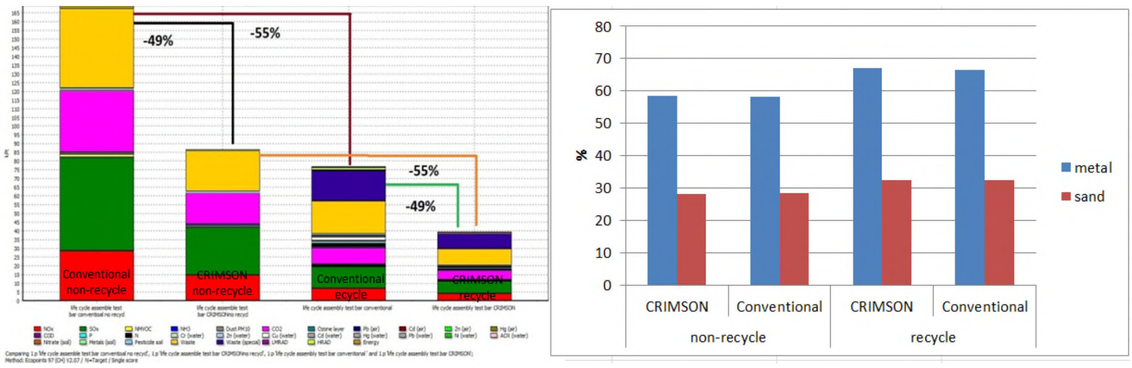


Figure 4: ECO-point single score results for four casting scenario

## 5 DISCUSSION

It was found that the CRIMSON process has less impact compared with the conventional casting process. In fact, no matter which impact assessment method is used, the environmental impact for the CRIMSON is about half of conventional one. Such result is quite interesting because it match with the metal input as table 2 shows. It means that the environmental impact is mainly influenced by the metal input. In fact, this should be expected because the aluminium data used is the primary ingot produced in plant. In reality, such production includes a refinery, a smelter and an ingot casting plant. Compared with ingot production from bauxite, the resource and energy input to make tensile test bar is very insignificant. According to evidence shows in SimaPro inventory database, the secondary production only account for 2% of primary production energy consumption. Therefore, the impact results are mainly influenced by the amount of primary ingot input

Furthermore, if we investigate why metal input are different for both casting process. It can be found that everything is related to Operational Material Efficiency (OME). The OME for the CRIMSON and the conventional process are 23.9%and 12.3%. Therefore, the CRISMON process only use half of metal to produce same casting compared to conventional process (table 2). The associate energy consumption also halved. Meanwhile, because of the OME, the sand demand and associate process energy for CRIMSON process also halved (table 2). Since all of the input data for the CRISMON process were halved, its environmental impact also halved.

## 6 CONCLUSION

In reality, the materials that go through the casting process are not split. However for the purpose of investigating recycling influence, it is useful to split the material flow as table 2 shows. This ensures alumina and dead sand send to landfill, scrapped metal and reusable sand send to recycle, test bar send to customer. The difficult of modelling recycle model is solved. Mind mapping shows at figure 3 is the logic of the simulation model. Each sub-assembly has its process input and resource input according to the data shows in table 2. Gathering all the sub-assemblies, the Life Cycle of the casting process can be assessed.

In this paper the LCA methodologies have been used for comparing the environmental damage of the CRIMSON process and the conventional casting process. Because of the operational material efficiency, tensile test bar made by the CRIMSON process only use half metal compared with the conventional process. Furthermore, because the metal input reduced, the corresponding sand, energy and other consumables also reduced. Therefore, the CRIMSON process only has half of the environmental impact compared with the conventional process.

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