

---

## Comparison of conventional injection mould Inserts to Additively Manufactured inserts using life cycle assessment

Thomas Hofstätter<sup>1\*</sup>, Niki Bey<sup>2</sup>, Michael Mischkot<sup>1</sup>, Andreas Lunzer<sup>1</sup>, David Bue Pedersen<sup>1</sup>, Hans Nørgaard Hansen<sup>1</sup>

<sup>1</sup>Department of Mechanical Engineering, Technical University of Denmark, DK-2800 Kgs. Lyngby, Denmark

<sup>2</sup>Department of Management Engineering, Technical University of Denmark, DK-2800 Kgs. Lyngby, Denmark

\*thohofs@mek.dtu.dk

---

### Abstract

Polymer Additive Manufacturing can be used to produce soft tooling inserts for injection moulding. Compared to conventional tooling, the energy and time consumption during production are significantly lower. As the life time of such inserts is significantly shorter than the life time of traditional brass, aluminium, or steel inserts, multiple inserts might be needed to produce a large number of parts.

In an ongoing study, a simplified Life Cycle Assessment has been carried out in order to provide information on how the four alternative insert materials perform in comparison in terms of their potential environmental impact and yield throughout the development and pilot phase. Insert geometry is particularly advantageous for pilot production and small production sizes.

In this research, Life Cycle Assessment is used to compare the environmental impact of soft tooling by Additive Manufacturing (using Digital Light Processing) and three traditional methods for the manufacture of inserts (milling of brass, steel, and aluminium) for injection moulds during the pre-production phase.

Additive Manufacturing Technology, Injection Moulding, Life Cycle Assessment, Soft Tooling

---

### 1. Introduction

The aim of this paper is to investigate how multiple insert materials – used in the field of Injection Moulding (IM) – compare with each other. Commonly used materials such as brass, steel and aluminium usually require considerable physical and economic efforts in their production. Additive Manufacturing Technology (AMT) such as Digital Light Processing (DLP) can be used in order to manufacture inserts made from photopolymer – involving potentially lower efforts and even higher degrees of detail. Using Life Cycle Assessment (LCA) it is aimed to compare those four materials for IM inserts with a focus on two environmental impact categories, that were considered relevant for such a comparison: Climate Change Warming as well as Human Toxicity. Identification of break-even points for the single technologies was a target as well, in order to identify until which number of shots (i.e. lifetime of the tools), which option would show to be environmentally preferable compared to the others.

### 2. Method

All investigated inserts had dimensions of 3mm x 20mm x 20mm. The experience-based assumed life times for all three metal inserts was 10,000 shots, while it was 30 shots for the polymer insert. The metal inserts were modelled to be produced from 5-mm sheet metal, and thus the gross amount of material was included in the calculation, not just the net amount.

Applying a simplified approach (see e.g. [1]), the LCA comprised the respective weights of the involved materials

including upstream processes but excluding disposal processes. Functional Unit was “Total gross weight of the inserts needed to run a given number of shots at the same given quality level”. Calculations were made with the LCA Software Simapro 8 using the generic average data from the database ecoinvent 3.0 and using ReCiPe as impact assessment methodology, both as integrated into the software tool. While modelling data sets on the metals could be obtained directly from the ecoinvent database, the photopolymer (PM) had to be modelled by the authors. This was done based on scientific literature and an MSDS (Material Safety Data Sheet) provided by the supplier. Some literature points out Antimony (Sb) content as being a key environmental issue of the photopolymer, and, for instance, [2] state a content of between 0.1 and 10 wt% of Antimony in available photopolymers.

Calculations were made for the four materials hypothetically applied for different numbers of shots, between 50 and 100,000 in seven steps, as shown in Tables 1 and 2. Since prototyping context was in focus, five of the selected seven shot numbers were at or below 1,000.

### 3. Results

Overviews of the results for the impact categories Climate Change and Human Toxicity are shown in table 1 and 2. Due to the shorter assumed life time of the photopolymer (PM) insert vs. the metal inserts (30 shots vs. 10,000 shots, respectively), the PM has a much more rapid increase in contributions to both Human Toxicity (HT) and Climate Change (CC) than the metals with increasing numbers of shots. Potential HT impacts for brass are an order of magnitude higher than for all others, except for the two largest numbers of shots, where the PM exceeds it. In both impact categories (CC and HT), PM has

lowest potential impacts of all options for the 50-shot level, for Climate Change even also at the 90-shot level. For the 90-shot level, PM is not only best-in-class in CC but also only 40...50% higher in HT than steel and aluminium, which still is within expectable uncertainty ranges for first iterations and simplified LCAs.

**Table 1.** Contributions to Climate Change coefficients, in kg CO<sub>2</sub> eq.

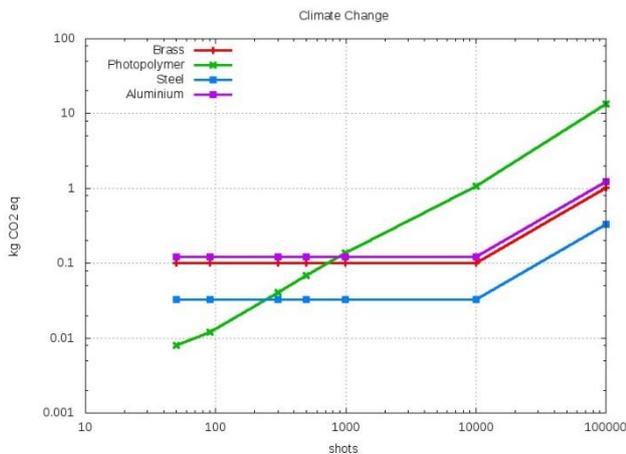
SHOTS	BRASS	PM	STEEL	ALUMINIUM
50	0.101	0.008	0.033	0.123
90	0.101	0.012	0.033	0.123
300	0.101	0.041	0.033	0.123
500	0.101	0.069	0.033	0.123
1,000	0.101	0.138	0.033	0.123
10,000	0.101	1.072	0.033	0.123
100,000	1.009	13.537	0.331	1.233

**Table 2.** Contributions to Human toxicity index in kg 1,4-DB eq.

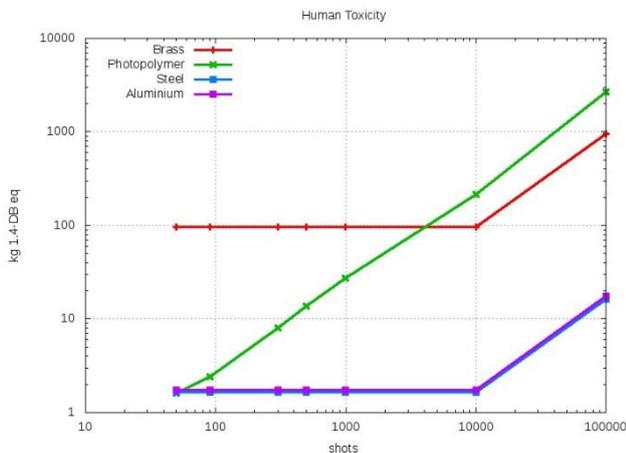
SHOTS	BRASS	PM	STEEL	ALUMINIUM
50	95.459	1.619	1.629	1.753
90	95.459	2.429	1.629	1.753
300	95.459	8.096	1.629	1.753
500	95.459	13.763	1.629	1.753
1,000	95.459	27.526	1.629	1.753
10,000	95.459	213.729	1.629	1.753
100,000	954.590	2699.014	16.294	17.533

Results of the break-even were conducted using linear interpolation between the calculated contributions regarding Climate Change and Human Toxicity. They are shown in Figures 1 and 2 on logarithmic scales.

It can be stated that the photopolymer has the lowest contributions of all options for shot numbers of up until 200 shots.



**Figure 1.** Comparison of the insert materials in terms of climate change coefficient in kg CO<sub>2</sub> eq.



**Figure 2.** Comparison of the insert materials in terms of human toxicity in kg 1,4-DB eq.

#### 4. Conclusions

The comparison using LCA indicates that, for the chosen insert size and geometry, additive manufacturing with the chosen polymer (PM) is environmentally preferable against all compared options for small numbers of shots, i.e. until about 90 shots. The steep rise in potential impact for the PM above the 90 shots does not surprise, since the assumed lifetime for the metals is much longer than for the PM, in fact, 333 times longer. The break-even graph shows that PM is the preferable option for up to between about 100 and 300 shots, both in terms of Climate Change and Human Toxicity.

The shown study is a first iteration. It shows promising results towards an environmental preferability of the photopolymer inserts for application in low-volume prototyping. Further research will enlarge the scope of the comparison by investigating and including more details of processes in the individual life cycles, e.g. more precise origin of raw materials, manufacturing location, cleaning processes, and related transportation of materials and with the end-of-life stage. Also it should include parameters such as the higher grade of detail achievable with PM, and what influences different geometries can have on the results. And also uncertainties influencing the results, such as the most realistic expectable life time need to be investigated and ultimately lowered in the comparison, especially for the photopolymer.

#### References

- [1] Vink E T, Rabago K R, Glassner D A, and Gruber P R 2003 *Polymer degradation and stability* **80(3)** 403-419
- [2] Short D B, Volk D, Badger P D, Melzer J, Salerno P, and Sirinterlikci A 2014 *3D Printing and Additive Manufacturing* **1(1)** 24-33
- [3] ISO 14040/44:2006 "Environmental management -- Life cycle assessment -- Principles and framework" 2006 *International Organization for Standardization'*
- [4] Lenau T, and Bey.N 2001 *Part B: Journal of Engineering Manufacture* **215.5** 637-645
- [5] Tabone M D, Cregg J J, Beckman E J, and Landis A E 2010 *Environmental science & technology* **44(21)** 8264-8269
- [6] Azapagic A 1999 *Chemical engineering journal* **73(1)** 1-21
- [7] Guinee J B, Heijungs R, Huppes G, Zamagni A, Masoni P, Buonamici R, Ekvall T, and Rydberg T 2010 *Environmental science & technology* **45(1)** 90-96