



A LCA Analysis of SMC Solution for Electrification

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Abstract

The intensifying electrification trend in the automotive industry along with calls for high-efficiency, low-cost industrial applications drive the demand for energy- and cost-efficient electromagnetic components. Electromagnetic components of soft magnetic composite (SMC) materials can play an important role in this trend, making it possible to manufacture more compact and cost-efficient motor and inductor solutions compared to using traditional designs.

SMC materials are made of iron powder particles coated with an electrically insulating layer and can be formed into complex shapes by means of powder metallurgy (PM), thereby allowing three-dimensional magnetic circuit design.

This study mainly evaluates and analyses a partial carbon footprint of a product (CFP), applied to SMC powder production including raw materials, atomizing, annealing and surface insulation coating. Some life cycle analyses (LCA) of component manufacturing and benefit in electromagnetic application are also presented. A primary investigation to recycle SMC part is reported in this study as well.

Keywords: LCA, SMC, carbon footprint, sustainability.

Introduction

Materials science and engineering is broadly considered to be an enabling technology, providing the foundation upon which other technologies advance. Many advances in materials have also provided the foundation needed to develop technologies that address sustainability goals such as reduced carbon footprint as a strategy to mitigate climate change. For example, materials science also has enabled the development of electric vehicle technologies with high efficiency driving system and high energy/power density batteries. Both traction motor in drive system and DC-DC boost, on-board charger in battery system and other motors such as water pump and HVC unit need soft magnetic components. The intensifying electrification trend in the automotive industry along with calls for high-efficiency, low-cost industrial applications drive the demand for energy- and cost-efficient electromagnetic components. Electromagnetic components of soft magnetic composite (SMC) materials can play an important role in this trend, making it possible to manufacture more compact and cost-efficient motor and inductor solutions compared to using traditional designs.

SMC materials are made of iron powder coated with an electrically insulating layer and can be formed into complex shapes by means of powder metallurgy (PM) process, thereby allowing three-dimensional magnetic circuit design for many applications.

A LCA, which evaluates and measures the environmental impacts associated with products, services, processes, or activities, from the extraction of raw materials to the end of the lifecycle, is evidence of a player adopting more sustainable practices. This study mainly analyses and demonstrates sustainable development of soft magnetic material with aspects of application efficiency, product production and circular possibility/economy as shown the Figure 1.

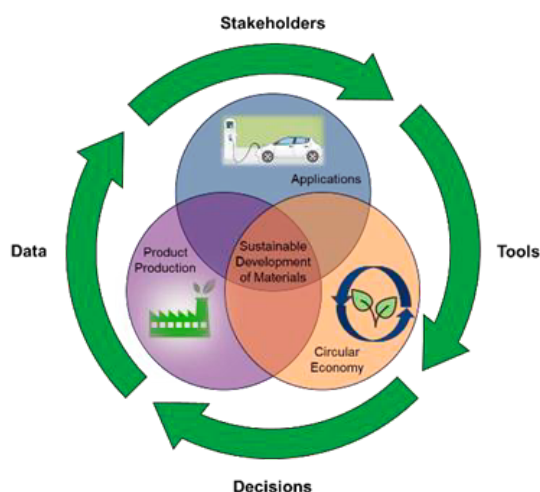


Figure 1 Graphical Abstract Diagram for Sustainable Development of Material

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Material development for sustainable applications

Electric motors are one of the biggest consumers of electricity in the world with a consumption of almost 45 % and it is predicted to increase. Since electric motors play an important role today, and in the future, it is important that businesses take their responsibility to make them as sustainable as they can possibly be. One major development area of e-motor is to improve the efficiency, which will have huge impact on sustainability. Drive E-motor for EV is not an exception. For example, newly registered electric cars in Europe currently emit an average of 75 grams (g) CO₂/km over their entire life cycle 1). If an EV runs 200000 km over its life cycle and its motor efficiency is improved by 1%, it will save 150 kg CO₂ over its entire life cycle. An electrical motor efficiency can be improved by decreasing different losses, such as controller losses, permanent magnet loss, winding loss and soft magnetic core loss. SMC materials are a powdered ferromagnetic material. They are isotropic by nature: magnetically, mechanically, and thermally. This leads to great design flexibility, enabling the construction of 3D topologies, such as axial and transverse flux machines, with little difficulty 2-4). Axial flux machines (AFMs) can provide a torque dense solution in several different applications, which could have a further positive impact on sustainability by down-sizing drive system for EV. SMC material consist of high purity iron powder particles which are insulated from one another by an inorganic coating. The resistivity of the coating is significantly higher than that of iron, restricting the flow of eddy currents to within the particle. Consequently, very low eddy current loss is achieved. However, relatively high hysteresis loss limits wide application of SMC in comparison to Fe-Si laminate material. In past more than 25 years, Höganäs AB has developed and produced the particular SMC materials considered here with the trade name Somaloy® 5-7). The main focus area for material development is to decrease hysteresis loss. Table 1 shows some properties of Somaloy developed by Höganäs in the last two decades. All these three materials are based on 100 mesh powder (mean particles size, D50, is about 100µm). By improving base powder treatment and coating concept, the latest developed one shows better performance in all aspects, not only lower core loss, but also better strength and higher saturations. This can be beneficial for the application.

Table 1 Some properties of Somaloy developed by Höganäs

Materials	Resistivity [µOhm*m]	TRS [MPa]	B @ 4kAm-1 [T]	B@10kAm-1 [T]	µ _{max}	Core loss@1T	Core loss@1T
						and 100Hz [Wkg-1]	and 400Hz [Wkg-1]
Somaloy 500	70	45	1.26	1.51	500	13	54
Somaloy 130i 5P	>10000	35	1.14	1.47	350	8	34
Latest developed	>10000	60	1.31	1.57	500	6	27

A lower core loss can make e-motor higher efficiency directly as mentioned above and a high permeability could decrease copper loss in the winding. A simple simulation of an AFM motor with single stator and double rotor, as shown in Figure 2, indicate that the latest developed one can make a 100 kW motor with 0.2-0.6% efficiency improvement due to 10-20% lower iron loss in comparison to Somaloy 130i5P and a 34 kw motor with 0.3% efficiency improvement due to 15% lower iron loss. Furthermore, the new material can make a benefit of 0.4-0.8% efficiency improvement for a radial flux machine (30-60 Nm and 1000-12000 RPM).

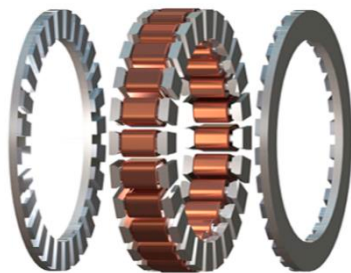


Figure 2. 3D isometric view of Active parts of an AFM with single stator and double rotor

Material development for product production with low CO₂ emissions

The sustainable development of materials requires the systematic reduction of resource inputs and the mitigation of environmental and human health impacts. At first, it should focus on its own product’s CO₂-footprint as material supplier. SMC materials are made of iron powder particles coated with an electrically insulating layer. A detailed workflow is shown in Figure 3. Here, raw powder production with melting and atomizing and following step of refinement with annealing and sieving dominate CO₂ emissions of powder products. It is well known that to produce primary iron from iron ore releases much CO₂ with recent technology, which is similar to BOF-primary steel with ca 2.33 CO₂ eq per kg 8). An effective way to reduce CO₂ emissions is to use iron scrap instead of primary iron. However, impurities in iron scrap have negative effects on magnetic performance, such as increasing coercivity and low magnetic

saturation due to poor compressibility. During the last two decades, melting and annealing process has been developed so that raw material could have higher scrap ratio and still keep a high purity of base powders. In the refinement process, more green electricity and bio-gas are used. In this case, Höganäs SMC material has much lower CO₂ footprint in comparison to one for 20 years ago as shown in Table 2.

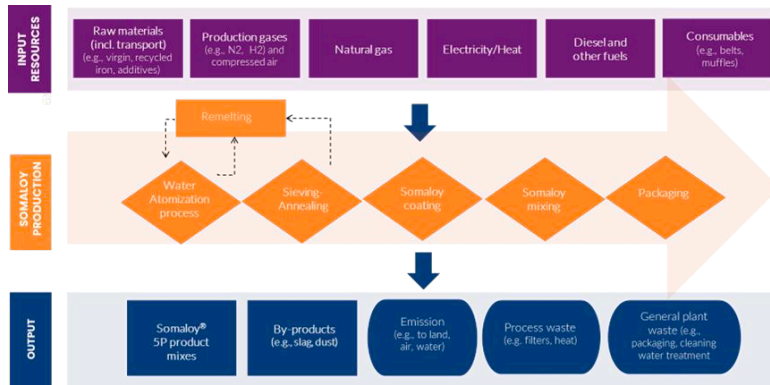


Table 2 CO₂ emissions of Somaloy

Year	CO ₂ emissions ep kg
2000	Ca. 2.0
2021	1.1-1.3
2022	0.8-1.0

Figure 3 Overview of the production process for SMC powders

SMC coating is very thin and its weight percent in SMC powder is less than 0.5% so it has very low CO₂ emission. However, some chemicals and solvents are needed. The latest coating concept developed by Höganäs as Somaloy 7P uses only water as solvent instead of an organic solvent, which become more sustainable.

SMC powder is compacted to components for applications such as stator, rotor and iron core of inductor by powder metallurgy process which is very sustainable. An improvement of compressibility, decreasing ejection energy and low scrap rate during component manufacturing process will further decrease CO₂ emissions of SMC components. A SMC powder with Somaloy 7P coating based on a mixing of fine pure iron powder and gas atomized sendust Fe-Si-Al has the similar magnetic performances as gas atomized Fe-Si powder. However, the compaction pressure for the mixture is only 1100 MPa, while Fe-Si powder must be compacted at 2000 MPa, as shown in the Table 3. The lowering of compaction pressure will decreasing tool wearing, energy consumption etc..

Table 3 A comparison of compaction pressure and magnetic properties of two materials

Material	Compaction pressure [MPa]	Density [gml ⁻¹]	Bs[T]	Core	Core
				loss@0,1T and 10kHz [Wkg ⁻¹]	loss@0,1T and 20kHz [Wkg ⁻¹]
Pure iron+GA					
sendust	1100MPa	6.60	1.50	18.2	40.6
GS Fe-Si	2000MPa	6.58	1.63	18.1	40.6

Material development for product production with long use life

The achievements of material development to benefit applications and the product manufacturing is discussed above. Furthermore, it is also very important to develop materials with long useful life. The useful life of materials means not only that products have a stable performance during its original application, but also can be extended through reuse, recycling, and recovery strategies, commonly referred to as implementing a “circular economy.” An EV has its use life over 10 years, SMC components in this application should not have a clear aging deterioration to avoid the need of part replacement. At this stage, it is hard to get SMC parts which have been used some real applications such as EV for more than 10 years. However, a SMC component which have been stored in 12 years has been tested, and it shows very stable performance as shown in Figure 4. The B-H curves does not have any change for both Somaloy 1000 5P and Somaloy 110i 5P.

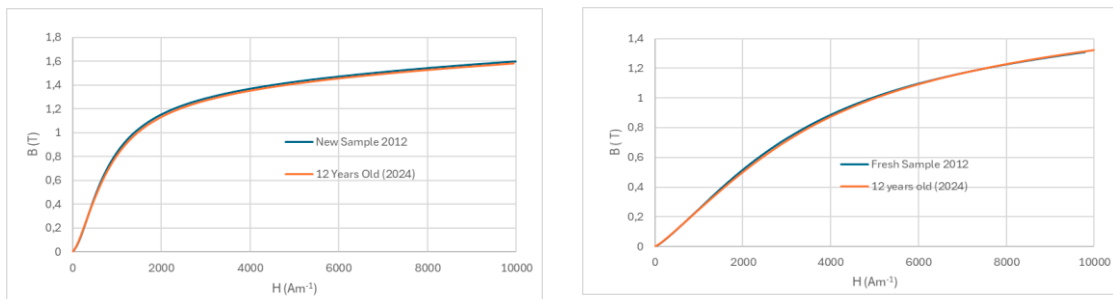


Figure 4 A comparison of B-H curves of Somaloy 1000 5P (left) and 110i 5P (right) before and after 12 year's storage.

Somaloy 1000 5P is made of 40 mesh powder (D50=230μm) with a thin 5P coating for active components in e-motors and Somaloy 110i 5P is made of 200 mesh powder (D50=45 μm) with a thick 5P coating for passive components in inductors. SMC parts have shown a stable performance even at tough conditions such as at high working temperature or with corrosive environment. Figure 5 and 6 show early published results of SMC components with the salt spray test according to ISO 16701 9).

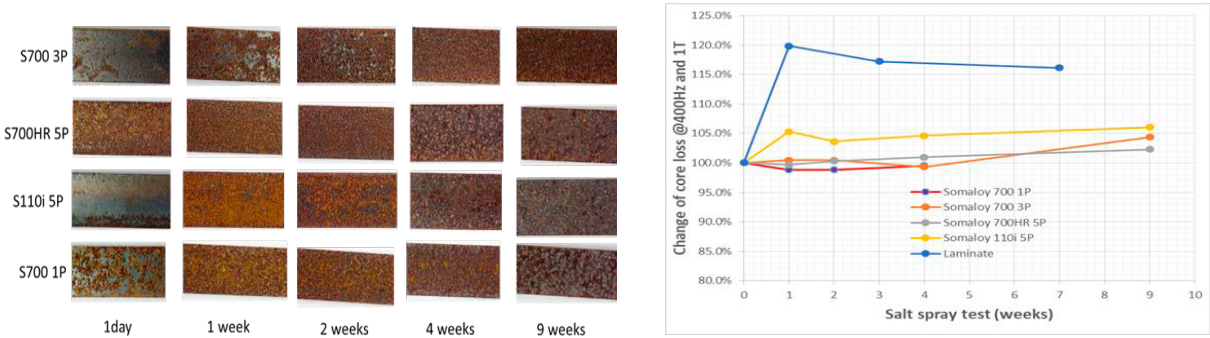


Fig. 6. Changes of core loss @ 400Hz 1T during the salt spray test.

Fig. 5 Photos of untreated Somaloy components corroded bar samples

These photos indicate that the Somaloy component surfaces have relatively low corrosion resistance and corrode fast in aggressive environments. For example, there was considerable rust on the whole surface of the S700 5P samples after only 1 day. From the change of the rust color, the reddish ferrous oxides products gradually turned into dark red ferrous ferric oxides. However, SMC parts show a relative stable performance except for some percent core loss increasing from the beginning and they are clearly better than Fe-Si laminate components. A surface treatment of SMC part can protect SMC parts as presented in early work 9). Another challenge for SMC components is working at elevated temperature up to 180°C such as in EV. Its thermal durability becomes very important. Figure 7 shows the performance of SMC component made of Somaloy 130i 5P in a thermal storage test at 150°C. The component shows only slight performance change in the beginning and then becomes very stable.

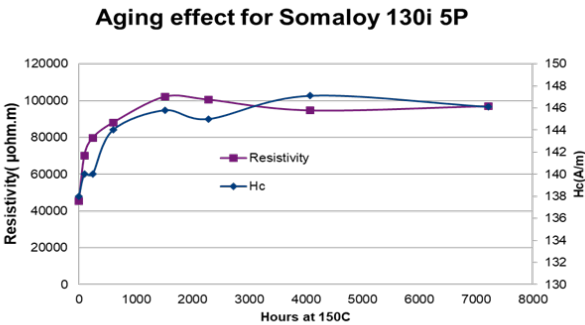


Figure 7, The resistivity and coercivity variation during a thermal storage test at 150°C

Recently some inductor applications have target to have a good thermal durability at up to 260°C. A test shows that Somaloy 110i 5P has a severe aging deterioration at 260°C, fortunately latest developed SMC powder with Somaloy 7P coating based on a mixing of fine pure iron powder and gas atomized sendust Fe-Si-Al shows much better thermal durability as shown in Table 4.

Table 4 The core loss [Wkg⁻¹] @ 0.1T and 30 kHz change after thermal storage test

Tests	Somaloy 110i 5P	Lates developed
Fresh sample	87	67
5 days at 150°C	89	
5 days at 200°C	96	
5 days at 260°C	144	70

A SMC component shows a very good performance stability, which makes it possible to reuse the part after its original application’s use life.

From both chemistry and physical metallurgy point of view as well as some practical trials, there is no technical difficulty to recycle SMC part or material by remelting because SMC powders or component contains 99.5% pure iron, and the coating is oxides which can be easily removed as slag. The question is if the SMC components can be recycled without melting. A preliminary experiment has

been tried. SMC components made of Somaloy 700 HR 1P were crashed to powder and the crashed powder was compacted to the SMC component again and heat treated with the same condition as 1P material. The results are shown in the Table 5. The resistivity of recompact SMC part is only 1% of resistivity of original parts, which means that coating is destroyed during crashing, recompact and re-heat treatment. Coercivity of recycled parts increases very much, which must be due to a stress caused by crashing. An optimizing crashing process to avoid/minimize stress introduction, to protect coating and further to repair coating so that reprocessed SMC parts have good performance will be a future work.

Table 5, A comparison of some properties between sample compacted from Somaloy and crushed powder

Sample	TRS	Density	Resistivity	DC Properties			Core loss@ 1T [Wkg ⁻¹]	
	[MPa]	[gcc ⁻¹]	[μOhm*m]	B@4000 [T]	B@10000[T]	Hc [A/m]	100Hz	400Hz
From Somaloy	35	7.48	1221	1.25	1.55	199	9.1	42
From crashed powder	34	7.40	20	1.20	1.50	263	12.5	66

Conclusions

By analyzing and demonstrating sustainable development of soft magnetic material with aspects of application efficiency, product production and circular possibility/economy, it can be concluded as following:

To decrease core loss of SMC component plays an important role for sustainable electric vehicle application.

By using scrap as raw material in powder production and green electricity as well as bio-gas as energy, Somaloy powder has very low CO₂ footprint, such as less than 1 kg CO₂ emission eq kg. Optimizing powder mixtures with Somaloy could further help component manufacturing company to decrease CO₂ emission.

SMC components made from Somaloy show good performance stability against time, working environment and temperature, which means the SMC components have long useful life.

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