Advances in SMC Technology – Materials and Applications

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ABSTRACT

Soft Magnetic Composite (SMC) challenges traditional material such as soft magnetic ferrites and electrical steels in applications with alternating magnetic fields. As the market potential is large this is an interesting area for the P/M industry. By utilising the features offered by the material itself as well as the P/M forming technique new competitive electromagnetic designs can be realised. This paper will describe main features and benefits offered by the technology with focus on electrical motors. Finally, the latest and future materials will be presented.

INTRODUCTION

SMC-materials (Soft magnetic composites) are basically iron powder particles separated with an electrically insulated layer as shown schematically in Figure 1. The powder metallurgy (P/M) process has for long time been used to manufacture SMC components for high frequency inductor applications. These traditional SMC materials consist generally of iron particles distributed in matrix of organic materials. Due to the distributed air gap and good high frequency behaviour cores made of iron based SMC materials is the most cost efficient solution for inductive components in various filter and power conversion applications.

Recently the group of SMC´s has been expanded by the introduction of new materials. These materials do not contain any organic matrix that set limitations on the processing conditions. This makes it possible to manufacture components with significantly higher saturation induction, permeability as well as lower hysteresis losses. As a result SMC´s are now also an alterative to electrical steels in applications in the low to medium frequency range such as rotating machines, sensors and fast switching solenoids. As the technology still is rather young applications, material, process and application development is ongoing at a high speed.

Basically there are three main features offered by the technology.

1. Unique combination of magnetic saturation and low eddy current losses. Figure 2 shows the position of SMC compared to traditional materials.
2. 3D-flux carrying capability.
3. Cost efficient production of 3D-net shaped component by the P/M process.

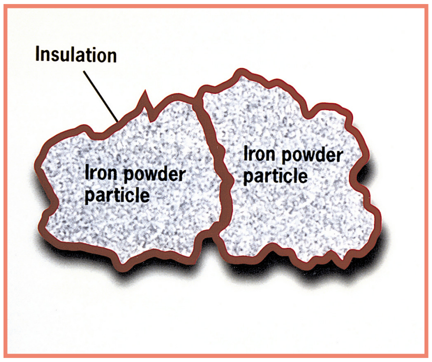

Figure. 1 Schematic picture of a SMC-material

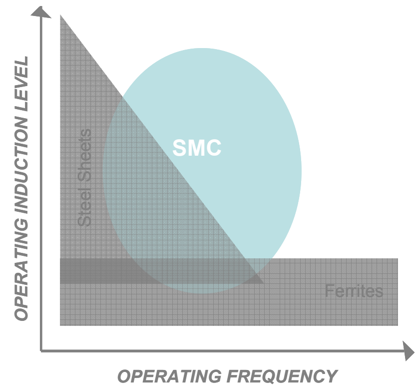

Figure 2: SMC, over bridges traditional materials

This paper will describe some of the benefits and trends with the technology focusing on electric motors as well as presenting the latest material development.

ELECTRICAL MOTORS

As the consumption of laminated steels for electrical motors is several times larger than the market for sintered structural parts this is an interesting target for the P/M industry. However, it is challenging as material, designs and manufacturing has been optimized for a 2D flux over a long period of time. A “drop–in” replacement of a laminated core by a SMC will result in best case in an equal performance at the same cost. One exception could be motors operating at high frequency where a direct replacement may result in some benefits. However, the key to success is found in utilising the three dimensional flux capability of the material. The possibilities for the designer to use new topologies with shape, winding and assembly solutions beyond today’s standards opens up for benefits such as better performance, reduced size and weight, fewer parts and lower cost.

A 3D design can be adopted for virtually all normal motor topologies. For instance a 3D-designed Universal motor can significantly reduce the Cu-wire and increase the performance of the application [1]. Despite of this it has been proven to be difficult to commercialise SMC in both induction and universal motors. These motors operate at low net frequency which allows them to use thick low cost lamination. Furthermore, in these motors the reluctance in the magnetic circuit is low as the air gaps are small and there are no permanent magnets present. SMC has a lower permeability than laminations and this influences the magnetic flux in the circuit and needs to be compensated by adding more iron.

The trend toward high efficiency permanent magnet motors and features such as variable speed increases the competitiveness for the modern SMC materials. Motors can be designed to operate at higher frequencies as a controller is needed. The permanent magnet has a very large influence of the reluctance which limits the effect of the lower permeability of the SMC material

An interesting motor topology for SMC is the axial flux motors. This has successfully been demonstrated in the life car project in UK where a high performance axial flux machine was designed for a traction application (Figure 3) [2]. In table 1 some of the motor characteristics are given.

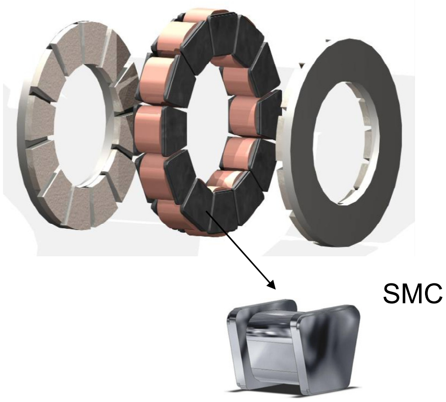

Figure 3: Axial flux motor designed and build by Oxford University

Table 1: Motor Performance

Torque = 130Nm	*Speed = 3600rpm*
Power = 50kW	*Frequency = 300Hz*
Weight = 11kg	

Perhaps are the most suitable motor topologies for SMC´s Claw pole / TFM (Transverse Flux Machine) or linear machines. The Claw pole / TFM machines have a 3D flux path and are therefore difficult to manufacture with laminations. These machines normally have a very simple hoop winding which is attractive form manufacturing point of view. Figure 4 shows a claw pole topology studied by University of Newcastle [3].

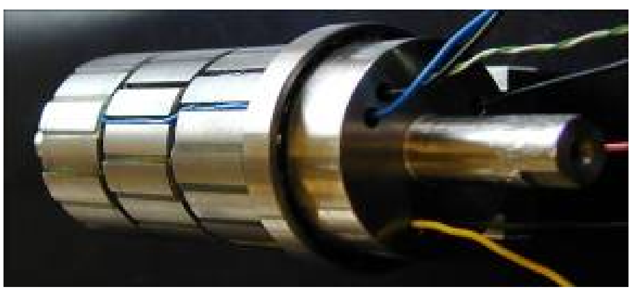

Figure 4: Three phase solution designed by University of Newcastle

The most striking advantage by using SMC in linear machines is from manufacturing point of view. It is clearly illustrated in figure 5 that the number of parts can be decreased and assembly simplified by changing from lamination to SMC. Moreover, by actually modifying the design for SMC the performance could not only be matched but improved [4].

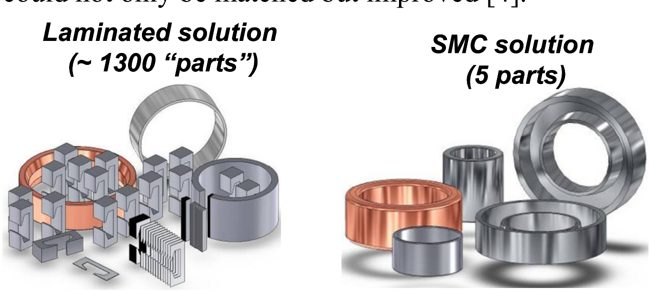

Figure 5: Parts required for laminated and SMC solution

MATERIAL DEVELOPMENT FOR ELECTRICAL MOTORS

As described in the previous section the competitiveness of the technology for motor applications depends to a large extent on the design. However, increasing SMC´s material performance naturally increases the benefits of using the SMC technology. Over the last 10-15 years significant material improvements has been achieved and the development is still ongoing. Projects that were rejected in the past may now be realised due to the material improvements.

Compared to lamination SMC has higher DC-losses (but lower eddy-current losses) which needs to be considered in the design in many cases. Therefore, reducing the losses is important in order to increase the competitiveness of SMC in electrical motor.

Figure 6 shows the core losses/frequency as a function of frequency measure at 1T for a number of materials. Somaloy® is the brand name for the SMC materials from Höganäs AB. The traditional polymer bounded SMC material is represented by Somaloy 500+0,6% binder (LB1). Extrapolating the graphs to 0 Hz indicates the DC losses and the slop is an indication of the eddy-current losses. It can be seen that all material have a good response to the increased frequency as the slope is modest. It is also clear that even at 1000Hz the dominating loss is DC-loss.

More than 10 years ago the Somaloy 500 1P was introduced to the market which had close to 30 % lower DC losses compared to the polymer bonded materials. A few years ago the Somaloy 700 1P was released to the market which lowered the losses by another 10%. The latest material development led to another reduction of the DC losses, which corresponds to more than 60% reduction compared to the traditional polymer bounded SMC material.

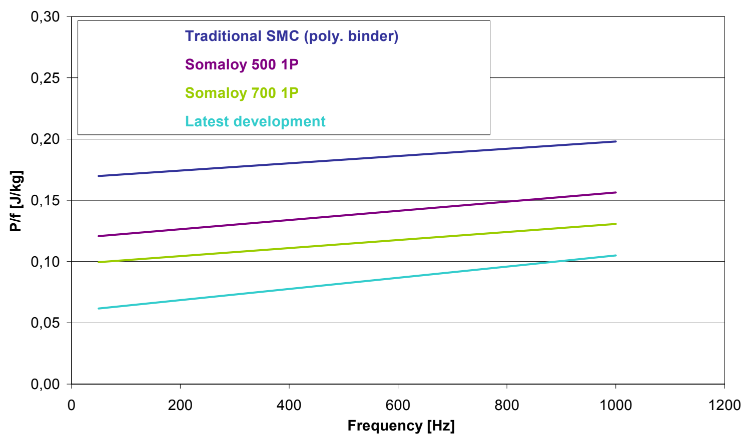

Figure 6: Losses/cycle (Core loss /frequency) plotted as function of frequency

The electrical resistivity of the SMC material gives an indication on the eddy current losses. In table 2 some SMC materials are compared to iron and alloyed sintered materials. It is clear that the electrical resistivity is several magnitudes greater than any alloyed material and this is the reason why SMC material and not sintered material is used in applications with alternating magnetic field. The improvement in resistivity from Somaloy 500 1P to Somaloy 700 1P makes the material more robust from a production point of view.

Table 2: Electrical resistivity of sintered and SMC materials

Material	Resistivity [μΩm]
Sintered iron	0,1
Sintered Fe+0,45%P	0,2
Sintered Ferritic Stainless	0,6
Somaloy 500 1P	70
Somaloy 700 1P	400

Losses are important for motor applications and the second important property is the B-H characteristics. Fortunately, the B-H characteristics have also improved which means that higher torque densities and/or lower Cu-losses can be obtained. Figure 7 shows the B-H curve for a selection of SMC materials.

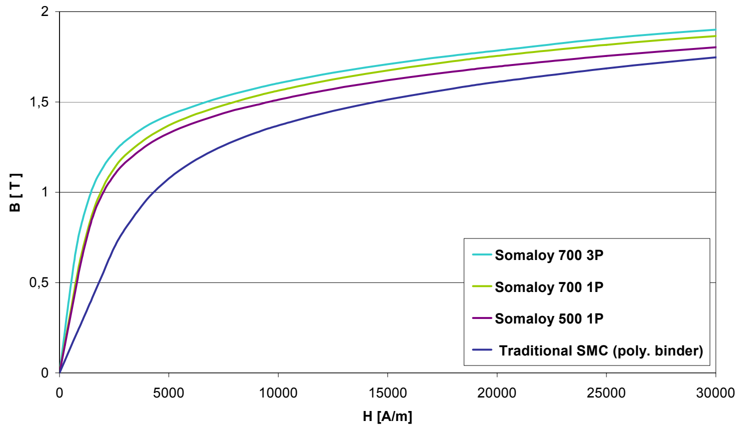

Figure 7: B-H curve

It is clear that significant improvement in B-H characteristics is obtained as compared to the polymer bounded material. One reason for the improvement of the B-H characteristics of the Somaloy 700 series is the extremely high compressibility of the powder. Figure 8 shows a compressibility curve for Somaloy 700 1P and compare it to ABC 100.30 which is also considered as a very compressible powder.

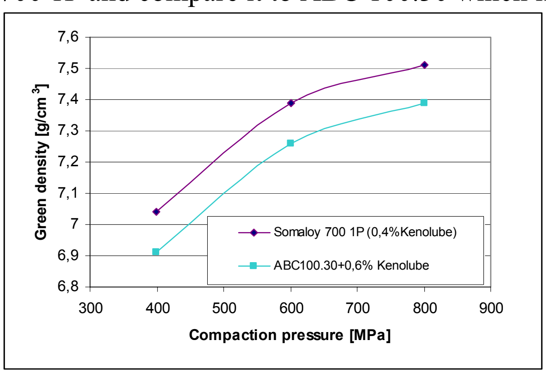

Figure 8: Compressibility curve of Somaloy 700 and ABC 100.30
(400MPa=28,8tsi; 600MPa=43,2tsi; 800MPa=57,6tsi)

Another very important property of SMC material is its mechanical strength. Since SMC materials is not sintered lower strength are typically achieved which needs to be considered in the design stage. Significant improvement was also achieved in this area. Materials that contain organic binders can be processed to relatively high strength as shown in table 3. However, these powders are quite often pressed without internal lubrication, which makes mass production much more challenging and costly. The Somaloy 700 3P material exhibits higher mechanical strength even if it contains internal lubrication.

Another advantage with the 3P system is that its magnetic saturation and permeability are also improved compared to the other materials. Table 3 shows the mechanical strength at ambient temperature as well as at 150°C and the induction at 4000A/m for some selected materials.

Table 3: Transverse rupture strength and magnetic induction at 4kA/m

Material	TRS at 25°C [MPa]	TRS at 150°C [MPa]	Magnetic induction at 4kA/m [T]
SMC polymer bonded (Somaloy 500+LB1)	100	35	0,96
Somaloy 700 1P	40	40	1,31
Somaloy 700 3P	125	125	1,37

MATERIALS FOR ELECTRICAL MOTORS

Table 4 shows a selection of different materials suitable for electrical motor applications. Data on the latest material development are also included.

Table 4: Selection of materials suitable for electrical machines operating up to kHz range

					Core loss @ 1T [W/kg]		
Material	**Resistivity [μΩm]**	**TRS [MPa]**	**B@ 10kA/m [T]**	μ_{max}	**100 Hz**	**400 Hz**	**1 kHz**
Somaloy 700 1P	400	40	1,56	540	10	44	131
Somaloy 700 3P	200	125	1,61	750	10	46	137
Latest development	700	60	1,57	600	6	32	104

- Somaloy 700 1P: Base line for PM machines operating at 50Hz to several hundred Hz.
- Somaloy 700 3P: This material offers a high mechanical strength and good B-H behaviour.
- Latest development: Offers very low losses which is important for high efficiency motors

SUMMARY

The material development of SMC materials has led to materials with significantly increased performance such as lower losses, higher permeability and increased mechanical strength. These improvements increase the competitiveness of technology and the development continues.

For successful implementation of SMC in electrical machines 3D-designs are very important. Examples of motor topologies that suite the technology is TFM/Claw pole, axial flux and linear machines.

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