Recent progress in Fe-based amorphous and nano-crystalline alloys for use in motor cores

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One of the most effective methods to reduce core loss in motor cores is to use superior soft magnetic materials. Non-oriented electrical steel (NO) is generally used for motor cores and core loss is reduced by decreasing its thickness to suppress eddy current loss. The thickness of currently commercial NOs ranges from 0.35 mm to 0.15 mm. However, from the standpoint of core loss reduction, it is much more effective to change core material from NO to Fe-based amorphous (Fe-based AM) or Fe-based nano-crystalline alloys (Fe-based NANO).

Table 1 lists magnetic properties of Fe-based AM Metglas® 2605SA1 (2605SA1), Fe-based NANO and NO. Core losses of 2605SA1 and Fe-based NANO are approximately 1/10 or less than that of a conventional NO (35H300). On the other hand, these materials have some disadvantages in manufacturing motor cores.

Fe-based AM is obtained in the form of thin strip by solidifying molten metal at cooling rates of more than 10^6 K/s which is faster than the growth rate of crystalline nuclei with single-roll rapid-solidification method. As-cast Fe-based AM has large internal stresses introduced by rapid solidification. Therefore, the stress relief annealing is essential to obtain better magnetic properties as indicated on “Non-field annealing” line in Table 1. However, the annealed Fe-based AM becomes slightly brittle. When the as cast Fe-based AM on “Non-annealing” in Table 1 is mainly considered in AM motor core, the core loss of the motor core is still much lower than that of NO. The thickness of an Fe-based AM strip is much smaller at approximately 0.025 mm, which is less than 1/10 of that of a conventional NO. And its Vickers hardness is 900, which is approximately 5 times that of NO. Therefore it is difficult to apply the conventional punching technique to Fe-based AM core manufacturing. Therefore IE5 efficiency class axial gap motors using Fe-based AM laminated stator cores manufactured with slitting and shearing methods, which are widely used for manufacturing Fe-based AM transformer cores, have been developed and commercialized.

Fe-based Nano is also cast by single-roll rapid-solidification method. Therefore the as-cast state has almost the same physical properties, such as thickness and hardness, as those of Fe-based AM. And Fe-based NANO requires high temperature annealing comparable with Fe-based AM in order to create nanocrystalline structure. Therefore Fe-based NANO is much more brittle than annealed Fe-based AM. In order to commercialize an Fe-based NANO motor, it is necessary to develop a core manufacturing method that is applicable to brittle alloy thin strips.

References

1) M. Ohta and Y. Yoshizawa, Appl. Phys. Express 2, 023005 (2009)

2) M. Ohta and R. Hasegawa, IEEE Trans. Magn., vol. 53, 2000205 (2017).

Table 1 Magnetic properties comparison between nanocrystalline alloys and conventional materials

Material		B_s (T)	$P_{15/50}$ (W/kg)	$P_{10/400}$ (W/kg)	$P_{10/1k}$ (W/kg)
Fe-based AM 2605SA1	Non-field annealing	1.56	0.22 typ.	0.81 typ.	3.0 typ.
	Non-annealing		—	2.2 typ.	7.4 typ.
Fe-based NANO	FINEMET® FT-3M	1.23	—	0.12 typ.	0.57 typ.
	$Fe_{82}Cu_1Nb_1Si_4B_{12}$ (1)	1.78	0.20	1.3	4.4
	$Fe_{80.8}Cu_{1.2}Si_4B_{11}P_2$ (1)	1.79	0.18	1.8	6.8
	$Fe_{80.5}Cu_{1.5}Si_4B_{14}$ (1)	1.80	0.27	1.6	5.8
	$Fe_{81.8}Cu_{1.0}Mo_{0.2}Si_4B_{14}$ (2)	1.75	0.28	1.5	5.0
NO	35H300 (t=0.35 mm)	2.0	2.4 typ.	18 typ.	78 typ.
	15HX1000 (t=0.15 mm)	2.0	2.0 typ.	9.3 typ.	33 typ.
	6.5% Si-Fe 10JNEX900 (t=0.1 mm)	1.8	—	5.7 typ.	18.7 typ.