Recent advancement of permanent magnet materials developments for vehicle electrification and expectation for future research.

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1.Background

Recently, vehicle electrification expands rapidly. It is well known that electrified vehicle has additional component compare to conventional gasoline vehicle, i.e. battery, inverter and electric motor. At this moment, supply and demand seems to be acceptable for all additional electric component. However, most of future forecast says that amount of electrified vehicle become two to five times larger than current vehicle sales. This means that we need number of electrified unit, at least, more than two times compare to current demand. For example, IEA scenario described in Energy Technology Perspective 2017 forecasts electrified vehicle increase from 14 million in 2020 to 40 million in 2030 [1]. When we look at even only around vehicle technological shift, it is easy to forecast enormous number of rare-earth magnet will be needed. From this circumstance, we are researching coerciviy mechanism of rare-earth magnet and consider what we can do for balancing global supply and demand of rare-earth materials.

Beside vehicle application, future demand of magnet may rise not only from vehicle electrification but from mobility for short commute, logistics, robotics etc. When we include these application for future forecast of rare earth demand, larger amount of rare earth demand is expected. In order to get over this problem, we should look at wider magnet composition range. In this talk, I will present recent progress of magnet R&D in TMC based on data driven approach.

2.Current situation of magnet research in TMC

Regarding $RE_2TM_{14}B$ compound, we adopt informatics technique for accelerating magnet research. For designing performance of magnet, we need not only magnetic properties of compound but microstructural control technique. From research achievement in the past, we already aware that coercivity can be enhanced by surface modification. It is well known that surface modification consists of two parts, one is compositional control of grain shell [2,3,4] and recovering surface distorted region [5]. In order to control these two parts, we can use grain boundary diffusion technique and low temperature annealing. On the other hand, compositional dependence of magnetic properties, many reports were published in the past, but information had not stored systematically. To get over this situation, we are now producing data space for designing magnet [6]. When we look only at room temperature, it seems that there is no room to enhance magnet performance in $RE_2TM_{14}B$ system. Combining experimental data, empirical model and first principle calculation, our group expand data space, about 100 data from experiment and several thousand data from first principle. Mining established data space, we can find better performance potential composition range in elevated temperature. Currently, we are strongly push forward data driven research. To utilize all information contained in all data, e.g. XRD, SAS, micro-scope image etc., we develop data extraction technique utilizing informatics algorithms and integrate these achievements into cloud server system.

3. Future perspective

In near future, many kind of electro-magnetic devices become important for future application not only for vehicle electrification but for various application. In order to Designing magnetic performance suited for each application, magnetic properties data space will take important role, I think. I hope “Data driven material research” will evolve “Data driven material design and development”. To achieve this context, culture for storing research data will become more important.

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<u>Reference</u>

1) Energy Technology Perspective 2017; IEA
2) K. Machida et al; Abstracts of Spring Meeting of Japan Society of Powder and Powder Metallurgy. 2004.;
3) H. Sepehri-Amin et al; Journal of Applied Physics **107**, 09A745 (2010); T(K)
4) M. Ito et al; AIP Advances **6**, 056029 (2016);
5) G. Hrkac et al; Appl. Phys. Lett. **97**, 232511 (2010);
6) Y. Harashima et al; submitted