Research on Binder of Binded NdFeB Magnets from Injection Molding

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Abstract: The injection molding of magnetic powder could cost-effectively mass-produce net shape magnets. The important influence of binder to the molding process and applied properties of injection molding magnet was discussed. Based on the test and analysis of physical and mechanical properties of the three type important binders, the effect of binder on the magnetic property, molding process property and mechanical property of injection molding magnets were investigated. The injection molding bonded NdFeB magnets with better combined properties were prepared. The research and develop directions of the binder were probed.

1 INTRODUCTION

Magnetic material is one of the important functional materials. As third generation permanent magnetic material, NdFeB rare-earth permanent magnetic magnet has been extensively used in computer, move-phone, acoustics equipment, electric motor and so on; because of its small volume, small weight, high magnetic property, high properties-price ratio etc[1]. NdFeB magnets include sintered NdFeB and bonded NdFeB. The production technologys of bonded NdFeB magnet include pressing molding, injection molding and extruding molding mainly. Pressing molding has been used for mass-production. The injection molding of NdFeB magnets have many features such as accurate dimensional tolerances, high productivity, low production cost, combined molding and easy achieve complicated geometries, so it has very good developing prospects[2]. But the injection molding of NdFeB magnets not only need to resolve the oxidation and hardly flow problems in melt mixing and injection molding of NdFeB magnetic powder, but also to reduce wearing of NdFeB magnetic powder with the screw and the mould, so lead to the injection molding difficult[3-4]. At present, the research on bonded NdFeB magnets prepared by injection molding is in start stage. The properties of three type binders and the effects of binder on the molding process and applied properties of injection molding bonded NdFeB magnets were investigated in this test.

2 THE PROPERTIES THAT BINDER SHOULD POSSESSED

Bonded magnet is a compound material that consists of permanent magnetic powder, binder and additives. The magnetic property of magnet is offered by permanent magnetic powder; but the shape, size, strength, corrosion resistance and fluidity for molding of magnet are offered by the binder mainly; so it is very important to research and develop the binder. The two main effects of binder in injection molding magnet are: ① Make flowing and turning of magnetic particle possible when magnet molding. ② To bonding the magnetic powder together effectively to offer shape and mechanical property for magnet[5-6].

To see macroscopically, the injection molding process of NdFeB magnet exactly is the flowing process of magnetic particles. The fluidity of alloy powder is bad which decided by it's shape and outward; but the high polymer binder possess of good fluidity at liquid state and the flowing demand of magnetic particle can be satisfied, furthermore it has definite shape and mechanical property. The viscosity of binder must be suitable. When the viscosity is too high, although the magnetic

mechanical property is good, but the fluidity is bad that will hinder magnetic particle from turning and orienting and make the mold cavity filling failure, then damage the magnetic property and outward of magnet. When the viscosity is too low, the magnetic powder will be separated from binder and lead to injecting process failure. To see microcosmically, bonding exactly is a mechanical linking of magnetic powder and binder. Which include liquid state binder moistens solid state magnetic powder and forming physical and chemical bonding force between them. So the properties which the binder should possess as follow.

2.1 The Injection Technology Property of Binder

The binder should possess excellent fluidity for injection molding technology, so we can add stearate or polyolefine to decrease the fluidity of injection molding mix. The molding temperature of resin must be suitable, and the space between melting temperature and thermo-division temperature should be great enough to ensure molding operation, magnetic property, magnet quality and productivity.

2.2 The Physical and Chemical Property of Resin Binder

The resin absorbs moisture in the moist environment and lead to rare-earth permanent magnetic powder corroded, so the easy absorb moisture resin need to be modified to rise it's corrosion resistance. Besides the important employing property of binder such as heat-resistance, environment-resistance, ageing-resistance can be modified if necessary.

2.3 To Ensure the Size Accuracy of Magnet

Comparing with other forming technology, the injection molding NdFeB magnet can achieve better size precision, but the affect elements more and complicated such as the shrinkage rate, fluidity, expanding coefficient of binder, and the shrinking rate with remarkable affect among them. The difference of shrinkage rate for different binder is great, large shrinkage rate benefit to raise density and magnetic property of magnet, but small shrinkage is better to ensure the size precision.

2.4 Effects of Binder to Injection Molding NdFeB Magnet Properties

According to the magnetic property of ideal permanent magnet, the magnetic property of bonded magnet can be expressed as follow:

$$Br = P \cdot A \cdot \mu_0 M_s$$

$$(BH)max = Br^2 / 4$$

In the expression: Br —Br of bonded magnet

(BH)max—(BH)max of bonded magnet

$\mu_0 M_s$ —Br of ideal magnet (density is 100%, orienting degree is 100%)

P —percentage volume of magnetic powder in bonded magnet

A —orienting degree

Show in the expression, the magnetic property of bonded permanent magnet decided by the density and orienting degree of magnet. The binder is no-magnetic material and binder and pore decrease the magnet density, and decrease the magnetic property of magnet certainly. So the content of binder should be as low as possible when it satisfied the technology and employ property.

The injected magnet ensure certain pressure when forming, if the compression density of pure magnetic powder is dp(g/cm3) and the real density is dt(g/cm3), then the volume percentage of magnetic powder is Vf :

$$Vf = dp / dt \times 100\% (Vo.\%)$$

The volume content of magnetic powder in magnet should below this value, and the remained space should be filled by binder. In fact the content of binder is more because the fluidity of compound needs to be considered sufficiently. This section must be in two

2.5 Effects of Binder to Injection Molding Nd FeB Magnet Mechanical Properties

The mechanical property of bonded magnet is decided by the type and content of binder. Although increase magnetic powder loadage can rise magnet magnetic property, but lead to the mechanical property decrease. Besides adding sufficient binder, we need to modify the binder to ensure the mechanical property of magnet. For example add plasticizing agent, strengthening agent, coupling agent to gain high strength, good toughness and pretty outward appearance.

2.6 The Main Component of Injection Molding NdFeB Magnet

The binder is different according to the uses of injection molding magnet. Generally it is high polymer binder consist of a few composition that include resin, coupling agent, plasticizing agent, strengthening agent, stabilizing agent, antioxidant, burning resistance agent etc.. Resin and coupling agent are necessary compositions, the others can be selected according to the technology and property.

Resin is the basic and most important composition of binder, generally it is synthetic high-molecular compound, include resinoid and thermoplastic resin. Only very rarely do we find that resinoid is used for binder because of it's difficult control of injection technology and difficult reprocessing of the solidified pouring system material. But the thermoplastic resin without shortcoming above, and can gain fairly good fluidity, accurate production size, fairly good magnet property. Generally the resins can be used for binder are: PA, PPS, PE, PBT, PP, PC and so on, and PA and PPS are the most in use. All of them are engineering plastics that with very low viscosity and excellent injection molding property at melting state and can ensure maximum loadge of magnetic powder.

Coupling agent is a high-molecular additive that one side of the molecular contain unit reacting with NdFeB and the other side contain unit reacting with binder, so the inorganic material and organic material can be coupled by chemical bond. Besides the NdFeB powder is extremely easy oxidized when the temperature more than 150℃, then lead to magnetic property decrease rapidly, so the magnetic powder need anti-oxidation treatment. After the surface treated by coupling agent, the property of NdFeB magnetic powder can keep stabilization at high temperature and 100% humidity environment, and the anti-oxidation property of the magnet made by the magnetic powder raised remarkably.

3 TEST METHOD

For the binder PA, heat-resistance PA, and PPS: According to the ASTM methods, drying the binder and injection molding the testing samples use injecting machine and accurate mould, then testing the physical and mechanical property of binder use special equipments.

For injection molding magnet: The ferroxcube magnetic powder particle is fine and no high temperature oxidation problem, so the injection molding is easy relativity. The MQP-B NdFeB magnetic powder is adjusted on particle size, coated with coating agent and surface treated with coupling agent; then is mixed with drying binder, lubricant, antioxidant according to different loadage of magnetic powder in high speed mixer. And then the compound is melted and mixed and extruded in the double screw extruder and cutting. At last, injecting mold appropriate property testing samples use injecting machine and accurate mould. According to the Chinese GB method, test physical property, mechanical property and magnetic property of magnet by special equipments.

4 TEST RESULTS AND DISCUSSION

4.1 Polyamide Resin Binder

Polyamide resin is a type of high-molecular compound which contain many repeated amide unit (-NH-CO-) in the molecular main chain and is popular named PA. PA is made from polyiondensation reaction of carbonic acid and amine, or polymerization reaction of amide, so it can be classified as many kinds according to the unit for polymerization reaction, for example PA6, PA66, PA12, PA6/66, PA6/12 etc.. PA is a thermoplastic resin and with excellent strength, toughness, heat-resistance property, wear-resistance, corrosion-resistance property and so on, and is nonpoisonous. So it is used as engineering plastics extensively.

PA have the specific property of suck up moisture because it contain the amide unit which is close to moisture. The saturation moisture capacity (at 23℃) of PA6, PA12, PA66, PA6/6T are 9.5%, 1.8%, 8.5%, 7% respectively. So the moisture capacity of PA is need to pay special attention when design magnet product. PA need to be modified when used for injection molding magnet binder by add additives, for example plasticizing agent, strengthening agent, stabilizing agent, lubricant etc. to modify the strength, toughness, heat-resistance, fluidity, molding property etc.. The properties of PA are shown in table 1.

Table1: General physical properties of polyamide resin.

BINDER	Density g•c m^{-3}	Melting point ℃	M.F.R. g•10min^{-1}	Tensile strength kg•c m^{-2}	Percentage elongation %	Flexural strength kg•c m^{-2}	H.D.T. ℃
PA6	1.14	215-225	80-95	750	10	1100	175
PA12	1.02	176-180	55-70	430	>250	560	145
PA6/12	1.05	140-150	60-70	230	>250	230	46

In the production of injection molding permanent magnet, use polyamide resin as binder have excellent blending processing property, forming property, physical property, magnetic property compared with other thermoplastic resin. Characteristic of injection molding NdFeB magnet is shown in table 2.

Table 2: Characteristics of injection molding NdFeB magnet.

BINDER	Powder loadage wt.%	Density g•c m^{-3}	H.D.T. ℃	Tensile strength kg•c m^{-2}	Percentage elongation %	(BH)max kJ•m^{-3}
HT-PA(1)	88.0	4.55	225	918	0.8	35.2
HT-PA(2)	88.0	4.52	215	663	0.7	28.0
PA12	90.0	4.69	130	510	1.0	27.2
PA12	91.0	4.8	125	510	0.7	40.8
PA12	92.0	4.92	115	510	0.7	48.8

4.2 Heat-resisting Polyamide Resin Binder

To raise the properties of bonded magnet, study on permanent magnetic powder is important no doubt, but research on binder polymer is fairly important too. In the field of automobile, electrical appliances and electronic industry, besides magnetic characteristics, the magnet generally need to possess high-level heat-resistance, durability, heat-impact resistance, size stability, high-strength, forming property, reprocessing property etc., and many of these properties are related to binder. The bonded permanent magnet is applying to automobile field along with the high-property and low-cost change of rare-earth permanent magnetic powder. In the automobile engine room, the working temperature can achieve to 130℃, so the magnet should can long time working at -40℃~140℃. Only heat-resistance polyamide can meet the demand above. Polyamides include fat-family and benzenoid-family two types. The benzenoid-family PA have higher heat-resistance and strength than fat-family PA(include PA6, PA12, PA66) because it contain more upright and strong benzene molecular chain. The heat-resistance of benzenoid-family PA is higher than PA12 and lower than PPS. The testing result is shown in table 3, T_g is glass transition temperature, T_m is melting temperature, GF% is glass fiber content added.

Table 3: Heat-characteristics of polyamide.

POLYAMIDE		Density g•c m^{-3}	T_m ℃	T_g ℃	H.D.T. ℃/GF%
PA	PA12	1.02	180	41	167/30GF
	PA6	1.14	220	48	215/30GF
	PA66	1.14	225	50	249/30GF
HT-PA	PA46	1.18	290	78	285/30GF
	PA6T	1.15	320	—	295/30GF
	PA6/6T	1.18	295	110	255/35GF
	PA66/6T	1.1	310	85	290/30GF
	PA6/61/6T	1.1	320	125	310/35GF
	PA66/61/6T	1.2	312	135	285/33GF
	PA6T/M-5T	1.19	300	140	260/35GF

4.3 Poly Phenylene Sulfide Resin Binder

Poly phenylene sulfide is a engineering plastic with high property. At the initial developing stage, the PPS was cross-linking type resin and too brittle to use although it have many excellent properties. In recent years, the new developed PPS is straight chain type resin and changed the brittle property remarkably. The typical property of PPS is shown in table 4.

Table 4: Characteristics of PPS.

PPS	Density g•c m^{-3}	Moisture capacity %	Tensile strength kg•c m^{-2}	Percentage elongation %	Flexural strength kg•c m^{-2}	H.D.T. ℃
PPS-1	1.66	0.015	1750	1.6	2500	>260
PPS-2	1.66	0.015	1850	1.4	2600	>260
PPS-3	2.00	0.013	1450	1.0	2100	>260
PPS-4	2.00	0.014	1050	0.6	1550	>260
PPS-5	1.39	—	1600	1.7	2350	>260
PPS-6	1.45	0.024	2050	1.0	2650	>260
PPS-7	1.68	0.018	1500	1.5	1900	>260

Comparing with other binder, the characteristics of new-type PPS as follow: ①Good heat-resistance: heat distortion temperature is more than 260℃ and can be continuous using at 200~220℃; ②High strength and rigidity: with high tensile strength, flexural strength, flexural modulus; ③Excellent size stability, linear expansion coefficient extreme low, forming shrinkage small; ④Excellent corrosion

resistance: no solvent can dissolve PPS below 200℃; ⑤Forming process property and fluidity fine.

The properties of injection molding magnet by different binder are shown in table 5 (isotropic ferroxcube). The new-type PPS resin have the sticky and firm characteristic which the straight chain type macromolecule peculiar. Comparing with the injection molding magnet bonded by PA, the magnet bonded by PPS has characteristics as follows: ①The same magnetic feature; ②Hardness and flexural modulus high; ③Excellent heat-resistance; ④The same tensile strength and flexural strength; ⑤Small linear expansion coefficient and forming shrinkage; ⑥Small moisture capacity and heat expansion coefficient. It is expected that more PPS bonded injection molding magnet will be applied in automobile because it has excellent heat-resistance.

Table 5: Property of injection molding magnet.

BINDER	Density $g \cdot c\ m^{-3}$	(BH)max $kJ \cdot m^{-3}$	Tensile strength $kg \cdot c\ m^{-2}$	Percentage elongation %	Flexural strength $kg \cdot c\ m^{-2}$	H.D.T. ℃
PA12	2.8	2.16	346	14.4	842	115
PPS	3.06	2.16	355	6.5	890	169

5 THE RESEARCH AND DEVELOP DIRECTIONS OF THE BINDER

The application prospects of injection molding NdFeB magnet is very promising and the magnet output will increase rapidly. In view the important function of binder, the research and develop direction of binder should be concentrated on the following aspects.

①To develop binder with better bond strength and fluidity. One of the main reason to decrease bonded magnet magnetic property is the adding of binder, so the increasing of (BH)max need to develop better binder to reduce the binder content and raising the orienting degree of magnetic particle.

②To develop new type additive and related treatment technology to raise the coupling property of NdFeB magnetic powder and binder, and to modify forming technology and property of injection molding magnet.

③Proper treating the magnetic powder with physical or chemical method before mixing the NdFeB magnetic powder and binder to modify surface state of magnetic powder and it's combing force with binder. At the same time the magnetic property is raised too.

④To develop heat-resistance binder. Injection molding NdFeB magnet applied in automobile will be a vast market, but one of the key problems need to be solved is the heat-resistance of magnet. The heat-resistance is mainly decided by binder, so the developing of heat-resistance binder provoke extensive interest of related people.

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