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A STUDY ON VOLUMETRIC MAGNETIC SUSCEPTIBILITY OF WEIGHT DUE TO ITS MANUFACTURING PROCESS

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Abstract – The OIML R 111-1 requirements on magnetic properties such as the volumetric magnetic susceptibility (χ) and the magnetization of weights used in legal metrology. So far, these requirements cannot met by weights produced locally in Thailand. This research, therefore, aims to study manufacturing processes that may influence the magnetic properties. In order to reduce the magnetic susceptibility of the weights. Preliminary results show that the magnetic properties are stainless steel type dependent. Moreover, controlling process such as cutting, turning with lathe, grinding and heat treatment process can reduce the volume magnetic susceptibility of weights.

Keywords : weight, magnetic susceptibility, manufacturing process

1. INTRODUCTION

Magnetic force can adversely affect the weighing process, since without systematic investigation, these spurious forces cannot be distinguished from gravitational forces in the determination of mass. Magnetic force can arise from the mutual interaction of two mass standard, as well as between a mass standard, the mass comparator being used for the weighing, and other magnetic objects in the vicinity.[1]

At present, weights manufactured in Thailand can not be in line with the specified limitation of OIML R111-1. The main obstacle due to the manufactory process was covered by the condition of magnetism which both the limits of polarization and magnetic susceptibility for E2 weights which nominal weight $\geq$20 g must be less than 2 μT and 0.07, respectively. However, those measured values were still higher than the requirement. Eventhough, the austenitic stainless such as 304 or 316L were chosen as the material of the manufactured weight. In order to improve the technology in the standard weight manufacture, the study on the volumetric magnetic susceptibility of weight due to its manufacturing process was done.

The most variable of weight manufactured, OIML R1111-1 for class E2 is magnetic permeability which is confined mainly to ferromagnetic and ferromagnetic materials. Ferromagnetism exists is a number of metals including iron, many forms of steel, nickel and cobalt. A similar phenomenon occurs in certain non-metals known as ferrites, which are said to be ferrimagnetic. These materials, which can be magnetized, are characterized by variations of magnetic permeability with magnetic field strength, generally in a nonlinear manner and giving rise to hysteresis.[2].

2. INFORMATION BACKGROUND

The magnetic properties of material are affected by composition, methods and physical condition. Ferromagnetic materials are strongly attracted to a permanent magnet and may also be magnetized to act as a permanent magnet. [3]Magnetic permeability is the ability of a material to carry magnetism, indicated by the degree to which it is attracted to a magnet. Stainless steels are high-alloy steels that have superior corrosion resistance than other steels because they contain large amounts of chromium. Stainless steels can contain anywhere from 4-30 percent chromium, however most contain around 10 percent. All stainless steels, with the exception of the austenitic group, are strongly attracted to a magnet.

Austenitic Grades - All austenitic grades have very low magnetic permeabilities and hence show almost no response to a magnet when in the annealed condition; the situation is, however, far less clear when these steels have been cold worked by wire drawing, rolling or even centreless grinding, shot blasting or heavy polishing. After substantial cold working Grade 304 may exhibit quite strong response to a magnet, whereas Grades 310 and 316 will in most instances still be almost totally non-responsive. The change in magnetic response is due to atomic lattice straining and formation of martensite. In general, the higher the nickel to chromium ratio the more stable is the austenitic structure and the less magnetic response that will be induced by cold work.

Stress Relieving - Any austenitic stainless steel which has developed magnetic response due to cold work can be returned to a non-magnetic condition by stress relieving. In general this can be readily achieved by briefly heating to approximately 700 - 800°C (this can be conveniently carried out by careful use of an oxy-acetylene torch). However, unless the steel is a stabilised grade it could become sensitised to carbide precipitation. Full solution treatment at 1000 - 1150°C will remove all magnetic response without danger of reduced corrosion resistance due to carbides. If magnetic permeability is a factor of design or is incorporated into a specification, this should be clearly indicated when purchasing the stainless steel from a supplier.

Cold Working - Many cold drawn and/or polished artefact, weight, have a noticeable amount of magnetism as a result of the previous cold work. This is particularly the case with grades 304 and 303, and much less so for the higher nickel grades such as 310 and 316. Even within the chemical limitations of a single standard analysis range there can be a pronounced variation in the rate of inducement of magnetic response from cold work.

Effect of cold work on- austenitic stainless steels

The table1. shows the relative permeability of 304 and 316 at a low magnetic field strength and various cold reductions. Highly alloyed austenitics including the high nitrogen grades do not develop low carbon martensite on cold work and so their relative permeability typically remains below 1.02. The values may be compared with mild or carbon steel which has a ferritic structure and a relative permeability of at least 200. The effect of composition and degree of cold work (measured by the tensile strength) on the permeability, and hence the strength of any magnetic attraction, is plotted below fig below for a series of austenitic alloys. It shows that increasing the nickel content reduces the effect of cold work on magnetic properties, shows as Fig.1 below[3].

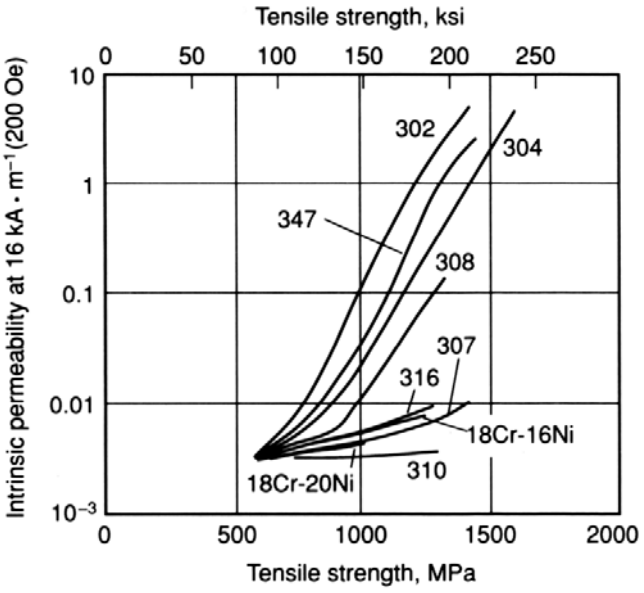

Table 1. Relation of relative permeability of 304 and 316 at a low magnetic field strength and various cold reductions.

Alloy	Cold reduction (% reduction in area)	Relative Permeability
304 (Chromium 19%, nickel 10.7%)	0	1.0037
	13.8	1.0048
	32.0	1.0371
	65.0	1.540
	84.5	2.20
316 (Chromium 17.5%, nickel 13.4%, molybdenum 2.4%)	0	1.003
	20.8	1.003
	45.0	1.004
	60.8	1.0065
	81.0	1.0070

3. EXPERIMENT AND RESULTS

Firstly, we considered about the component of material. So, the OIML weight class E2 was analysed the compound by Optical Emission Spectrometer. The result shows in table 2.

Table 2. The element compound of OIML weight class E2 in percent of total weight

Element compound	Weight in %
C	0.010
Si	0.496
Mn	0.167
P	0.019
S	0.004
Ni	25.512
Cr	20.436
Mo	3.266
Cu	1.085
Mo	3.266
Ti	0.008
Nb	0.014

This result shows the largest element compound of OIML weight class E2 is Nickel (Ni) and close up the specification of stainless type SUS 809L[4]. Unfortunately, we can not find this type stainless steel in commercial Thailand. Next step, the type and price of stainless steel in local are pick up, shows in table 3.

Table 3. The price each type of stainless steel in Baht* (ϕ2.5 cm. X 6 m.)

Type	904L	310S	304	316L	303
price	41,910	11,500	5,900	9,000	8,500

(*about 31 Baht = 1USD)

Therefore, the Fig.2 shows the austenitic stainless such as 304 and 316L were chosen as the material of the manufactured weight.

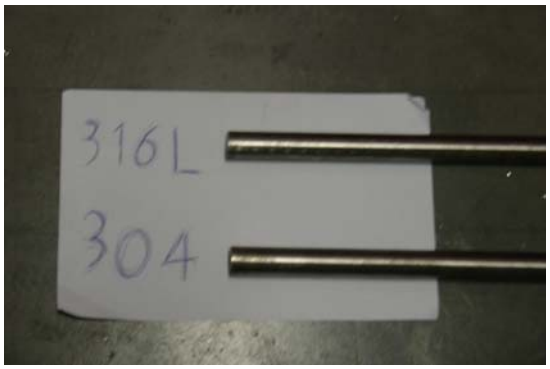

Fig.2 shows the rod of austenitic stainless 304 and 316L

Then, Cutting both rod and mark point of each pieces with the control process with fix the feed at 224 cycle/minute, compare with cooling water, as Fig.3 and except cooling water, as Fig.4

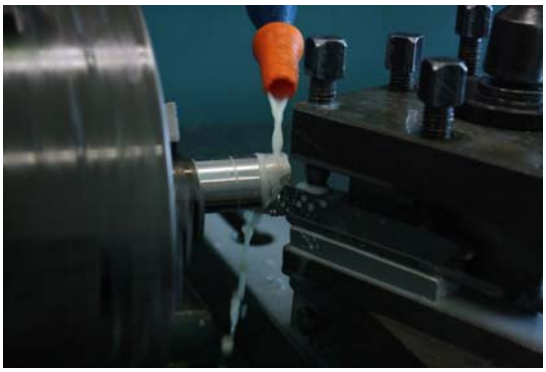

Fig.3 shows cutting process with cooling water

Fig.4 shows cutting process without cooling water

The magnetic properties results use the BIPM susceptometer that was set up at NIMT mass laboratory for measurement of Volume magnetic susceptibility on these sample. Regarding to the theory, measurement procedure and uncertainty calculation from [1] and [5]. The mass comparator is Mettler Toledo UMT5 with a capacity 5.1 g and readability 0.1 μg. The rare-earth magnet is material of Nd Fe and B, diameter 4.8 mm, height 5.1 mm, magnetic moment 0.085 Am^2 and relative magnetic permeability is 1.00506 at 99.97 kA/m of magnetic field strength.

The results measurement of comparing the volume magnetic suscepability at maximum magnetic field is 788.25 $A.m^{-1}$ before and after process of cutting, turning with lathe for both type stainless shows in table 4 below.

Table 4. The results of volume magnetic suscepability at maximum magnetic field is 788.25 $A.m^{-1}$

Type	Process cutting and turning with lathe		Volume magnetic suscepability at Maximum magnetic field = 788.25 $A.m^{-1}$			
	Condition	S/N	Before process	After process	% Deviation	% Uncertainty U_c (k=2)
316L	Cooling water	A10	0.101	0.125	23.76	3.6
		A11	0.119	0.170	42.86	6.4
		A12	0.117	0.156	33.33	5.0
	except	A13	0.100	0.128	28.00	4.2
		A14	0.089	0.108	21.35	3.2
		A15	0.089	0.110	23.60	3.5
304	Cooling water	B10	0.109	0.124	13.76	2.1
		B11	0.119	0.161	35.29	5.3
		B12	0.122	0.142	16.39	2.5
	except	B13	0.129	0.157	21.71	3.3
		B14	0.117	0.156	33.33	5.0
		B15	0.100	0.175	75.00	11.3

Regarding to the tooling machine maintenance and results from table4 , so our team decide to use cooling water in fix the condition process shows as Fig.5.

Fig.5 shows using cooling water

Next, studying about heat treatment process at temperature 768, 850 and 1100 ^oC shows as Fig 6 and stop hot by dipping water shows as Fig 7. The results shows in table5. Then, the final adjust weight by polishing process is pick up to study for improvement the manufacturing process of weight shows as Fig 8 and the results of volume magnetic suscepability in table 6.

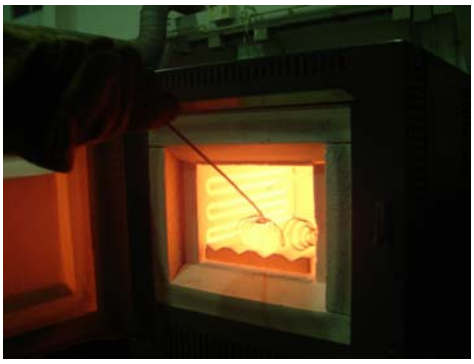

Fig.6 shows heat treatment process

Fig.7 shows dipping water to stop hot

Table 5. The results of volume magnetic suscepability before and after the heat treatment process

Type	Heat treatment process		Volume magnetic suscepability at Maximum magnetic field = 788.25 A.m^{-1}			
	Temperature (^{o}C)	S/N	Before	After	% deviation	% U_c (k=2)
316L	768	A7	0.105	0.060	-42.86	6.4
		A8	0.083	0.043	-48.19	7.2
		A9	0.104	0.060	-42.31	6.3
	850	A1	0.100	0.044	-56.00	8.4
		A2	0.085	0.043	-49.41	7.4
		A3	0.104	0.040	-61.54	9.2
	1100	A4	0.094	0.176	87.23	13.1
		A5	0.099	0.170	71.72	10.8
		A6	0.094	0.173	84.04	12.6
304	768	B7	0.143	0.068	-52.45	7.9
		B8	0.101	0.058	-42.57	6.4
		B9	0.138	0.064	-53.62	8.0
	850	B1	0.100	0.047	-53.00	8.0
		B2	0.097	0.046	-52.58	7.9
		B3	0.106	0.046	-56.60	8.5
	1100	B4	0.094	0.172	82.98	12.4
		B5	0.096	0.164	70.83	10.6
		B6	0.091	0.152	67.03	10.1

Fig.8 shows polishing process

Table 6. The results of volume magnetic suscepability before and after final polishing process

Type	Volume magnetic suscepability at Maximum magnetic field = 788.25 A.m^{-1}				
	S/N	Before process	After process	% deviation	% Uncertainty U_c (k=2)
316L	A10	0.125	0.106	-15.20	2.3
	A11	0.170	0.124	-27.06	4.1
	A12	0.156	0.113	-27.56	4.1
304	B10	0.124	0.118	-4.84	0.7
	B11	0.161	0.128	-20.50	3.1
	B12	0.142	0.101	-28.87	4.3

4. CONCLUSIONS

The process of manufacturing weight in Thailand may influence the magnetic properties. In order to reduce the magnetic susceptibility of the weights to meet OIML R111-1 technical requirement about magnetism. Preliminary results show that the magnetic properties are stainless steel type dependent. The results of comparison between 304 and 316 austenitic stainless steels show the the volume magnetic suscepability change during the manufacturing process such as cutting, turning with lathe, grinding and heat treatment process.

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