Study of Elastic Moduli of Sintered Low Alloy Steels by Acoustic Pulse Method

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Abstract

The influence of porosity (P) on Young's modulus (E) and Poisson's ratio (υ) of sintered steels produced from four types of steel powders was investigated. The values of E and υ depend mainly on the value of P, and those were a little affected by alloying elements. The relationships between E, υ, and P were described as following equations:
$E = E_0\cdot(1 - k_E\cdot P)^2$ *and* $\upsilon = (\upsilon_0 - \upsilon_{sub})\cdot(1 - k_\upsilon\cdot P)^2+\upsilon_{sub}$, *where subscript 0 means P = 0, and* k_E, k_υ *and* υ_{sub} *are empirical constants. These approximate equations showed good agreement with empirical results.*

Keywords : P/M Machine Part, Young's Modulus, Poisson's Ratio, Diffusion Bonded Powder, Prealloyed Powder

1. Introduction

Sintered steels are usually used for P/M machine parts. For designing or for finite element calculation of P/M parts, elastic moduli, such as Young's modulus and Poisson's ratio, are required. The elastic moduli of wrought steel, which are published in many reports, can not be used for sintered steel because of its porosity.

There are some reports of the Young's modulus of sintered steel [1, 2] and but not for that of Young's modulus with Poisson's ratio. Both Young's modulus and Poisson's ratio are affected mainly by porosity, secondly by the kind of base iron powder or sintering temperature, but are shown to be independent of alloying elements, heat treatment, and sintering atmosphere [3].

In this report, the effects of the type of powder (diffusion bonded or prealloyed powders), porosity, and alloying elements on Young's modulus and Poisson's ratio were investigated.

2. Experimental and Results

Four types of base iron powders produced by Höganäs AB were mixed with natural graphite powder were prepared.

Table 1 shows a mixed composition of each powder type. The powders were compacted at pressures up to 882 MPa. A die wall lubrication with zinc stearate was applied. The dimension of green compacts was 11mm in diameter and 5mm in thickness. They were sintered at 1423 or 1523K for 1.8 ks in a $75N_2/25H_2$ atmosphere. The sintered compacts were carburized at CP of 0.8% and oil-quenched at 1173 K for 3.6 ks and tempered at 453 K for 3.6 ks in air.

Table 1. Chemical composition of powders

Type	Mixed powder [%: mass%]
A	[Fe - 0.5%Mo - 4%Ni - 1.5%Cu] + 0.8%C
B	[Fe - 1.5%Mo - 2%Ni] + 0.5%C
C	[Fe - 1.5%Mo - 4%Ni - 2%Cu] + 0.5%C
D	[Fe - 1.5%Mo] + 0.5%C

Underline: diffusion bonded element
Double underline: prealloyed element

The porosity (P) was calculated using the relation of $P = 1 - \rho/\rho_0$, and ρ_0 is the theoretical density. In this study, ρ_0 was calculated using the density of pure material and mixed composition. Each ρ_0 of sintered type A, B, C, or D compact was 7.89, 7.90, 7.94, or 7.88 Mg/m^3, respectively.

Longitudinal wave velocity (V_l) and shear wave velocity (V_s) were measured by an acoustic pulse method [4] with a center frequency at 5 MHz. Young's modulus (E), shear modulus (G), and Poisson's ratio (υ), were calculated by V_l, V_s and ρ [4].

The values of E, G, and υ of each powder increased with increasing sintering temperature. Consequently, the pores became rounder with increasing sintering temperature which increased the elastic moduli. However, above effect is smaller than that of porosity.

Figure 1 shows elastic moduli vs. P for each steel powder.

Although the effect of the type of steel powder on elastic modulus can be seen, the effect is not significant. The fitting curves in Fig. 1 were drawn by Eqs. (1) and (2) [5].

$$E = E_0 (1 - k_E P)^2 \quad (1)$$
$$\upsilon = (\upsilon_0 - \upsilon_{sub})(1 - k_\upsilon P)^2 + \upsilon_{sub} \quad (2)$$

where the subscript 0 means P = 0, k_E, k_υ, and υ_{sub} were empirical constants.

The G {= 0.5E / (1 + υ)} versus P was calculated by Eqs. (1) and (2). The fitting curve of G corresponds to the measured value. The value of E_0 depends on the kind of steel powder. The value of k_E at higher sintering temperature, 1523K becomes smaller, and then the E value of them decreased more gently with the increase of porosity. The values of υ_0 and υ_{sub} are a little affected by sintering temperature or the type of steel powder. The value of k_υ depends on both parameters.

For practical PM structural components, we assume porosity is below 20%. Here, the elastic moduli of sintered steels were compared with those of sintered plain iron (atomized plain iron powder: 1423K). Figure 2 shows the difference between calculated value and measured value. The values of E_{calc} and υ_{calc} were calculated using the following equations obtained from the measured values of sintered iron.

$$E_{calc} = 220.4\cdot(1 - 1.477\cdot P)^2 \quad (3)$$
$$\upsilon_{calc} = (0.300 - 0.273)\cdot(1 - 4.98\cdot P)^2 + 0.273 \quad (4)$$

The measured values are plotted from E_{calc} - 10 to E_{calc} [GPa] and from υ_{calc} - 0.002 to υ_{calc} + 0.004. The alloying element against mechanical property, such as tensile strength and proof stress, should be considered, but the above difference of elastic moduli is very small. The calculated elastic moduli by the equations of E_{calc} and υ_{calc} can be used as the elastic moduli of conventional P/M machine parts.

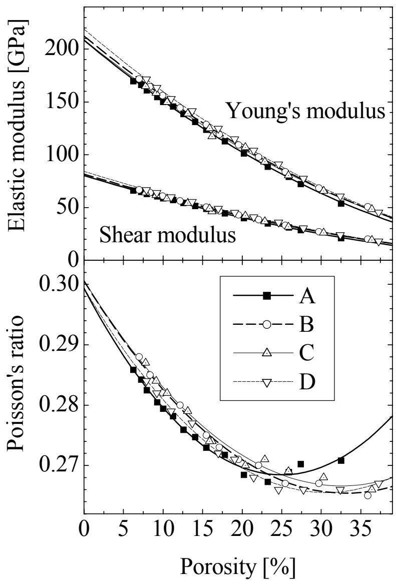

Fig. 1. Elastic moduli and Poisson's ratio vs. porosity of sintered steels (sintering: 1423K).

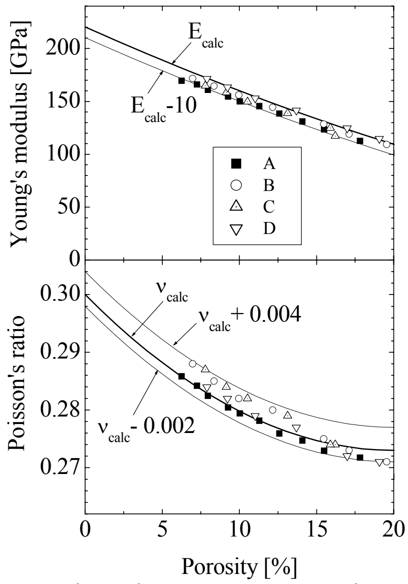

Fig. 2. Relationships between elastic moduli and porosity of sintered steels. The curves of E_{calc} and υ_{calc} were obtained from sintered atomized iron (both iron and steel powder compacts sintered at 1423K).

3. Summary

Young's modulus and Poisson's ratio of sintered low alloy steels with different porosities were investigated.

1) The equations used in this paper correspond to the measured relationships between elastic moduli and porosity of sintered steels.
2) The relationships between elastic moduli and porosity of sintered steels can be approximated by that of sintered plain iron, if the characteristics (size, shape, production method etc.) of base powders are similar.

4. References

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