

## Sonic Testing of Resinoid Grinding Wheels

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The grade is one of the most important characteristics of grinding wheels and generally determined by the mechanical device such as the Okoshi Grade Tester. The  $E$ -modulus as a measure of the wheel grade has a persuasive power to both grinding researchers and wheel manufacturers because of its real physical significance. This handy and non-destructive sonic method is already of considerable use for the vitrified grinding wheel but not yet satisfactorily applied to the resinoid one, because this method is supposed to be improper to determine the  $E$ -modulus of the resin by reason of its damping nature.

In this test, the Grindo-Sonic was adopted as a testing device to determine the  $E$ -modulus because of the measuring rapidness and the accuracy of the results. At the same time, the bending test was carried out using the same specimens.

In order to put the sonic grade of the resinoid grinding wheel into practice, it was necessary to know the correlation between the  $E$ -modulus and the Okoshi grade. According to the test result, it was seen that there existed an inverse correlation between them.

The relation between the  $E$ -modulus and the grinding performance, i.e. metal removal rate and grinding ratio was apparently uncertain, but there seemed to exist good relations between them if examined in detail concerning the wheel composition. Among the various manufacturing factors, the  $E$ -modulus of the resinoid grinding wheel was influenced significantly by such factors as the amount of bond, green density, type of bond, type of wetter and curing condition, whereas no significant difference was observed in the type of abrasive grains, grain size and filler. Unlike the bending strength, the  $E$ -modulus was very sensitive to the nature of the bond itself. In conclusion, it was clear that this sonic method of the grade determination would be also serviceable for the resinoid grinding wheel.

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### レジノイド砥石の音響試験

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研削砥石の性能を左右する結合度は、一般に機械的な方法で測定されているが、物理的意味に乏しくまた砥石を傷つけるなどの欠点があるため、あまりすぐれた方法ではない。最近、砥石の固有振動数からその動弾性率を求めて結合度を判定する方法が提案され、測定値に普遍性があり非破壊的にじん速に測定できるため、広く用いられる傾向にある。しかし、これに関する研究はビトリフエイド砥石に限られ、レジノイド砥石に関するものは見当らない。高能率研削の進展と共に、レジノイド砥石が研削砥石の主流を占めるようになった現在、この音響試験のレジノイド砥石への早急な適用が望まれる。本報では、この見地からレジノイド砥石の製造方法と組成と動弾性率との関係を、固有基準振動数をじん速に検出できるグリンソニックにより求めた。この結果、この方法はレジノイド砥石の結合度の判定に十分利用できることがわかった。

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#### 1. Introduction

The grade or so-called hardness is one of the

most important characteristics of a grinding wheel, as it is closely related to the grinding performance

at work. Although numerous methods for the grade testing have been proposed by many researchers and already used practically, a conclusive method has not yet been agreed upon to the satisfaction of all.

Most of grinding wheel manufacturers make use of their own mechanical grade testers such as scratching or sand-blasting grader. In Japan, Okoshi Grade Tester is used under an obligation of Japan Industrial Standard. A chisel tipped with cemented carbide is screwed down into the grinding wheel, and the depth of indentation is measured resulting in the grade conversion. This type of grade tester is not internationally accepted and therefore some other device having a universal validity has long been awaited.

Sonic method has recently been in use for this purpose, because the measuring procedure is handy and non-destructive, and the measured value has a real physical significance.

Even though several investigations of sonic testing were done as to the grinding wheel, they all concerned the vitrified grinding wheel, which occupied a majority in former days. With increasing demands for higher grinding productivity, resinoid grinding wheels have held the greater part of grinding wheels. For this reason, it has become necessary to make clear the sonic hardness of resinoid grinding wheels.

In this paper, resinoid grinding wheels were subjected to the sonic testing using Grindo-Sonic to find their possibility of practical application.

## 2. Present status of sonic testing

### 2.1 Test device

The  $E$ -modulus of a grinding wheel is statically measured by bending test in most cases. It is also measured dynamically by means of acoustic method. The sonic devices refer to the measurement of dynamic  $E$ -modulus of a grinding wheel in spite of their different origins. Sonic Comparator and Grindo-Sonic are based on detecting the natural frequency of a grinding wheel within an audible range, and the measured values represent the overall characteristics of an entire test piece. Sonic Comparator is extensively used in many grinding wheel manufacturers in U.S.A. and Japan, and characterized by the  $E$ -modulus calculation from any natural frequency regardless of the mode of vibration. Grindo-Sonic is mainly used in Europe, and characterized by measuring the gravest resonance frequency of fundamental mode. The values obtained by these two devices are quite the same, because the measuring principle is based on the natural frequency in both cases.

Ultrasonic Grader is different in principle from the said devices<sup>1)</sup>. A beam of high frequency vibrations is transmitted into a grinding wheel, so that the  $E$ -modulus evaluation is accomplished at a given

location of the wheel but not as a whole. In this case, it is necessary to know Poisson's ratio in advance.

### 2.2 Research situation

As the sonic hardness has a persuasive power to both grinding researchers and wheel manufacturers because of its real physical significance, several investigations of sonic testing can be found. However they are all concerned with vitrified grinding wheels.

A. Decneut and his coworkers investigated the relation between the  $E$ -modulus and the volumetric wheel composition using Grindo-Sonic and made a grade chart<sup>2)</sup>. They also investigated the grinding performance of grinding wheels in connection with the sonic hardness and concluded that the  $E$ -modulus was a good measure for this purpose in much the same way as other grade. The conversion table from the  $E$ -modulus to the hardness letter for vitrified grinding wheels was proposed by them and it is generally accepted in the field of grinding. This table is reproduced in the literature<sup>3)</sup>.

F.G. Rammerstorfer and his coworker investigated the  $E$ -modulus in relation to the conventional wheel grade, structure, grain size, types of grain and bond using the same device<sup>4)</sup>. According to their test results, the type of bond has no correlation to the  $E$ -modulus but that of abrasive grain is fairly related to it.

The author investigated the relation between the sonic value  $k$ , which is a function of the natural frequency of the fundamental flexural mode, the wheel using Sonic Comparator<sup>5)</sup>.

## 3. Experimentals

### 3.1 Preparation of test pieces

Most of abrasive products are in the shape of perforated disk but sometimes of rectangular bar. Such both shapes are suited for the sonic testing, and the obtained values by these two types of specimens almost agree within the experimental errors, as much as they are composed of the same material.

Because of the measuring rapidness and the accuracy of the results, Grindo-Sonic was adopted in this test. In order to know the relation between the  $E$ -modulus and the grinding performance of resinoid grinding wheels in comparison with the Okoshi hardness, test specimens were made under the preparations using the phenolic resin of snagging use as shown in Table 1. The size of the specimens is: 180 mm outside diameter  $\times$  22 mm thickness  $\times$  19 mm hole diameter. This disk shaped specimen is available for measuring both the  $E$ -modulus and the Okoshi hardness before the grinding test.

In order to put the sonic hardness of resinoid grinding wheels into practice, it is necessary to know

**Table 1.** Preparations of test pieces (in weight %).

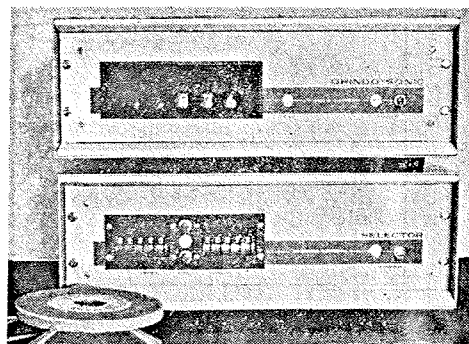
No.	Abrasive grain regular A# 46	Bond, powdered resin and pure content of liquid resin*	green density (g/cm <sup>3</sup> )
1	100	11.5	2.2
2	100	11.5	2.3
3	100	11.5	2.4
4	100	13.7	2.2
5	100	13.7	2.3
6	100	13.7	2.4
7	100	15.9	2.2
8	100	15.9	2.3
9	100	15.9	2.4
10	100	18.2	2.2
11	100	18.2	2.3
12	100	18.2	2.4

\* powdered resin/liquid resin=4.2  
 powdered resin: Novolak resin, hexamethylene-tetramine =11 phr, melting point=88°C, average molecular weight=750  
 liquid resin (wetting agent): Resol resin, water soluble, viscosity at 25°C =320 cP

**Table 2.** Preparations of test pieces.

Manufacturing factors	levels		
	1	2	3
Fused alumina grain	Regular	White	Single
Grain size (#)	24	46	100
Powdered resin	A	B	C
Amount of bond (wt % per 100 grains)	12	14	16
Filler	D	E	F
Wetting agent	G	H	I
Green density (g/cm <sup>3</sup> )	2.1	2.2	2.3
Curing condition	J	K	L

A: Novolak resin, hexamethylenetetramine=6 phr, melting point =94°C, average molecular wt.=500  
 B: Novolak resin, hexamethylenetetramine=6 phr, melting point=83°C, average molecular wt.=600  
 C: Novolak resin, hexamethylenetetramine=11 phr, melting point=88°C, average molecular wt.=750  
 D: cryolite  
 E: pyrite  
 F: none  
 G: Resol resin, water soluble, viscosity at 25°C=700 cP  
 H: Resol resin, water soluble, furfural modified, viscosity at 25°C=220 cP  
 I: Resol resin, water soluble, high ortho-methylolmelamine type, viscosity at 25°C=300 cP  
 J: slow temperature rise of 10°C/h up to 190°C, keeping for 9 h.  
 K: rapid temperature rise of 20°C/h up to 180°C, keeping for 9 h.  
 L: slow temperature rise of 10°C/h up to 180°C, keeping for 15 h.

**Fig. 1.** Grindo-Sonic.**Table 3.** Grade of the resinoid grinding wheel in relation to its composition in practical production.

hardness letter	grain ratio (vol %)	bond ratio (vol %)	porosity (vol %)
H	46.2	12.2	41.6
K	46.5	16.5	37.0
N	48.0	23.0	29.0
Q	49.4	27.3	23.3

the relation between the  $E$ -modulus and the manufacturing condition of the wheels. In this case, test pieces of following size were made according to the preparations as shown in **Table 2**: 150 mm length  $\times$  15 mm width  $\times$  15 mm height. The preparations were determined so as to become the 3 levels orthogonal array of 27 sizes.

Grinding wheel manufacturers determine the grade of resinoid grinding wheels by changing both the amount of bond and molding density apart from the type of bond. This means that the grade is a function of both structure  $v_g$  and bond ratio  $v_b$ . Another important characteristic of grinding wheels is the strength, because they are used in severe condition. The  $E$ -modulus is not always unrelated to the strength in case of the grinding wheel. For these reasons, the third test was performed concerning the influence of the wheel composition upon both the  $E$ -modulus and the bending strength using the test pieces of the said size. The preparations are shown in **Table 3**.

### 3.2. Test procedure

The measurement of the  $E$ -modulus was performed by means of Grindo-Sonic instead of Sonic Comparator (**Fig. 1**).

The abrasive product to be tested was placed on a very soft material made of non-woven fabric or on a plastic cone so as to vibrate freely. The detection of piezo-electric transducer was held at the place of maximum vibration of the test piece, which was then excited with a hammer very slightly. On the display panel of the device, the Grindo-Sonic reading ( $R$  value) was directly seen. The relation between  $K$  and the natural frequency  $f$  is:  $R=2 \times 10^6/f$ .

In the case of disks with diameter-to-thickness ratio ( $D/h$ ) ranging from 3.30 to 25 and with hole-to-diameter ratio ( $d/D$ ) ranging from zero to 0.70, the  $E$ -modulus is calculated according to the equation:

$$E = \frac{P\phi D^2}{R^2} \left( \text{kN/mm}^2 \right)$$

where  $E$ :  $E$ -modulus (kN/mm<sup>2</sup>)

$P$ : shape factor<sup>9)</sup>

$\phi$ : mass density (g/cm<sup>3</sup>)

$D$ : outside diameter of the wheel (mm).

For the rectangular bar, whose length-to-thickness ratio ( $l/h$ ) is between 3 and 24, the  $E$ -modulus is calculated according to the equation:

$$E = \frac{P\phi l^3}{R^3} \quad (\text{kN/mm}^2)$$

where  $P$ : shape factor<sup>6)</sup>  
 $l$ : length of the bar (mm).

Bending strengths of the specimens were determined by means of 3 points bending tester, Toyo Seiki Co. with a span length of 140 mm.

The Okoshi hardness was determined by measuring the indentation depth in millimeter. In this case, the chisel was turned for 120° under the load of 80 kgs for resinoid grinding wheels.

Grinding tests were performed with an electric portable grinder Type QRT, Hitachi Koki Co.. Unhardened carbon steel S-45 C was ground at a peripheral speed of 30 m/s under 5 kgs load in a swing frame way.

#### 4. Results and consideration

##### 4.1 $E$ -modulus vs. Okoshi hardness

Regardless of the wheel preparations, the relations between the  $E$ -modulus and the Okoshi hardness

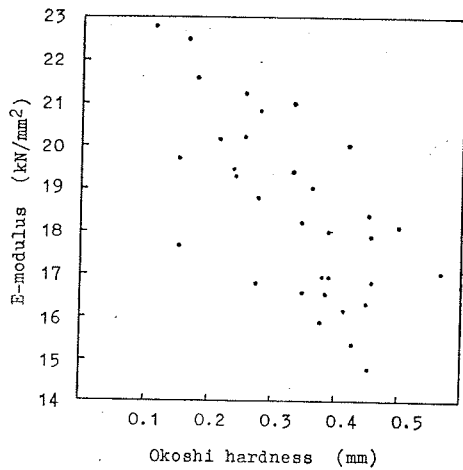


Fig. 2. Relation between  $E$ -modulus and Okoshi hardness.

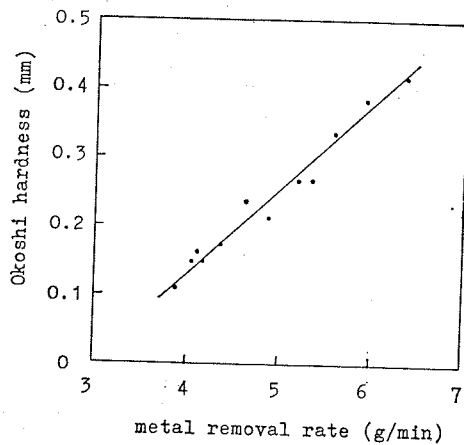


Fig. 3. Metal removal rate vs. Okoshi hardness.

are plotted on Fig. 2. From this figure, it is seen that there exists an inverse correlation between them.

##### 4.2 $E$ -modulus vs. grinding performance

In the first test series, grinding performances such as metal removal rate (g/min) and grinding ratio (g/g) were determined. Fig. 3~6 show the influences of the  $E$ -modulus and the Okoshi hardness upon the grinding performances. From these figures, it is clear that the Okoshi hardness determined by a kind of scratching method represents the grinding characteristics of the wheel more closely than the  $E$ -modulus. Considering both the amount of bond and molding density, these influence can be observed separately as seen from Fig. 4 and 6.

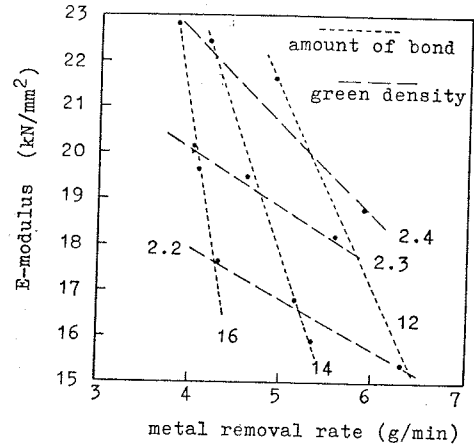


Fig. 4. Metal removal rate vs.  $E$ -modulus.

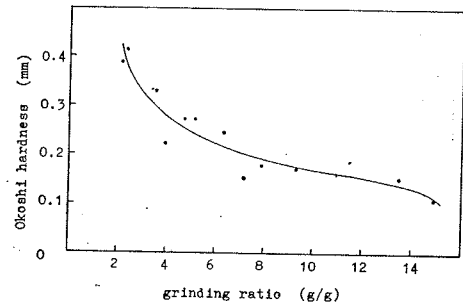


Fig. 5. Grinding ratio vs. Okoshi hardness.

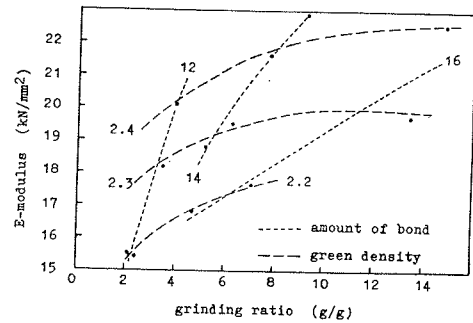


Fig. 6. Grinding ratio vs.  $E$ -modulus.

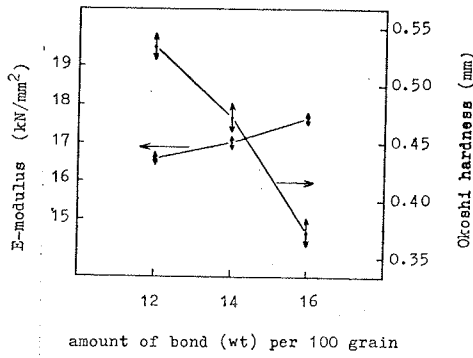


Fig. 7. Effect of amount of bond on *E*-modulus and Okoshi hardness.

**4.3 Effect of manufacturing conditions**

In the second test series, an experimental design was adopted to make the test pieces.

Concerning the effect of the type of abrasive grain, there exists a remarkable difference between the *E*-modulus and the Okoshi hardness. White fused alumina gives softer grade in the Okoshi hardness, whereas regular fused alumina produces harder one. This is understood by the fact that the former is by far the friable grain of the two. In the case of the *E*-modulus, however, there is no significant difference between the abrasive grains, because it is insensitive to the structure.

Coarser abrasive grain results in softer Okoshi hardness and the reverse is also true. This is perhaps due to the grain toughness as well as the bulk density of abrasive grain. On the contrary, the grain size does not seem to have a direct effect on the *E*-modulus, so far as the conventional phenolic resins are used as a bond.

The amount of bond, which naturally means both powdered resin and wetting agent, is highly significant to both the *E*-modulus and the Okoshi hardness as shown in Fig. 7.

The filler does not affect both types of hardness.

The wetting agent is a significant factor only to the *E*-modulus as shown in Fig. 8. This is an interesting thing to the wheel manufacturer.

The molding density, i.e. green density is highly significant to the *E*-modulus as well as the Okoshi hardness as shown in Fig. 9.

Concerning the curing condition, a significant correlation is observed only in the *E*-modulus as shown in Fig. 10. This means that the *E*-modulus is very sensitive to the nature of the bond itself.

**4.4 Effect of wheel composition**

The third test series refers to the influence of the wheel composition upon the *E*-modulus and the bending strength. From the wheel composition, it is possible to calculate the volumetric ratios of three elements, i.e. structure  $v_s$ , bond ratio  $v_b$  and porosity  $v_p$ . For this purpose the wheel density of cured

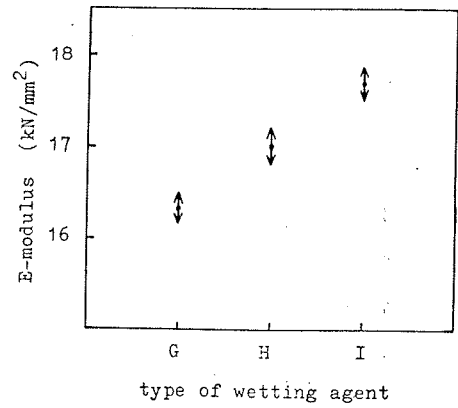


Fig. 8. Effect of wetting agent on *E*-modulus.

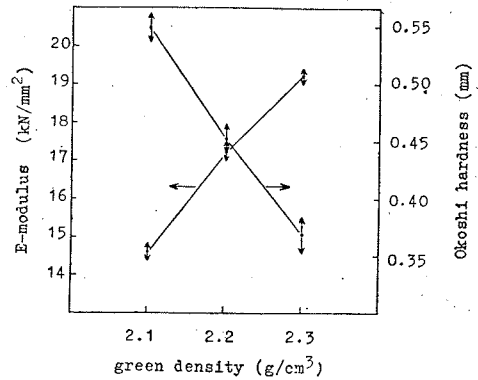


Fig. 9. Effect of green density on *E*-modulus and Okoshi hardness.

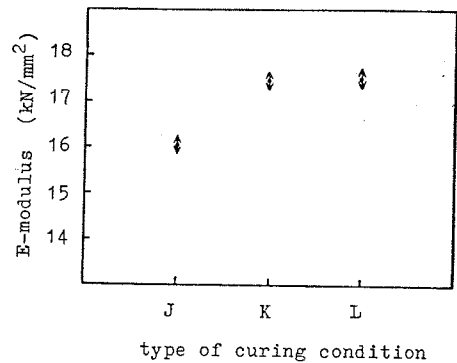


Fig. 10. Effect of curing condition on *E*-modulus.

state must be adopted, because the resinoid grinding wheel changes its initial volume during curing.

The effect of the variation in wheel composition on the *E*-modulus is shown in Fig. 11. It is said that the *E*-modulus is independent of grain size, and this is also confirmed in this test. As is obvious from the figure, however, finer abrasive grain brings larger *E*-value in some measure. This tendency can be recognized when tested with the grinding wheels of various grain sizes of the same composition.

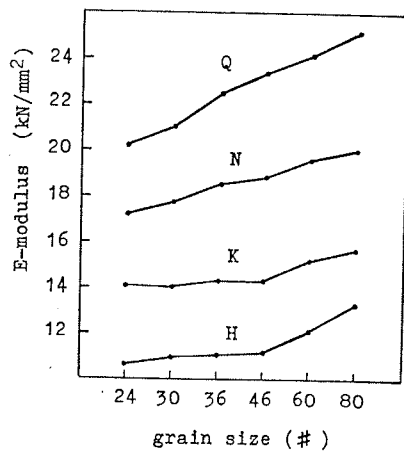


Fig. 11.  $E$ -modulus in relation to the wheel composition for various grain sizes.

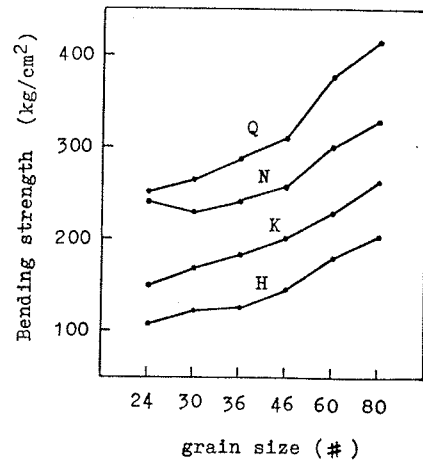


Fig. 12. Bending strength in relation to the wheel composition for various grain sizes.

The effect of the variation in wheel composition on the bending strength is shown in Fig. 12. It is evident from this figure that the finer abrasive grain brings the greater bending strength considerably.

The ratio of the bending strength to the  $E$ -modulus is considered as some measure of evaluating the wheel stickness. This value increases with decreasing grain diameter, and is twice as large as that of corresponding vitrified grinding wheel.

### 5. Summary

The grade of resinoid grinding wheel was acoustically investigated using Grindo-Sonic.

It became clear from the test results that the sonic hardness corresponding to the  $E$ -modulus of the wheel was strongly influenced by the wheel composition, i.e. structure and porosity. Moreover the nature of the bond had a considerable effect on the value

of the  $E$ -modulus.

Although the  $E$ -modulus cannot be a direct measure to evaluate the grinding performance at work, it was concluded that this non-destructive method of the grade determination would be serviceable for resinoid grinding wheels.

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