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Effect of Austempering Treatment on Dynamic Characteristics of Brake Drums

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오스템퍼링 처리가 브레이크 드럼의 동적 특성에 미치는 영향

임경빈*

Abstract

The effect of austempering treatment on the dynamic properties of a brake drum was investigated to primarily evaluate the potential damping advantage of an AGI (austempered gray iron) drum over a PGI (pearlitic gray iron) drum. This investigation provides valuable information for brake noise reduction since the brake drum is most often the outstanding component that generates the noise of the brake assembly. Test results show that the AGI drum provided slightly larger damping values than the PGI drum for the first few major resonances observed. A finite element model of a drum was also developed to aid in studying its dynamic behavior. A good correlation was obtained between the analytical results and the actual measurement data.

Key Words : Brake drum(브레이크 드럼), Austempered Gray Iron(오스템퍼드 회주철), Dynamic Characteristics(동적 특성), Damping(감쇠)

1. Introduction

The noise problems of drum brakes have long been studied by various investigators.[1~4] Many different methods to suppress brake noise have been suggested. One of them is to increase the damping capacity of the brake material. Miller[5] studied the influence of the metallurgy of the brake component on damping for the suppression of squeal in disc brake system. He changed the contents of the pearlitic gray iron material used for the disk rotor and found that high carbon equivalent pearlitic gray irons can substantially reduce the occurrence of disc brake squeal. His results indicated that gray iron damping capacity is a function of graphite type, size and quantity and also of the lamallae spacing in the pearlite matrix. Commonly produced brake drums are made of pearlitic

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gray iron material. It is desired to study the dynamic characteristics of an austempered gray iron drum to evaluate the potential damping advantage of austempered gray iron over the pearlistic gray iron. An AGI drum has a different microstructure from a PGI drum, even though both drums have similar chemical compositions. VanMaldegiam et al.[6] evaluated the structure and general properties of austempered gray cast iron and presented that austempered gray cast iron offers greater strength, ductility, toughness, and wear resistance than the pearlitic gray cast iron. A study on the damping capacity of austempered gray cast iron was conducted by Han et al.[7] They used test specimens produced from ingot to determine the best combination of tensile strength and damping capacity of gray cast iron by varying austempering conditions.

There are two major techniques generally used to study the dynamic behavior of mechanical structures. One is an analytical modal analysis that uses a finite element program and the other is an experimental modal analysis that employs a modal testing program. By utilizing the particular strengths of each technique, more reliable results can be effectively obtained. Therefore, both techniques are often used together, as in this study, to study the dynamic characteristics of a structure such as a micro milling machine.[8]

In this paper, ∅380 x 220 mm brake drums were used to investigate the effect of material change on the dynamic properties of the drums. The natural frequencies, mode shapes, and damping of the brake drums were measured and analyzed by employing both the experimental modal analysis and the finite element analysis. An experimental modal test was also conducted to have a better understanding of the significance of the damping value. This study is believed to provide valuable information for the brake noise reduction since the brake drum is most often the outstanding component that generates the noise of the brake assembly.

2. Experiments

2.1 Test Procedure

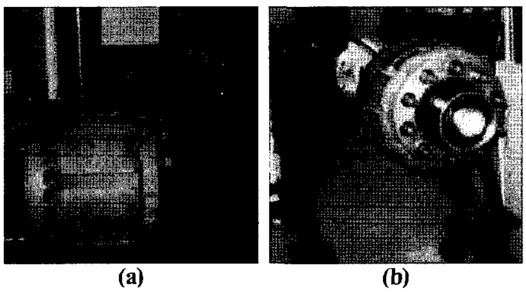
Two pearlitic gray iron drums and two austempered gray iron drums were prepared for the test. The AGI drums tested were made from the same batch, and produced by austeniting at 860°C degrees for 120 minutes and then tempering at 260°C degrees for 120 minutes. Prior to each test, all test samples were visually inspected to check for any structural defects. Two PGI drums and two AGI drums were then assembled in turn on the half axle stub assembly that was bolted to the specially designed cart as shown in Figure 1.

Each drum was marked at 24 equally spaced locations along the rim of the drum for impact tests. Impact tests were conducted by striking the drum radially with the force instrumented impulse hammer to investigate the dynamic behavior of the drum. The striking was repeated five times at the marked locations. The resultant motion was measured with an accelerometer mounted on the rim of the drum. The response signal was amplified by a charge amplifier and fed to the DIFA SCADAS system which was the front end of the LMS measuring system. The LMS system averaged the repeated transfer functions between input and output responses to reduce the signal noise. A HP dynamic signal analyzer was also used to quickly examine the response signal in the frequency domain as well as in the time domain.

The block diagram of the instrumentation setup from a drum to the plotter is shown in Figure 2.

2.2 Experimental Results and Discussion

The effect of austempering treatment on the dynamic properties of a brake drum was first investigated through



(a) (b)

Fig. 1 Drum assembled on (a) the half axle stub and mounted on (b) the cart

a series of impact tests.

Figures 3 and 4 show the typical response of the free vibration of the PGI and the AGI drums in time domain and frequency domain under an impact, respectively. As shown in Fig. 3(a) and Fig. 4(a), the response of the AGI drum in time domain is less dense than that of the PGI drum because the reponses of the AGI drum at certain frequencies decay faster due to larger damping effect. The results from a series of impact response measurements were analyzed by the simulation solution of the LMS measuring system to produce the dynamic parameters of drums and are presented for the first three major resonances of drums in Table 1.

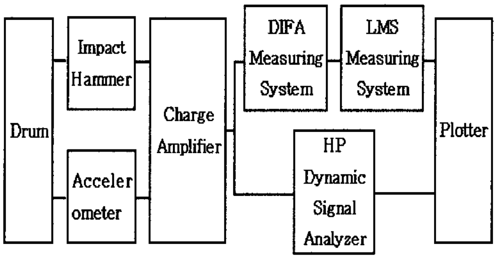


Fig. 2 The block diagram of the instrumentation setup

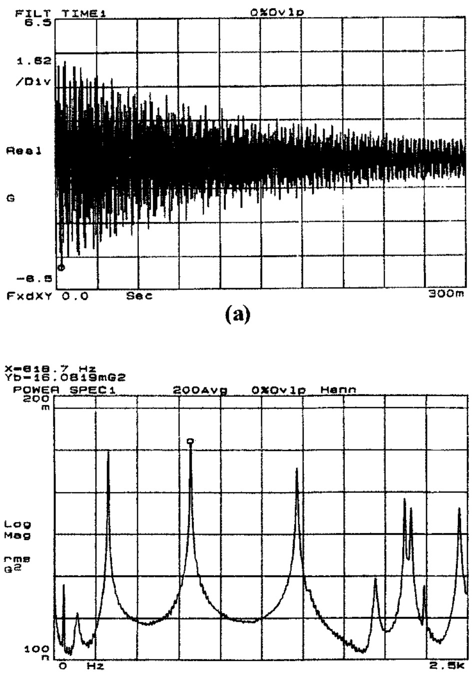


Fig. 3 Responses of a PGI drum in (a) time domain and (b) frequency domain

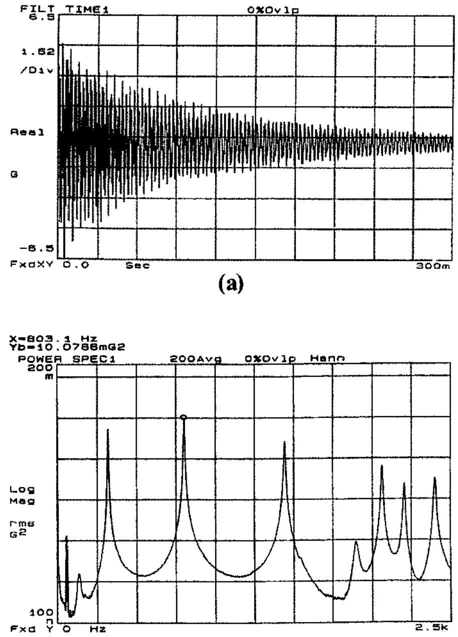


Fig. 4 Responses of an AGI drum in (a) time domain and (b) frequency domain

Table 1 Results from impact tests

Major Resonances	First		Second		Third	
	Frequency (Hz)	Damping (%)	Frequency (Hz)	Damping (%)	Frequency (Hz)	Damping (%)
PGI drum 1	324	0.13	820	0.07	1469	0.12
PGI drum 2	337	0.11	841	0.07	1521	0.11
AGI drum 1	319	0.20	805	0.17	1445	0.18
AGI drum 2	323	0.18	837	0.14	1497	0.17
PGI w/ Hose	320	0.13	829	1.54	1470	0.48

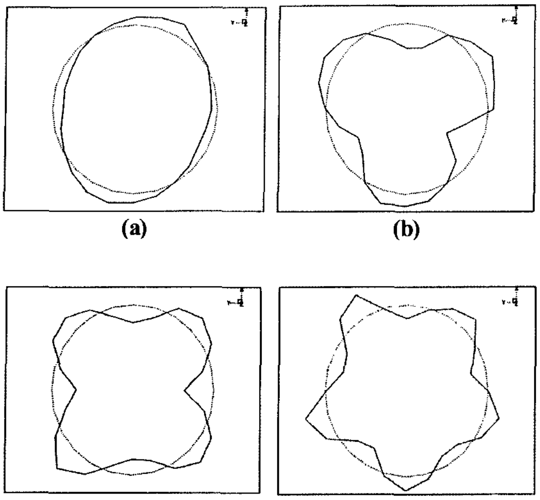


Fig. 5 (a) Elliptical (b) Triangular (c) Square (d) Pentagon mode obtained from modal testing

As shown in the table, the natural frequencies of drums vary some but the differences in resonances among these drums are considered to be relatively small and insignificant. However, both AGI drums consistently provided slightly larger damping values than PGI drums for the first three resonances observed. Although the difference appears small, this could offer a meaningful improvement since the magnification factor, the ratio of output amplitude to input amplitude, is inversely proportional to the damping value in a SDOF (Single Degree Of Freedom) system for light damping, typically less than 5%.

The associated mode shapes of a drum obtained from impact response measurements are shown in Figure 5. The elliptical, triangular, and square modes correspond to the first, second, and third resonances, respectively.

Impact tests were also conducted after a hose (SAE 20R3 Class D2) was wrapped around PGI drum 1 to have a deeper understanding of the significance of the damping values. This trial stems from the fact that installing a coil-spring around a drum is a proven method of reducing the brake noise in certain applications.

Figure 6 presents the response after winding the hose around the drum in both time and frequency domains.

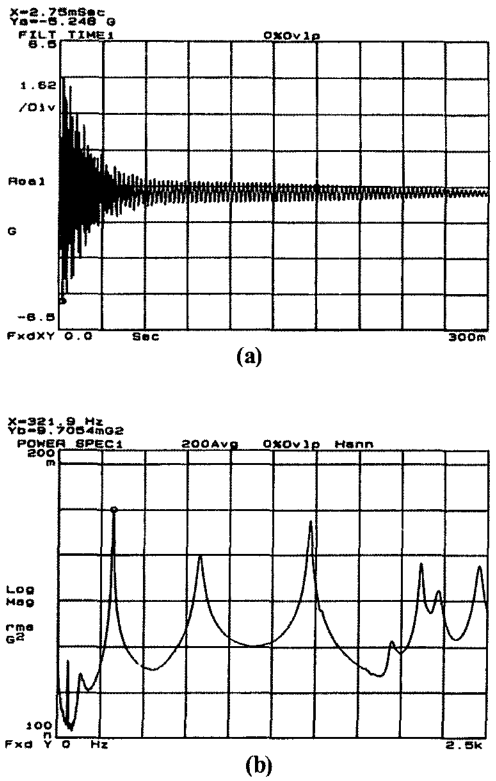


Fig. 6 Responses of a PGI drum with hose in (a) time domain and (b) frequency domain

The difference of the response of a drum before and after winding the hose becomes quite clear when Figures 3 and 6 are compared directly.

As can be seen in Table 1, adding a hose increases the damping values noticeably for the triangular and the square modes while hardly for the elliptical mode. It seems that the winding becomes more effective to suppress the motion of a drum in the radial direction as the number of vibration mode axes increases since the elliptical, triangular, and square modes have one, three, and two vibration mode axes, respectively, as shown in Figure 7. This result indicates clearly that the effectiveness of a treatment depends strongly on the mode shape of a structure. It also explains why a treatment that works well for suppressing a certain type of noise is not effective at all for other types of noise. This study shows that a small change in damping value could bring a noticeable improvement on reducing the brake noise. As expected, wrapping a hose around the drum did not significantly change the resonances of the drum as can be seen in Table 1.

3. Finite Element Analyses

A finite element model of a drum was developed to examine the dynamic behavior of a drum as shown in Figure 8. Quadrilateral shell elements were used to evaluate the natural frequencies and mode shapes of a drum.

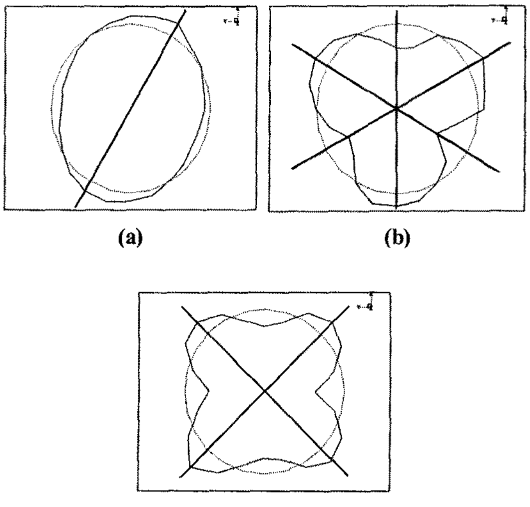


Fig. 7 Vibration mode axes of (a) Elliptical (b) Triangular (c) Square mode

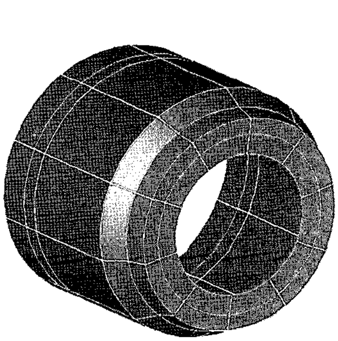


Fig. 8 FEA model of drum for dynamic analysis

For calculating results and determining their accuracy, the single-pass adaptive convergence method was employed. The analytical model developed provides similar results to the measured ones as presented in Table 2.

The associated mode shapes of a drum obtained from finite element analyses are shown in Figure 9. The finite element model of a drum employed and confirmed here can be used for future studies on an entire brake assembly.

Table 2 Comparison between experimental and analytical modal methods

Resonance	Experimental Modal Method (Hz)	Analytical Modal Method (Hz)	Difference (%)
First	331	329	0.5
Second	831	815	1.9
Third	1495	1483	0.8
Fourth	2247	2296	2.1

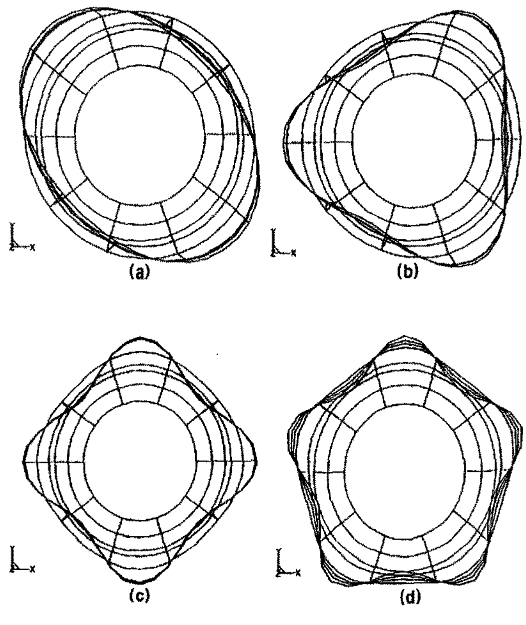


Fig. 9 (a) Elliptical (b) Triangular (c) Square (d) Pentagon mode obtained from finite element analyses

4. Conclusions

The effect of material change on the dynamic properties of the drum was investigated. By employing both experimental modal analysis and finite element analysis, the following results were obtained:

(1) The austempered gray iron drum provided slightly larger damping values than the pearlistic gray iron drum for the first few major resonances observed. Further investigation is planned to determine the significance of the increase in damping value with an austempered gray iron drum under the field application.
(2) It was found that the effectiveness of a treatment for suppressing brake noise depends strongly on the mode shape of a brake drum.
(3) The analytical results obtained from the finite element program were in good agreement with the actual measurement data.

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