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Experimental study on loss factor for corrugated plates by bandwidth method

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Abstract

The material loss factor for technically orthotropic plates was measured by half-power bandwidth method. Rectangular and trapezoidal corrugated plates of steel were considered. A simple isotropic steel plate was also considered for comparison of the results. The concept of single degree of freedom system was adopted. The tests were undertaken at very low frequency range (0–100) Hz. The plate models were suspended freely with two wires to minimize or prevent excessive extraneous energy dissipation. Out of plane point force, random in nature was applied to the top middle of the plates and the responses were measured from the middle point of the plates by FFT analyzer using miniature small mass accelerometer as sensor. The aim of these tests is to investigate the effects of bending rigidity and mode orders over material loss factor. The values of estimated modal damping loss factors are compared and tabulated for the plates models considered. Natural frequencies of some of the initial modes of the plates are also presented.

It is observed that the higher the value of bending rigidity of the plates, the larger the values of loss factor of it. There was a significant increase in value of loss factor in corrugated plates to that of the isotropic plate.

1. Introduction

Damping is an effective way to attenuate structural vibration and reduce the excitation transmitted to the radiating surface. For these purposes,

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damping materials are used for direct application to the surfaces radiating noise into the surrounding medium Cremer and Heckl, (1988); Nashif et al. (1985). In the case of dealing with inhomogeneous arrangements such as plates with attached layers in particular, are therefore of great practical importance in noise and vibration control. Typical configuration consists of a base plate (usually metal) to which is attached a damping layer (high polymer) and with or without the use of a cover plate at the top over damping layer. Apart from this surface damping treatment in inhomogeneous arrangement, care should be taken to find material loss factor for homogeneous material. As corrugated plates alone are usually used in different industries, it is necessary to estimate its loss factor for practical reason. It is important to note that the loss factor of the plates with attached damping layer may differ greatly for different types loading. But the equation of loss factor incorporating resonance half-power bandwidth for homogeneous material is same for all types of loading such as bending, longitudinal and torsion for example Cremer and Heckl (1988).

For small sample, half-power bandwidth method is useful for only small loss factor and the thickness of the sample must be significantly smaller than the corresponding wavelength. In the case of beam and plates, this method can also be used to estimate loss factor Cremer and Heckl (1988). In this paper, the half power bandwidth method is used to estimate material loss factor for technically orthotropic plates. The values of loss factor using this method in technically orthotropic plates are quite new and useful for controlling noise and vibration in industries. Two types of corrugated plates such as rectangular corrugated plate and trapezoidal corrugated plate are considered. An isotropic plate is also considered for comparison. Other useful methods are 'reverberation time method' and 'decay method'. Analytical investigation of effect of constrained layer damping treatment using finite element method is now becoming common Ghoneim (1996); Baz and Ro (1996).

2. Half-power bandwidth method

The most common method of determining damping is to measure frequency bandwidth, between points on the response curve, for which the response is some fraction of the resonance of the system. The usual convention is to consider points Z_1 and Z_2 as in the Fig. 1 below, to be located at frequencies on the response curve where the amplitude of response of these points is $\frac{1}{\sqrt{2}}$ times the maximum amplitude. The bandwidth at these points is frequently referred as 'half-power bandwidth'.

The half-power points or 3 dB points for small damping correspond to the frequencies $\omega_1 = \omega_n(1 - \zeta)$ and $\omega_2 = \omega_n(1 + \zeta)$, where ζ is the damping ratio. The frequency interval between these two half power points is $\Delta\omega = \omega_2 - \omega_1$. Loss factor of this method is defined as

$$\eta = \frac{\Delta\omega}{\omega_n} \tag{1}$$

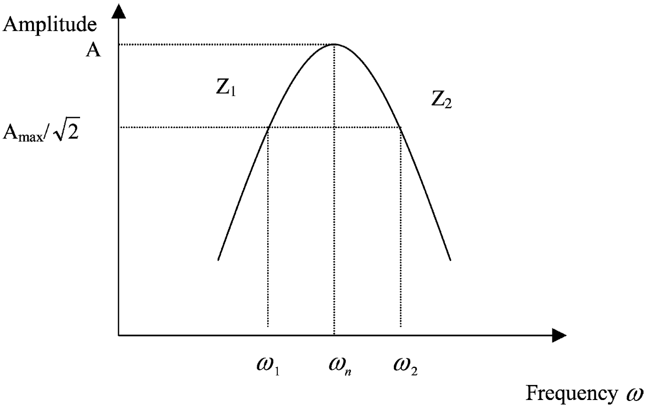

Fig. 1. Half-power bandwidth method (half power points occur at ω_1 and ω_2, bandwidth $\Delta\omega = \omega_2 - \omega_1$).

3. Measurement of loss factor of plates

All the plates used for this measurement were square (900 × 900 mm). They were fabricated from steel sheet of 0.8 mm thick and mass per unit area of 5.55 kg/m^2. Two types of corrugated plate such as rectangular (big and small) and trapezoidal (big and small) were used. Physical dimensions of these plates are illustrated in Table 2 and Fig. 3 (repeating section). There are ten repeating sections of corrugation for small-corrugated plates and six for big corrugated plates. In addition, a simple isotropic plate of uniform same thickness and same size was also considered to compare the loss factor values.

Important part of measurement of damping loss factor accurately is to make a suitable test rig. The test rig used for this measurement is shown in Fig. 2. Excitation was given by a mini shaker (B&K type 4810) at the top middle position of the plate and responses were measured by a lightweight ICP accelerometer (Piezoelectric type—model 353B67) from the middle of the plates using FFT analyzer (HP 35670A). The mini shaker was connected to the internal noise source of the analyzer. In this narrow band analysis, frequency of resolution was set to 0.5 Hz. The setting of the test panel was performed in a closed controlled condition so as to make only lateral motion to the plates.

The method and instrumentation for the determination of loss factor and complex modulii of different substances or samples are different. For the sample in the shape of plates, rings, cylinders and the like, measurements of resonance frequencies, half-value bandwidth, reverberation time (decay rate), may be used. Evaluation of results is however somewhat more difficult, because the resonant frequencies of the plate of shell samples are more closely spaced than those of beams, and are often distributed rather irregularly. Due to this complicated distribution of the modal lines, it is also often difficult to find appropriate measurement points.

A panel is a multi-modal system whose response may be visualized as composed of response of many single degree of freedom systems. Caution must therefore be taken in applying any of the single degree of freedom concepts to the measurement of panel damping. At low frequency, at or near the fundamental resonance, single mode concept using pure harmonic excitation may be used. The panel loss factor could be carried out by fixing on response maxima and measuring the associated half value bandwidth or by decay rates. At higher frequencies, any excitation is likely to excite several modes simultaneously, and in a frequency sweep the resonance decrease near one peak may be affected by the resonance increase associated with another peak. Consequently, measurements of logarithmic decrement, bandwidth, and resonance amplification cannot be performed accurately in such frequencies. The most useful and convenient technique for characterizing the damping of panels consists of measurements of decay rates (reverberation time) in a convenient frequency band Cremer and Heckl (1988).

The concept of single degree of freedom is considered as the tests were undertaken at low frequency range (0–100 Hz) and calculation of loss factor of plate models was carried out considering some initial modes. Here is an attempt to show a calculation of loss factor in simple isotropic plate for the second mode without damping sheet on it. The resonance frequency (f_n) at this peak is 46.5 Hz and associated half-power bandwidth frequencies are 45.8 Hz (f_1) and 47.25 Hz (f_2). Thus the loss factor of this plate is 0.031. Similarly, the loss factors of other plates for the first mode are estimated and are shown in Table 1 and different modes in Table 4.

Table 1
Loss factors for different plates at fundamental frequency (first mode)

Different plates	Loss factor	
	Without damping sheet	With damping sheet
Simple isotropic plate	0.0307	0.14
Small rectangular corrugated plate	0.059	0.083
Big rectangular corrugated plate	0.11	–
Big trapezoidal corrugated plate	0.088	–

Table 2
Physical dimensions of one repeating section of rectangular and trapezoidal corrugated plate (big and small)

Types of plate/physical quantities	Rectangular corrugated pates		Trapezoidal corrugated plates	
	Small	Big	Small	Big
Length of one repeating section, d in mm	90	150	90	150
Actual flat length of one repeating section, s in mm	120	250	111.6	232

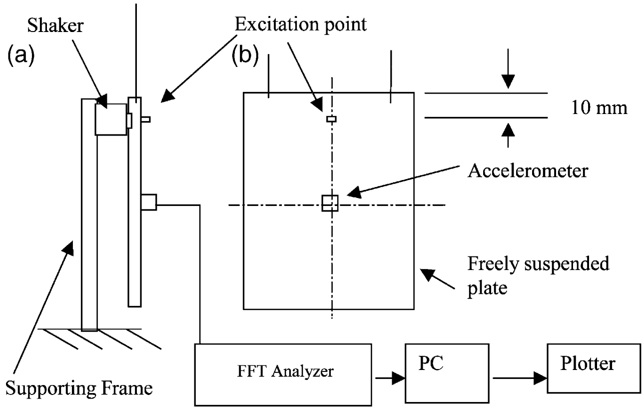

Fig. 2. Schematic diagram for the test rig having two orthogonal views (a) and (b) showing positions of excitation, response and related instrumentation.

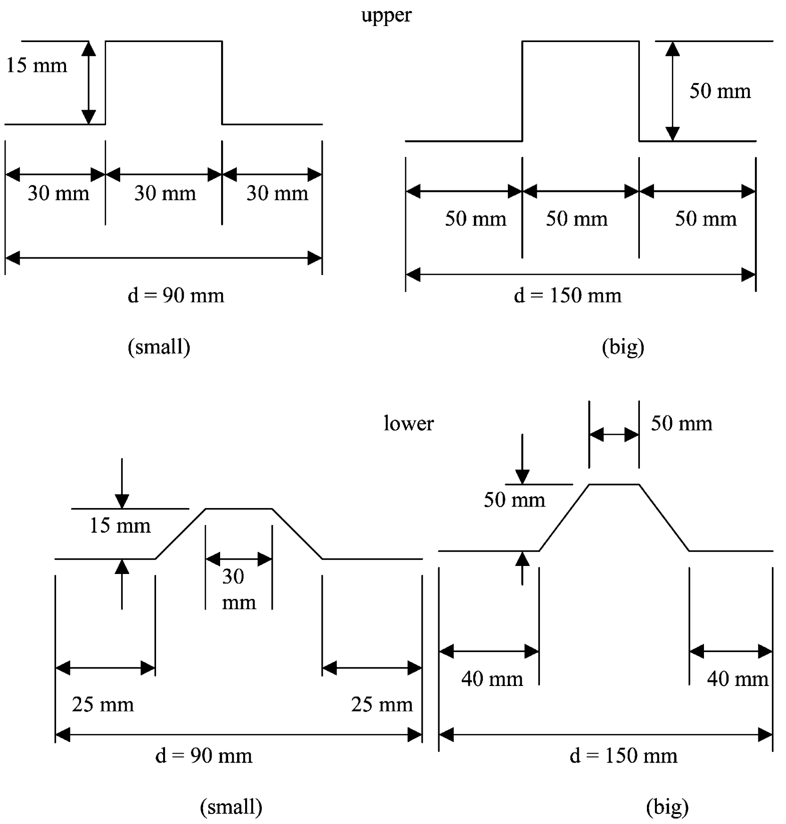

Fig. 3. Physical dimensions of one repeating section of rectangular corrugated (upper) and trapezoidal corrugated (lower) plates for both small and big corrugation.

4. Discussions

Damping is an important parameter for noise and vibration control. Although the prediction of damping in terms of loss factor is very difficult but its influence on reduction of vibration amplitude and attenuation of vibration energy transmission in structures is significant. In laboratory investigation of internal damping rates, it is very difficult to eliminate energy losses to external environment. Few critical cases should be considered during investigation. These are—losses due to attachment of sensing devices such as accelerometers, strain gauges etc; losses due to excitation of sound waves in the atmosphere; and losses due to interaction of the sample with the supporting structure such as clamp etc. Russel (1993). Optical method (laser technique) is a good solution as sensing devices. Alternately, accelerometers should be as light as possible so as not to disturb the response and the cables leading to it should be light and flexible Beranek (1971). In this investigation, miniature lightweight (1.7 gm) accelerometers were used. Losses due to excitation of sound waves in the environment dominate particularly in the high frequency range Russel (1993). This study was confined in the lower frequency range where structural damping dominated Keswick and Norton (1987). The problem of support related losses is removed as the test samples were suspended by two long strings.

In this study, material damping loss factor of various plates was estimated. Self-adhesive high-density bitumen pads with aluminum coating were used (attached by pressure) to isotropic plate and small rectangular plate. Figs. 4 and 5 show the responses of repeatability tests for instrument and resetting of test rig respectively. It was observed from these response curves that the responses were mostly unaffected for few initial modes in the lowest frequency range. The responses of the plates due to different corrugation (different flexural rigidity) and application of damping pad on some plates were measured and plotted in Figs. 6–9. The values of loss factor in Tables 1 and 4 and Fig. 10 show that the larger the flexural rigidity of the plates, the greater the value of loss factor of the plates. But especially for big trapezoidal corrugated plate (Table 4 and Fig. 10), some deviation is observed. The loss factor of big trapezoidal corrugated plate however had a value lower than that of big rectangular corrugated plate even though the former had a higher flexural rigidity. This study supports the well-known relationship between modal damping loss factor and complex bending stiffness. It states that hysteresis damping (loss

Table 3
Bending rigidities for different plates

Types of plates	Bending rigidity (Nm)
Isotropic plate	7.648
Small rectangular corrugated plate	7606.775
Big rectangular corrugated plate	94.424×10^3
Small trapezoidal corrugated plate	7922.93
Big trapezoidal corrugated plate	97.76×10^3

Table 4
Modal loss factors of various plates for different modes

Types of plate	Modal loss factor		
	First mode	Second mode	Third mode
Simple isotropic plate	0.0307	0.031	0.011
Small rectangular corrugated plate	0.059	0.035	0.0155
Big rectangular corrugated plate	0.11	0.0416	0.026
Big trapezoidal corrugated plate	0.088	0.021	0.014

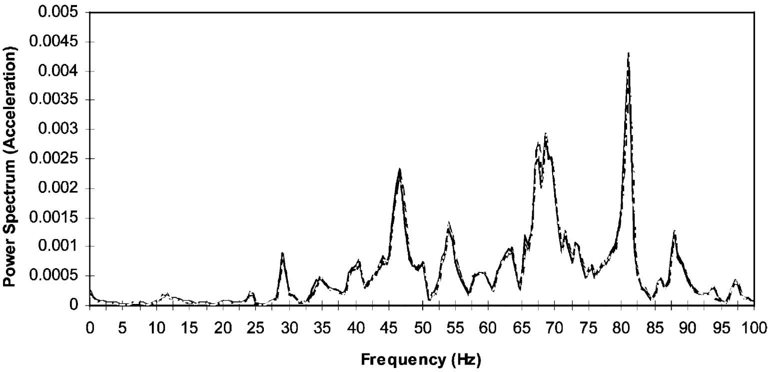

Fig. 4. Instrumental repeatability showing power spectrum of acceleration measured three times at ten minutes interval.

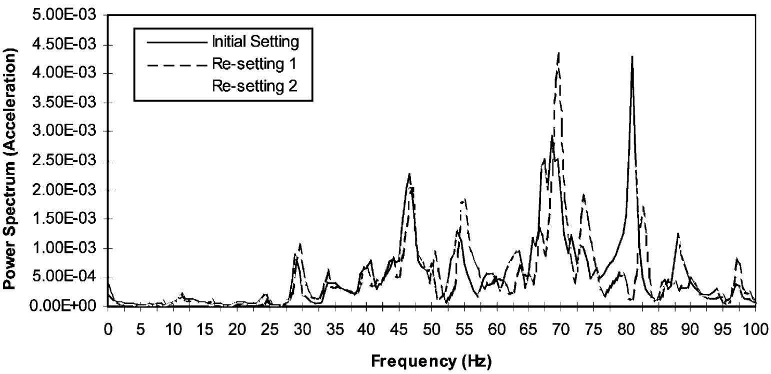

Fig. 5. Re-setting repeatability showing power spectrum of acceleration of test object by re-setting twice.

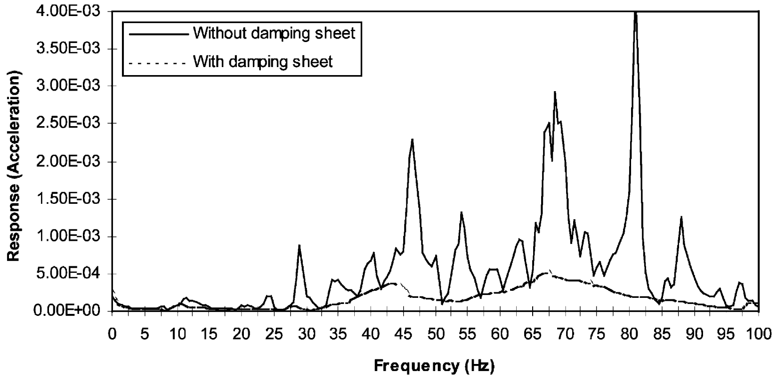

Fig. 6. Response of simple isotropic plate with or without damping sheet (self adhesive heavy bitumen lads with aluminum coating).

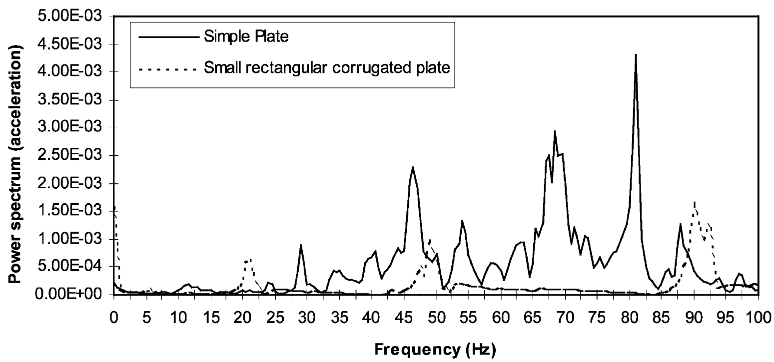

Fig. 7. Measurement of response of simple plate and small rectangular corrugated plate without damping sheet.

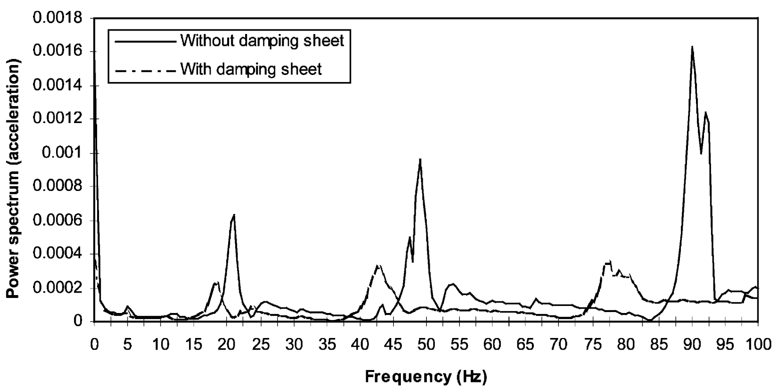

Fig. 8. Measurement of response of small rectangular corrugated plate with or without damping sheet attached to it.

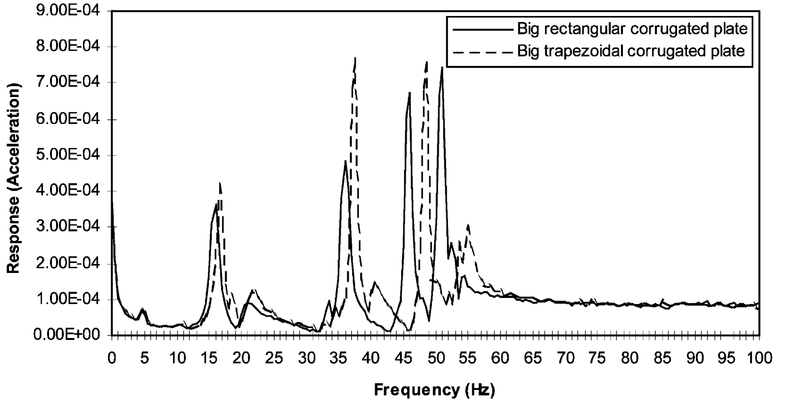

Fig. 9. Response of big rectangular and trapezoidal corrugated plates without damping sheet.

factor) is represented as the imaginary part of a complex elastic modulus of elasticity of the material Bies and Hansen (1998). The bending or flexural stiffness of structures can be increased by various ways. The higher the thickness of the structures (plates) the larger the bending stiffness of it. The bending stiffness may also be increased of the structures by making complex geometric shapes such as corrugation (present study), stiffening with other elements and so on.

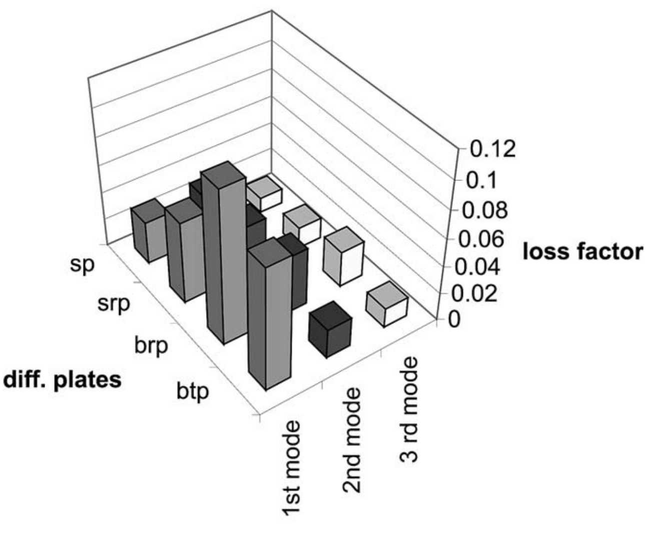

Fig. 10. Modal damping loss factors for different modes of various plates (sp represents: simple plate, srp for small rectangular corrugated plate, brp for big rectangular corrugated plate and btp for big trapezoidal corrugated plate).

It is also noted that initial modes are more damped. The higher the mode order of different plates (Table 4) the lower the modal damping loss factor of the plates. Material damping is proportional to the displacement from the neutral plane of the plate Bies and Hansen (1998). As frequency increases, the relative displacement of any particular point from the neutral plane decreases. Therefore loss factor decreases.

As the damping cannot be measured directly, it is usually estimated from the response curves of the vibrating system under study. In the case of plate, the concept of single degree of freedom in steady state condition using harmonic force of constant magnitude is useful to measure structural damping Nashif et al. (1985). This single degree of freedom concept is effective in the lower frequency range. Consequently this study was carried out in some lower frequency range and random white noise of constant magnitude was used. Further study for loss factor in higher frequency range (higher modes) would be encouraged using other method Ghoneim (1996); Baz and Ro (1996). A thorough prediction of material damping loss factor in many modes of the plates then could be made.

The different values of flexural rigidity and natural frequencies of the plates are shown in Tables 3 and 5 respectively. All the rigidities were calculated. However for corrugated plates, the rigidities were estimated using the method of elastic equivalence Troitsky (1976). The unit of rigidity is Nm^2 for beams and Nm for plates.

Loss factor also increases with application of damping pads (Table 1). In Fig. 7, the response of small rectangular corrugated plate was greatly reduced as compared to isotropic plate. The effect of damping pads was shown in Fig. 6 for isotropic plate and in 8 for small rectangular corrugated plate. In both the cases, the responses of the plates with damping pads were significantly less than that of the plates without damping pads. It was also noted that the resonant peaks occurred at a marginally lower frequency with damping pads as compared to the case without pads (Fig. 8). The magnitude was however reduced considerable. The response of big rectangular and trapezoidal corrugated plates was however noted to be similar. The loss factor is dependent on material and frequency of the material. It was observed that stiffer plate has less vibration response and thereby the higher material loss factor.

Table 5
Natural frequencies of various plates for different modes

Types of plate	Natural frequencies in (Hz)		
	First mode	Second mode	Third mode
Simple isotropic plate	29.3	46.5	81.25
Small rectangular corrugated plate	21	49	90.1
Big rectangular corrugated plate	16	36	46
Big trapezoidal corrugated plate	17	37.8	48.7

5. Conclusions

Half-power bandwidth method was used to estimate the material damping of the plates for few initial modes. The loss factor was calculated for different plates to determine the effect of corrugation (different stiffness). It was shown that loss factor increases due to corrugation. The larger the bending stiffness of the plate the higher the loss factor of it. It was also observed that with the increase of mode orders of the plates, the values of modal damping loss factor decrease especially in the lower frequency range. Due to a higher loss factor in corrugated plate, more vibration energy was absorbed in plates. Increased material surface damping treatment also shows significant reduction of responses of the plate. The above confirm the current practice on the use of damping pads and corrugated plates for noise and vibration in thin plate structures in the industries. The estimate of loss factors is not global as the study considers peak peaking technique. However, the nature of dependency of loss factor to bending stiffness is important. This study exposes the area of further investigation of dependency of loss factor in terms of plate thickness, band angle, shape of the bend, ratio of plate length to depth of corrugation, measurement locations etc.

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