

Application of Fibre Assemblies as Damping Elements in the Automotive Industry

E. Ghassemieh

*Mechanical Engineering Department, University of Sheffield
Mappin Street, Sheffield, S1 3JD, E.Ghassemieh@sheffield.ac.uk*

Abstract

This investigation aims to characterise the damping properties of the nonwoven materials with potential applications in automotive and aerospace industry. Nonwovens are a popular choice for many applications due to their relatively low manufacturing cost and unique properties. It is known that nonwovens are efficient energy dispersers for certain applications such as acoustic damping and ballistic impact. It is anticipated that these energy absorption properties could eventually be used to provide damping for mechanical vibrations. However the behaviour of nonwovens under dynamic load and vibration has not been investigated before. Therefore we intend to highlight these aspects of the behaviour of the nonwovens through this research. In order to obtain an insight to the energy absorption properties of the nonwoven fabrics, a range of tests has been performed.

Forced vibration of the cantilever beam is used to explore damping over a range of resonance modes and input amplitudes. The tests are conducted on aramid, glass fibre and polyester fabrics with a range of area densities and various coatings. The tests clarified the general dynamic behaviour of the fabrics tested and the possible response in more real application condition as well. The energy absorption in both thickness and plane of the fabric is tested. The effects of the area density on the results are identified. The main absorption mechanism is known to be the friction. The frictional properties are improved by using a smaller fibre denier and increasing fibre length, this is a result of increasing contact surface between fibres. It is expected the increased friction result in improving damping. The results indicate different mechanism of damping for fiber glass fabrics compared to the aramid fabrics. The frequency of maximum efficiency of damping is identified for the fabrics tested. These can be used to recommend potential applications.

Introduction

This investigation aims to characterise the damping properties of the nonwoven materials with potential applications in automotive and aerospace industry. Nonwovens are a popular choice for many applications due to their relatively low manufacturing cost and unique properties. It is known that nonwovens are efficient energy dispersers for certain applications such as acoustic damping and ballistic impact. It is anticipated that these energy absorption properties could eventually be used to provide damping for mechanical vibrations. However the behaviour of nonwovens under dynamic load and vibration has not been investigated before. Therefore we intend to highlight these aspects of the behaviour of the nonwovens through this research.

Predominant fabric deformation mechanisms in are determined by fibre physical properties such as diameter, length, modulus and fibre friction and microstructural properties such as fibre orientation distribution, and volume fraction. The freedom of fibres to move within the fabric suggests that there is good potential for dissipation of energy within the material through inter fibre friction. Since damping can be defined as energy

dissipation mechanisms that reduce the amplification and broaden the vibratory response in the region of resonance, it follows that these fabrics could provide efficient damping. The nonwoven structure has the added benefit of producing contact points at different orientations in three dimensions and the freedom of movement of fibers within the structure. Both can increase the energy absorption capabilities in the nonwoven fabrics compared to the woven fabrics. In order to obtain an insight to the energy absorption properties of the nonwoven fabrics, a range of tests has been performed. This includes forced vibration of cantilever beam and dynamic tensile tests.

Forced vibration of the cantilever beam is used to explore damping over a range of resonance modes and input amplitudes. In order to best represent real environments a random excitation signal is used. This method has a number of advantages compared to a sinusoidal input signal, firstly it distributes energy over a wide band of frequencies, and this gives more information about the response of the damping material and is a closer simulation of real environments. Allied to this is the simultaneous excitation of multiple modes of resonance within the test specimen. The results reflect the interaction between these modes.

The FVB tests clarify the general dynamic behaviour of the fabrics tested and the possible response in more real application condition as well. The energy absorption in both thickness and plane of the fabric is tested. The effects of the area density on the results are identified. The main absorption mechanism is known to be the friction. The frictional properties are improved by using a smaller fibre denier and increasing fibre length, this is a result of increasing contact surface between fibres. It is expected the increased friction result in improving damping.

Experimental Methodology

Forced Vibration of the Cantilever Beam (FVB)

The experiment aims to determine the damping properties of nonwoven fabrics through the dynamic excitation of a cantilever beam. The method employed is based on the ASTM standard E756 – 98 [1].

As the materials to be analysed are not self supporting, they are bonded to a metal base beam in order to form a composite cantilever beam. The specimen configuration used is that of the Oberst beam.

The primary experiment is dynamic tensile testing of the fabric via the excitation of a vertical cantilever beam. The basic test rig comprises a steel beam clamped with a torque wrench up to 70Nm in a stationary clamp. The beam is made from Kennedy Feeler Strip, which is manufactured from hardened, tempered polished steel to DIN 2275 specification. A magnetic exciter provides non-contact excitation of the beam. Input signal is specified by a computer via SigLab, this signal is then filtered and amplified before excitation of the beam. A laser set to record deflection at the top of the beam provides feedback. This feedback signal is returned via SigLab.

Table 1 – Test Beam Specifications

Beam Specifications					
Material	Total Length	Clamping Depth	Free Length	Width	Thickness
Steel (Feeler Strip)	242mm	41mm	201mm	12.7mm	0.5mm

The input signal is a randomly generated to test over a broad frequency range. A high pass filter is used to remove all components of the input below 40Hz as below this frequency

resonance is dominant but of little practical interest. Tests are conducted over a range of input amplitudes namely 2.5 – 0.5 RMS volts inclusive in 0.5 increments.

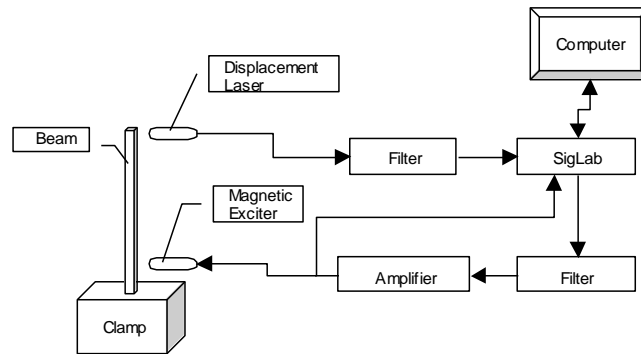


Figure 1 – Test Rig Block Diagram

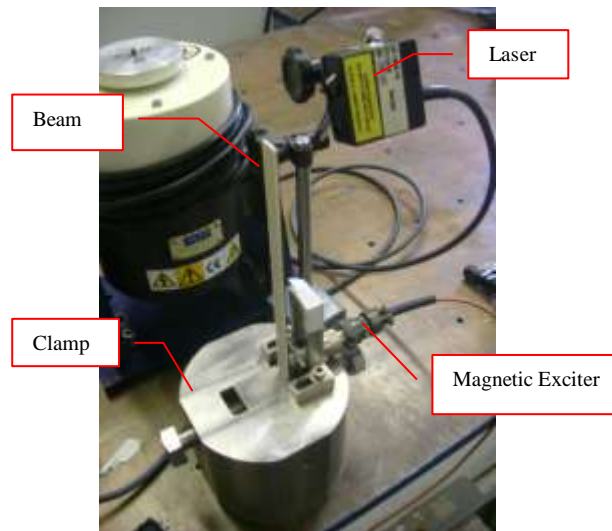


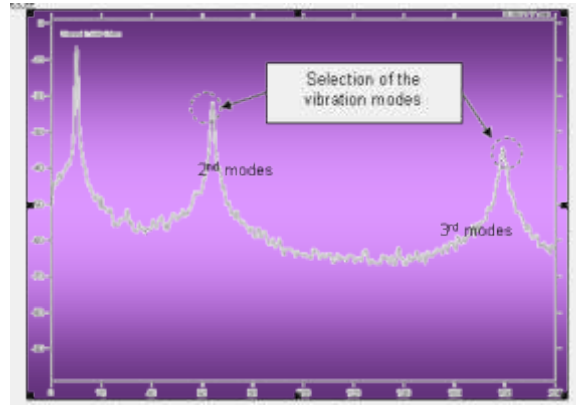
Figure 2 – Test Rig Set-up

The feedback range of interest was from 40 – 1000 Hz. This allowed us to record the damping ratio and the frequency of vibration for resonance modes 2 and 3. For each input amplitude, time- displacement graphs are generated. Amplitudes for mode 2 were tested between ranges of 0.5 – 2.5Vrms in 0.5V increments. This was modified for mode 3 to 0.2 – 1.0Vrms in 0.2V increments.

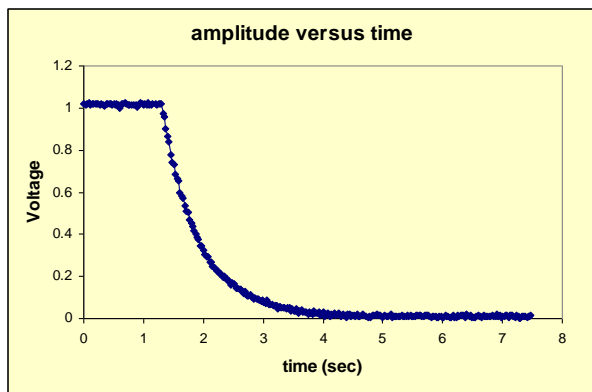
Test Procedure

A random signal is applied to the beam in order to determine the resonance frequencies and modes of vibration (figure 3(a)). The first mode is disregarded. Due to the nature of the mode shape, the stresses in the metal base beam will be concentrated near to the clamp. At high amplitudes of vibration the effects of micro-friction at the clamp may introduce nonlinearities into the measurements [2].

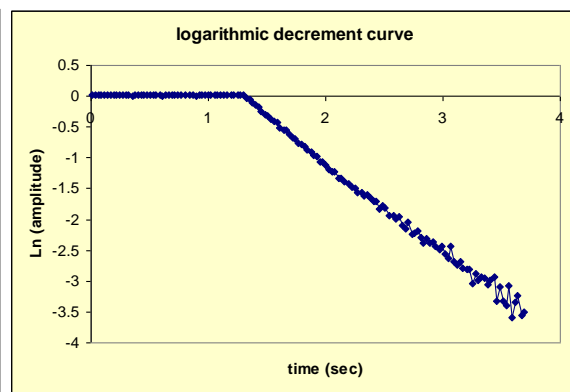
Starting with mode 2, the resonant frequency is applied to the beam using a sinusoidal signal. The amplitude decay is recorded for a range of input amplitudes. This is repeated for



(a)



(b)



(c)

Figure 3- Data processing (a) Modes of vibration, (b) Peak amplitudes (c) logarithmic decrement

mode 3. The output data is generated as Matlab file. The peak amplitudes and the envelope of the response are filtered out using a Matlab code (figure 3(b)). The logarithmic decrement (figure 3(c)) and the damping ratio are calculated using the slope of the semi logarithmic curves.

These values allow the amplitude dependency of the damping to be studied for each specimen at a certain frequency. The damping ratio can be compared at given amplitude for each specimen type. By looking at certain amplitude for a specific sample, the frequency dependency can be studied by comparing the response for different modes.

Results

Fibre Glass Tissues

Reinforced and un-reinforced fibre glass fabrics with different area density have been tested. Detail of the fabrics weight per square meter. Tensile strength in machine and cross directions along with the elongation at break in machine and cross direction is reported in table 2. The beam forced vibration test is performed on the fibre glass fabrics. The damping ratio for fabrics of different weight at different amplitudes for the mode 2 frequency is shown in figure 4(a). These results indicate that the damping ratio have almost a linear increase with the weight of the fabrics. The rate of increase of the damping ratio is affected by the amplitude. As the amplitude increases, it is expected that the rate of the increase of the damping ratio with the weight increases as well. The lighter fabrics are less sensitive to the

amplitude of vibration. For the heavier fabrics the damping ratio increases with the amplitude of vibration.

Table 2: Properties of the reinforced and unreinforced glassfibre tissues tested. [3]

Glass fibre	TS MD	TS CD
Un-reinforced (gsm)	N/5cm	N/5cm
110	490	280
100	440	240
80	380	210
50	175	95
40	160	90
35	140	90
Reinforced (gsm)		
100	440	240
80	380	210
60	250	140
50	210	100

Similar tests have been carried out for the mode 3 of vibration at the frequency of 180 HZ (figure 4 (b)). Similar to mode 2, the damping ratio for all the fabrics tested increases with the weight. The rate of increase is higher than mode 2, which indicates in general higher damping at higher frequencies.

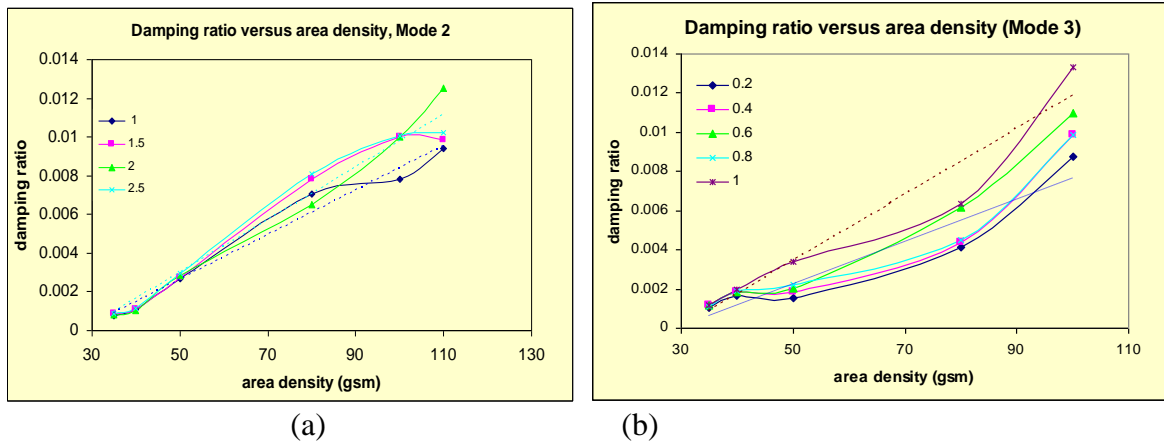


Figure 4: Dependency of damping properties on the weight of the fabrics (a) mode 2, (b) mode3

In the range of tested amplitudes, higher damping ratio is expected at higher amplitude. This is shown in figure 5(a-b). The dependency of the damping ratio to amplitude seems to be linear. In order to clarify the effect of frequency on the damping, the results for the two modes of frequency 64 HZ (mode 2) and 180 HZ (mode 3) are presented in figure 6(a). The efficiency of damping is higher in mode 3 and higher frequency. The properties of the unreinforced fabrics in table 1, shows that the tested fabric have higher tensile strength in machine direction (MD/Y) compared to cross direction (CD/ X) direction. It is expected that the energy absorption properties of the fabrics to be the same in MD and CD directions.

In order to examine this, we have repeated the tests for the MD and CD directions. The results presented in figure 6(b) for these tests confirm almost similar damping properties in the X and Y directions. This might be related to the fact that in the forced beam vibration test mostly the properties of the material through the thickness are examined. These properties do not change very much for the samples in CD and MD directions.

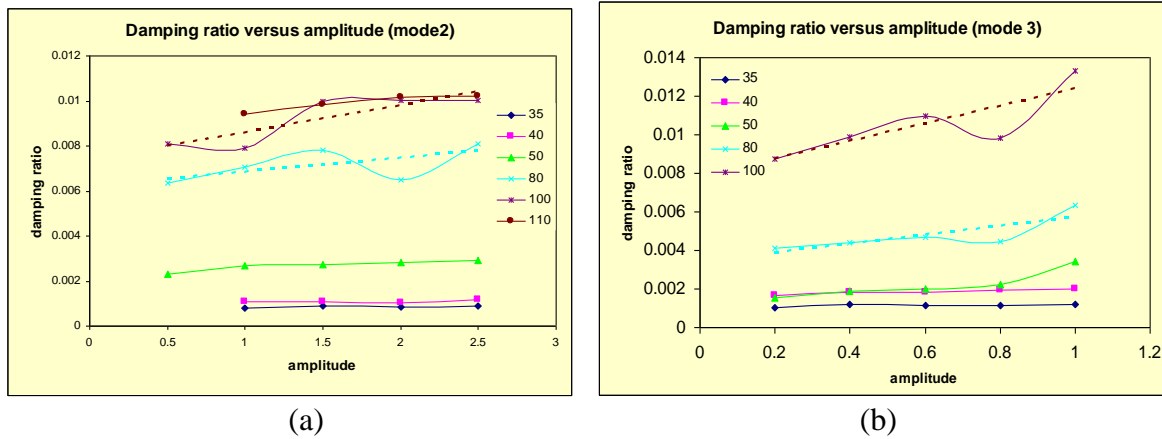


Figure 5: The effect of the amplitude of vibration on the damping properties (a) mode 2 (b) mode 3

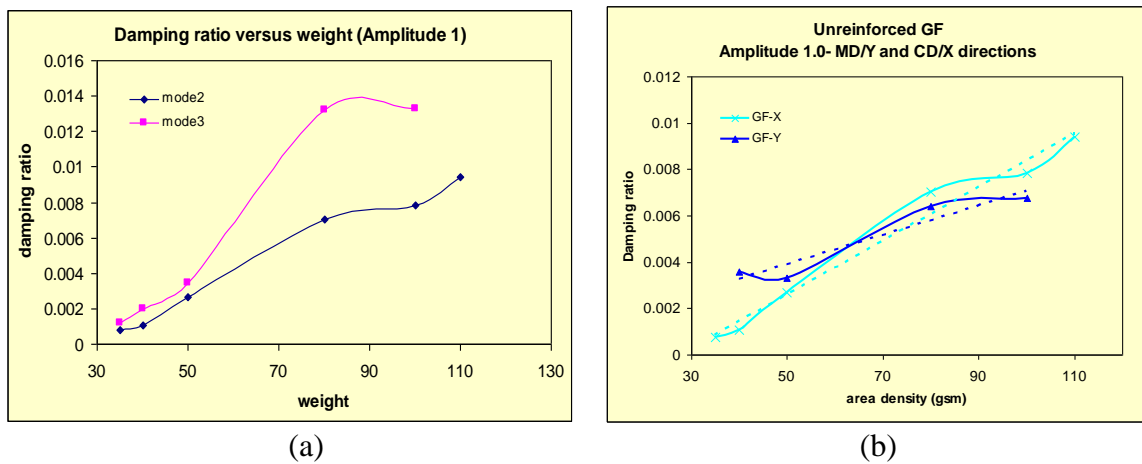


Figure 6: Unreinforced glass fibres comparison of (a) damping for modes 2 and 3, (b) damping in X and Y directions

The second set of fabrics tested is the reinforced fibre glass fabrics. The reinforcements are arranged in MD/Y direction in each ... mm. The properties of these fabrics are reported in second part of table 2. The fabrics are tested in MD/Y and CD/X directions for reinforced fabrics. The results are shown with dotted lines in figure 5. The reinforcement which is implemented in MD/Y reduces the damping in the samples of CD/X. The effect of reinforcement in the MD/Y samples is the opposite. The addition of reinforcement improves the energy absorption in the MD/Y direction. Similar trends are observed for higher amplitudes.

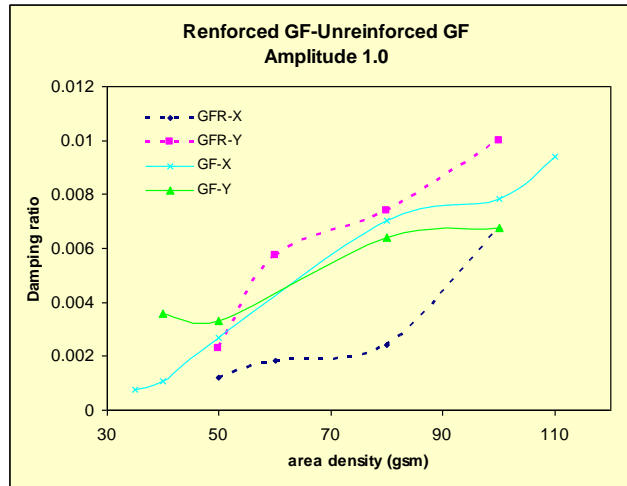


Figure 7: Damping of Reinforced and unreinforced glass fibres in MD/Y and CD/X directions

Aramid Fabrics

The second series of materials tested were the aramid fabrics of different gsm mostly scrim supported. The properties of these fabrics are reported in table 3 [4].

Table3: Properties of the Aramid fabrics tested [4]

Aramid (gsm)	Thickness (mm)	Density	TS, MD	TS,CD
350	1.66	0.21	500	500
500	2.1	0.24	600	600
400	1.98	0.2	500	500
550	2.35	0.23	650	650

The FVB test was repeated for the aramid fabrics registered in table 3. Since the properties of the fabrics reported were the same in MD/Y and CD/X directions, only one direction was tested. The aramid fabrics had much higher weight ratio compared to the glass fibres. Consequently the fabrics thicknesses were much higher for aramid fabrics. This resulted in the amplitude response collected for aramid fibres to be more erratic compared to the glass fibre.

The variation of the damping with the amplitude is much larger compared to the glass fibres (figure 8(a)). Therefore the curves relating to different amplitudes are more widely spaced. An almost linear increase with the weight of the fabrics can be observed.

The tests for aramid fabrics have been performed for modes 2-6 of vibrations at different amplitudes. The effect of frequencies can be explored within the results which are reported in figure 8(b). The damping reaches its maximum in the 3rd mode of vibration and then it decreases for the further modes. The effect of amplitude in increasing the energy absorption capacity is clearly indicated in these results as well.

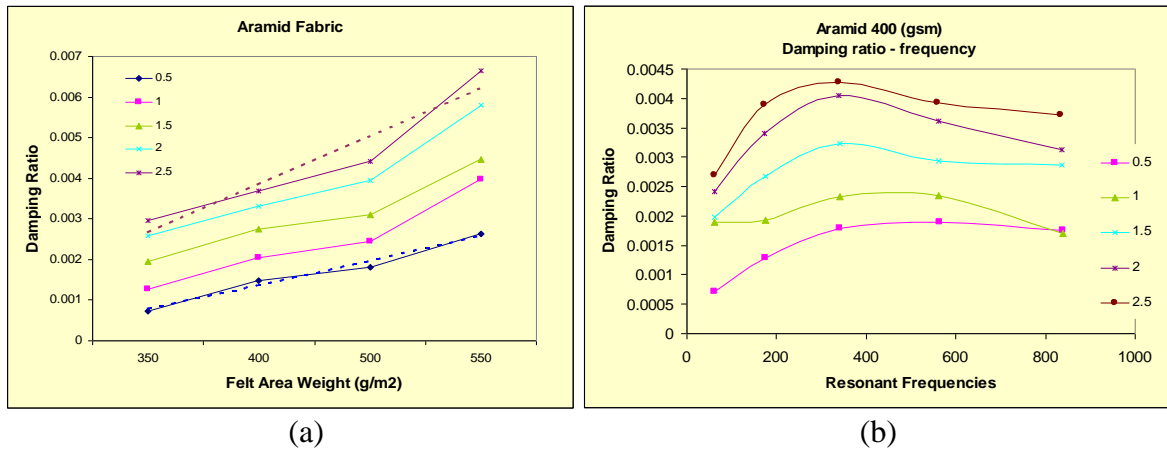


Figure 8: damping ratio for aramid fabrics (a) versus weight of the fabrics (b) versus resonance frequencies.

Conclusions

The damping capacities of the glass fibre tissues are significantly improved at higher densities.

Using the FVB, the potential of vibration damping in MD and CD are similar for the un-reinforced tissues.

Increasing the amplitude and frequency of vibration results in additional energy absorption

Addition of the reinforcement to the glass fibre tissues results in reduced damping in the direction normal to the reinforcement direction. The effect is the opposite in the direction of the reinforcement resulting in added damping in the MD/Y or reinforcement direction.

Aramid fabrics show much larger increase in damping with amplitude.

Similar to glass fibres there is an almost linear relation between the energy absorption potential of the aramid fabrics and the weight area of the fabrics.

Maximum damping of aramid fabrics occurs at mode three of vibration.

References

1. ASTM E756 – 98. Standard Test Method for Measuring Vibration-Damping Properties of Materials.
2. Nashif, A.D., Jones, D.I.G., Henderson, J.P., *Vibration Damping*, John Wiley and Sons, Inc., New York, NY, 1985
- 3- Technical product data of Saint Gobain textile.
- 4- Technical product data of Andrews Textile.

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