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Study on the Thickness Loss of Wilton-Type Carpets under Dynamic Loading

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Abstract
In the two earlier papers, evaluations were presented on the characteristic parameters determining the behaviour of three industrially produced Wilton-type carpets with different pile materials (wool, acrylic and PP) after a prolonged heavy static loading, and an extended analysis was carried out covering the energy absorption, damping characteristics and hysteresis effect of pile materials on carpet behaviour during recovery. In this study, the same carpets were tested under dynamic loading in order to evaluate and observe the thickness loss and carpet behaviour under dynamic loads. The results are given and discussed in this paper.

Key words: *Wilton type carpets, dynamic loading, thickness variation, thickness loss.*

Introduction

General information and a wide range of studies on carpets or floor coverings have already been reported in earlier papers dealing with static loading, thickness loss, pile recovery, characteristic parameters and behaviour analysis with respect to Wilton-type carpets [1 - 2]. Moreover, recent studies of interest to researchers of this field, such as the effect of pile height and density on the end use properties of face-to-face cut pile carpets [3] and the effect of different environmental conditions on the compressional creep behaviour of hand-woven carpets [4] have been added.

The deformation and thickness loss of carpets compressed by static and dynamic loads in use are of great importance as an indication of their quality as floor coverings. Owing to this loss, not only does the carpet's appearance on the face lose its original form, but the carpet's resilience capability is also greatly reduced. Factors decreasing the resilience capability are static pressures by massive goods such as furniture, and dynamic pressures such as walking, moving furniture and other household goods that a carpet has to bear during use [5 - 9].

In this study, we examined three carpets industrially produced by a manufacturer in Turkey. The samples were acrylic, wool, and PP piled carpets of the Wilton type. They were tested under dynamic loading in order to evaluate and investigate the carpets' behavior, deformation and thickness loss against dynamic loads. Information on the materials and method as well as detailed results are given and discussed in this paper.

In conclusion, it was observed that an increase in the number of impacts resulted in a decrease in the mean thickness for all the samples. Hence, the thickness loss increases with an increase in the number of impacts. In general, maximum deformation of the samples occurred after 1000 impacts. Acrylic carpet is thought to have more capability of recovering thickness loss after removing dynamic loads compared to the other carpets examined. On the other hand, wool was not very resistive against the impacts in comparison with the other samples. Hence, wool carpet is thought to be the worst under dynamic loads. Statistical evaluations of the experimental data showed that the pile material and number of impacts have a significant effect on variations in the mean thickness and thickness loss.

***Table 1.** Main parameters of the carpet samples selected.*

Parameters	Sample 1 (Acrylic)	Sample 2 (Wool)	Sample 3 (PP)
Weaving type, dimensions and end use of the carpets	1/3 V type, woven face to face in Wilton system, Full Dimensions: 2 x 3 m End use: home floor covering in saloon or other rooms	1/3 V type, woven face to face in Wilton system, Full Dimensions: 2 x 3 m End use: home floor covering in saloon or other rooms	1/3 V type, woven face to face in Wilton system, Full Dimensions: 2 x 3 m End use: home floor covering in saloon or other rooms
Weft in ground and weft density	Ne L 6 / 2 jute 450 x 3 = 1350 picks/m	Ne L 6 / 2 jute 700 x 3 = 2100 picks/m	Ne L 6 / 2 jute 400 x 3 = 1200 picks/m
Reeding	Reed number and drafting: 3/50 Warp ends in reed: 2 ground warp + 1 for wedding	Reed number and drafting: 3/50 Warp ends in reed: 2 ground warp + 1 for wedding	Reed number and drafting: 3/50 Warp ends in reed: 2 ground warp + 1 for wedding
Warp in ground and warp density	Ne 18 / 4 cotton/polyester 1000 ends of full weaving width in total	Ne 18 / 4 cotton/polyester 1000 ends of full weaving width in total	Ne 18 / 4 cotton/polyester 1000 ends of full weaving width in total
Warp for wedding and warp density	Ne 18 / 6 cotton/polyester 500 ends of full weaving width in total	Ne 18 / 6 cotton/polyester 500 ends of full weaving width in total	Ne 18 / 6 cotton/polyester 500 ends of full weaving width in total
Pile Material	acrylic; Nm 16/3 Pile density: 4500 piles/dm^2 Pile height:13 mm	wool; Nm 13/3 Pile density: 3500 piles/dm^2 Pile height: 12 mm	polypropylene; 2000 dtex Pile density: 2000 piles/dm^2 Pile height: 10 mm

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Materials and method

Table 1 gives structural parameters for the production and end-use properties of the carpet samples. These carpets were selected from a carpet manufacturer in Turkey. They were woven in the same mill conditions as for commercial production. In the study, the carpet samples examined were named with respect to their pile materials: 'Acrylic','Wool' and 'PP'.

As given in the table, the weaving type, dimensions and end use of the carpets are identical to those of the samples. From a technical point of view, the following structural parameters are also the same for all the carpets examined: Ne L6/2 jute and Ne 18/4 cotton/polyester yarns are used in ground as the weft and warp, respectively. The warps used for wedding are Ne 18/6 cotton/polyester yarns. A ground warp density of 1000 ends and a wedding density of 500 ends in total are set in the weaving width. The reed number is 50 and the number of ends in each reed dent is 3 arranged as 2 ground warp and 1 for wedding.

The carpet samples were different with respect to the pile material, the weft density in ground and the pile density. In this case, the highest weft density is for wool carpet, which is 2100 picks/m. The weft densities of the other carpets examined were 1350 picks/m for the acrylic carpet and 1200 picks/m for the polypropylene carpet.

An important difference in the structure can be noticed with respect to the pile densities, which are 4500, 3500, and 2000 piles/dm^2, and the corresponding yarn counts - Nm 16/3, Nm 13/3 and 2000 dtex. Approximately the same resulting yarn count of Nm 5, with a pile height of 13 mm, 12 mm and 10 mm is used for carpets of acrylic, wool, and polypropylene piles, respectively.

In order to determine the loss of thickness under dynamic loading, the thicknesses of the carpets were measured. The test method was processed in accordance with Turkish Standard TS 3375, which is equivalent to ISO 2094. The area of the 5 specimens used in the tests was 125 x 125 in mm. In the method, the initial thicknesses of the conditioned carpet specimens are measured under a pressure of 2 kPa before application of the dynamic loads. Then the first dynamic loads representing 50 impacts are applied to the specimens as defined in the relevant standards. The thicknesses of the specimens are immediately measured after this treatment. The specimens are then replaced on the dynamic loading machine again for further treatments. Thickness measurements are made and recorded at intervals of up to 1000 or more impacts (i.e. the measurements of this study were made after 50, 100, 200, 500, and 1000 impacts). Mean values are then taken to show the variations in thickness. The thickness loss is calculated using variations between the initial thickness and those measured after the number of impacts stated [10].

Experimental results and discussion

Thickness variation

Full test results are given in ***Tables 2, 3 & 4***, indicating the individual original thickness, that measured after a stated number of impacts of the 5 specimens, the corresponding arithmetic mean thickness, and the mean thickness losses calculated by the following Equations:

$$\delta = h_0 - h \quad (1)$$

$$h_L = (h_0 - h)/h_0 \times 100\% = \delta/h_0 \times 100\% \quad (2)$$

where,

h_0 - is the original mean thickness of the carpet sample before the application of the dynamic load, measured at a pressure of 2 kpa in mm,

h - is the general mean thickness measured after a stated number of impacts in mm,

δ - is the general difference (deformation) between the original thickness and that measured after a stated number of impacts in mm,

h_L - is, in general, the thickness loss of the carpet after a stated number of impacts in %.

In ***Table 4*** it can be noted that the original thickness and those measured after the stated number of impacts are slightly smaller than the pile height of the carpet with polypropylene pile, which was explained in our earlier paper [1]. The results obtained show that after 1000 impacts, the mean thicknesses are 12.33 mm, 10.83 mm and 7.22 mm, and the thickness losses are 15.02%, 27.26%

Table 2. *Test results of the carpet sample with acrylic pile (pile height:13 mm) – Sample 1.*

Dynamic loading and number of impacts	Thickness of specimen h, mm					Arithmetic mean of thickness h, mm	Thickness loss h_L , %
	1	2	3	4	5		
Before application h_0	14.90	14.36	14.40	14.66	14.21	14.51	-
After 50 impacts h_1	14.18	13.98	14.06	14.00	13.45	13.93	3.99
After 100 impacts h_2	12.72	12.14	12.98	12.75	12.58	12.63	12.96
After 200 impacts h_3	12.61	13.11	13.19	12.77	12.92	12.92	10.96
After 500 impacts h_4	12.85	12.62	11.60	12.20	12.39	12.33	15.03
After 1000 impacts h_5	12.54	12.04	12.48	12.34	12.24	12.33	15.03

Table 3. *Test results of the carpet sample with wool pile (pile height:12 mm) – Sample 2.*

Dynamic loading and number of impacts	Thickness of specimen h, mm					Arithmetic mean of thickness h, mm	Thickness loss h_L , %
	1	2	3	4	5		
Before application h_0	14.82	14.74	15.00	15.20	14.70	14.89	-
After 50 impacts h_1	13.34	14.32	13.73	12.86	12.94	13.44	9.74
After 100 impacts h_2	12.53	12.25	11.36	11.86	11.22	11.84	20.48
After 200 impacts h_3	12.22	11.55	12.01	11.31	11.41	11.70	21.42
After 500 impacts h_4	11.69	11.09	11.42	11.54	11.58	11.46	23.03
After 1000 impacts h_5	11.55	11.22	10.56	10.47	10.36	10.83	27.27

Table 4. *Test results of the carpet sample with PP pile (pile height:10 mm) – Sample 3*

Dynamic loading and number of impacts	Thickness of specimen h, mm					Arithmetic mean of thickness h, mm	Thickness loss h_L , %
	1	2	3	4	5		
Before application h_0	9.15	9.19	9.57	9.52	9.54	9.39	-
After 50 impacts h_1	8.88	8.07	8.06	8.14	8.13	8.26	12.03
After 100 impacts h_2	7.66	8.02	8.09	8.90	7.65	8.06	14.16
After 200 impacts h_3	7.48	7.89	7.95	7.40	7.59	7.66	18.42
After 500 impacts h_4	7.37	7.43	7.64	7.40	7.45	7.46	20.55
After 1000 impacts h_5	7.34	7.04	7.57	7.02	7.12	7.22	23.11

Table 5. Statistical parameters calculated from the experimental results

Dynamic loading and number of impacts	Parameters	CARPET SAMPLES		
		Sample 1 (Acrylic)	Sample 2 (Wool)	Sample 3 (PP)
Before application h_0	$\bar{x}$, mm	14,50	14.89	9.39
	S, mm	0.27	0.20	0.20
	V, %	1.89	1.39	2.19
After 50 impacts h_1	$\bar{x}$, mm	13.93	13.44	8.25
	S, mm	0.28	0.60	0.35
	V, %	2.02	4.48	4.25
After 100 impacts h_2	$\bar{x}$, mm	12.63	11.84	8.06
	S, mm	0.31	0.56	0.50
	V, %	2.46	4.73	6.31
After 200 impacts h_3	$\bar{x}$, mm	12.92	11.70	7.66
	S, mm	0.23	0.39	0.24
	V, %	1.84	3.38	3.20
After 500 impacts h_4	$\bar{x}$, mm	12.33	11.46	7.46
	S, mm	0.47	0.23	0.10
	V, %	3.86	2.00	1.42
After 1000 impacts h_5	$\bar{x}$, mm	12.33	10.83	7.22
	S, mm	0.20	0.52	0.23
	V, %	1.62	4.83	3.24

Table 6. Experimental mean values and results predicted.

Number of impacts applied	Carpet samples	Thickness level h, mm		Thickness loss h_L, %	
		Mean experimental value	Predicted value	Mean experimental value	Predicted value
50	Sample 1 (Acrylic)	13.93	13.495	3.99	5.17
	Sample 2 (Wool)	13.44	12.922	9.74	11.26
	Sample 3 (PP)	8.26	8.257	12.03	11.81
100	Sample 1 (Acrylic)	12.63	13.171	12.96	9.91
	Sample 2 (Wool)	11.84	12.394	20.48	17.44
	Sample 3 (PP)	8.06	8.002	14.16	14.88
200	Sample 1 (Acrylic)	12.92	12.855	10.96	13.13
	Sample 2 (Wool)	11.70	11.888	21.42	21.95
	Sample 3 (PP)	7.66	7.754	18.42	17.66
500	Sample 1 (Acrylic)	12.33	12.448	15.03	15.04
	Sample 2 (Wool)	11.46	11.250	23.03	25.34
	Sample 3 (PP)	7.46	7.438	20.55	20.90
1000	Sample 1 (Acrylic)	12.33	12.149	15.03	14.72
	Sample 2 (Wool)	10.83	10.791	27.27	25.95
	Sample 3 (PP)	7.22	7.208	23.11	23.03

and 23.10% for Acrylic, Wool, and PP, respectively. Hence, carpet with acrylic pile is thought to be more capable of recovery after removing dynamic loads compared to the other carpets examined. On the other hand, wool carpet might have the poorest capability of recovering thickness loss, which means that the resilience of wool carpet under dynamic loads will get less over long term use [5 - 6].

Table 5 summarises simple statistical parameters concerning the experimental results: the mean value of thickness ($\bar{x}$), standard deviation (s) and the coefficient of variation (V) of the corresponding data.

Figure 1 shows the mean original thickness and mean thickness at a stated number of impacts for the carpet samples examined. It was demonstrated that an increase in the number of impacts resulted in a decrease in mean thickness for all the samples. Maximum deformation occurred after 1000 impacts for each sample. It can be noted that the maximum deflections were detected at 2.18 mm, 4.06 mm and 2.17 mm for acrylic, wool and PP carpets, respectively. The reasons for these results can be interpreted from many points of views, such as the fiber characteristics, structural parameters and constructional properties of the samples examined, as explained in earlier papers [1 - 2]. However, they cannot be easily or predominantly attributed to any of these parameters due to the fact that the samples were chosen from industrially produced carpets. On the other hand, in this study the samples' behaviour indicate that wool carpet is somehow the worst under dynamic loads, being the least resistant in comparison with the other samples.

A logarithmic regression approximation to the mean thicknesses data is given by equations for acrylic, wool and PP carpet piles, respectively, shown in Figure 1 together with their correlation coefficients R^2. In the equations, x represents the number of impacts and y represents the mean thickness predicted at the stated number of impacts in mm. However, the horizontal axis illustrates logarithmic values of the impacts. As can be seen from both ***Figure 1*** and ***Table 6***, the results predicted are in good agreement with corresponding actual values. Therefore, these equations can be used as a model to predict carpet thickness changes in similar carpet constructions.

Thickness Losses

Figure 2 shows mean thickness loss variations at the stated number of impacts. Generally, the thickness loss increases with an increase in the number of impacts. The maximum thickness loss is 15.02%, 27.26% and 23.1% for the acrylic, wool and PP carpet samples, respectively. From these results, it can be observed that wool carpet shows the worst performance, whereas acrylic is the best in comparison. The results of a polynomial regression analysis are demonstrated in ***Figure 2*** with the help of regression equations. Here, x is the number of impacts and y the mean thickness losses in per cent. However, the horizontal axis is used to show the logarithmic values of impact numbers. It can be seen from both ***Figure 2*** and ***Table 6*** that these equations are in good agreement with the data measured. Since the prediction is reasonably accurate for all samples, these equations may also be considered when calculating theoretical thickness losses for the carpet samples examined.

Figure 3 shows the deformation (mm) and thickness loss in % after 1000 impacts. Acrylic carpet has the highest pile density, 4500 piles/dm^2,with a pile height of 13 mm, compared with the other carpets, and it is highly resistive against dynamic loading. From this point of view, wool carpet shows the worst performance, with a lesser pile density of 3500 piles/dm^2 (pile height: 12 mm). PP carpet is comparatively better than wool despite having the least pile density, which is 2000 pile/dm2 (pile height: 10 mm).

Statistical significance analysis

The experimental results were statistically evaluated using Design Expert Analysis of Variance (ANOVA) software, with F values calculated at a significance level of $\alpha = 0.05$, with the intention of exploring whether there is any statistically significant difference between the variations obtained. Results of the variance analysis are elaborated in ***Table*** *7*. It can be seen that there are statistically significant differences for both the mean thickness variation and thickness loss of the samples tested in terms of the pile material and number of impacts. In other words, the pile material and number of impacts have a significant effect on the mean thickness variation and thickness loss variation at a significance level of $\alpha = 0.05$.

Data have also been chosen to cover the relative importance of each source of variation in the ANOVA (including the pile material and numbers of impacts). The results thus obtained are shown in ***Table*** *7*. The main effect of pile material accounted for 83.06% of the total variation in mean thickness, whereas the number of impacts was a relatively minor factor, contributing to only 15.13% of the total variation. The interaction between the pile material and number of impacts accounted for 1.80% of the variation in mean thickness.

The main effect of the pile material accounted for 37.11% of the total variation in thickness loss, which is a major effect, whereas the number of impacts contributed to 56.06% of the total variation (the F test gives a P-value of 0.0005 compared with the corresponding value of 0.0004 in the case of the pile material). The interaction between the pile material and number of impacts accounted for a relatively low value of the total variation in thickness loss – 6.22%.

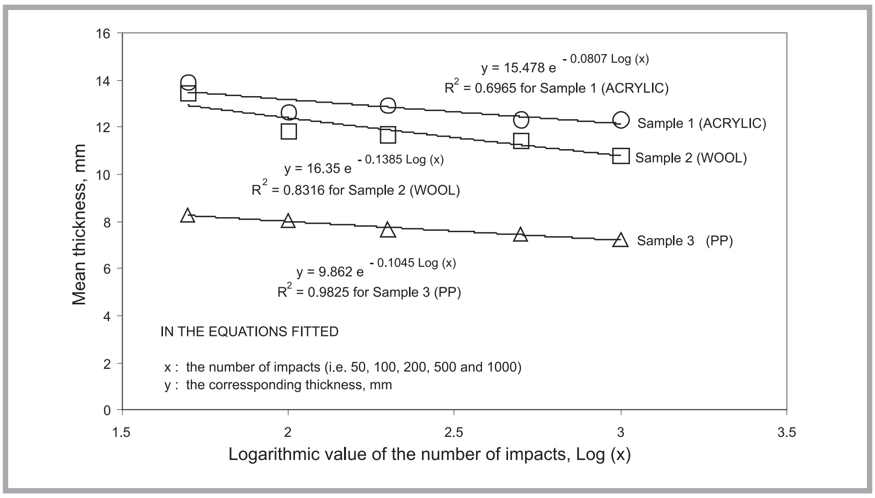

Figure 1. *Logarithmic approximation for the thickness values.*

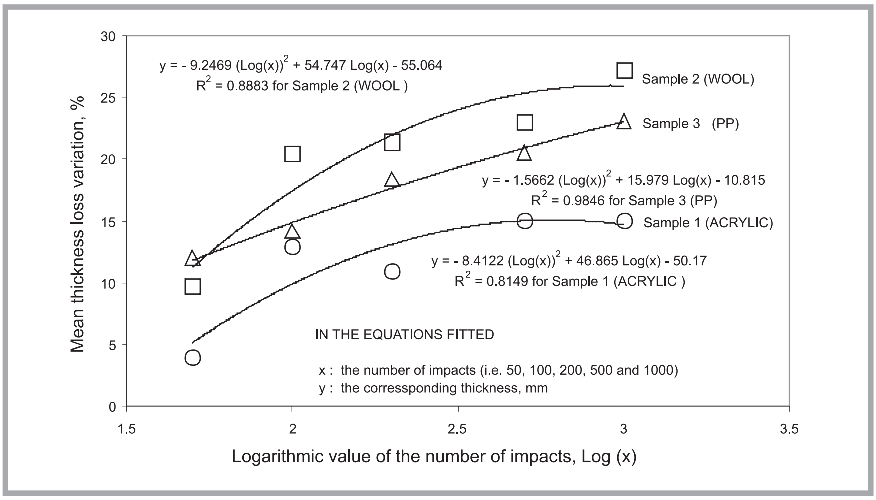

Figure 2. *Logarithmic regression approximation for the mean thickness loss.*

Conclusions

Based on the experimental study carried out on the performance of carpets examined as samples selected from commercially produced carpets and put under dynamic loading, the following conclusions can be drawn;

Generally, an increase in the number of impacts resulted in a decrease in the mean thickness for all the samples. Hence, thickness loss increases with an increase in the number of impacts. The results showed that after 1000 impacts, the mean thicknesses are 12.33 mm, 10.83 mm, and 7.22 mm, and the thickness losses are 15.02%, 27.26%, and 23.10% for Acrylic, Wool, and PP, respectively. Maximum deformation occurred after 1000 impacts for each sample, detected at 2.18 mm, 4.06 mm and 2.17 mm for acrylic, wool and PP carpets, respectively. Hence, acrylic carpet is thought to have more capability of recovery after dynamic loads compared to that of the other carpets examined. On the other hand, wool carpet might be the worst under dynamic loads

Table 7. *Statistical analysis of variance results; 1)* $F_{0.05, 2, 10} = 4.10$*, 2)* $F_{0.05, 5, 10} = 3.33$*, 3)* $F_{0.05, 2, 8} = 4.46$*, (4)* $F_{0.05, 4, 8} = 3.84$*.*

Parameters	Mean thickness, mm			Thickness loss,%		
	F values	P-value	% Contribution	F values	P-value	% Contribution
Pile Material, PM	230.18 > 4.10 (1)	0.0001	83.06	24.24 > 4.46 (3)	0.0004	37.11
Statistical evaluation	Significant			Significant		
Number of Impacts, NI	16.77 > 3.33 (2)	0.0001	15.13	18.02 > 3.84 (4)	0.0005	56.06
Statistical Evaluation	Significant			Significant		
PM x NI	-		1.80	-		6.22

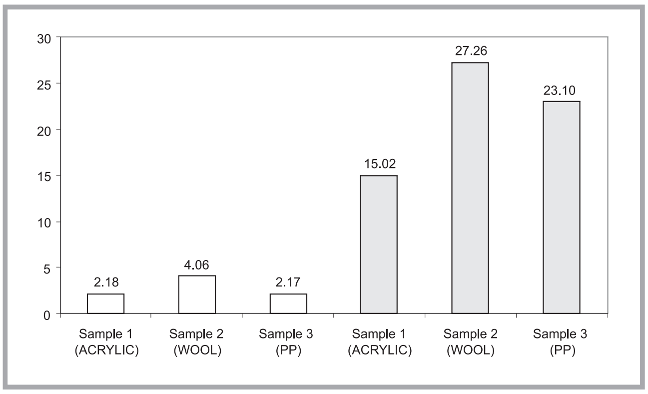

Figure 3. *Comparison of the deformation and thickness loss after 1000 impacts; □ - deformation, mm, ▣ - thickness loss, %.*

as it is not very resistive in comparison with the other samples.

However, wool carpet had a better performance despite a lower pile density (3500 piles/dm^2 with a 12 mm pile height). The PP carpet was found to be comparatively good, despite having the least pile density (2000 pile/dm^2 with a 10 mm pile height). The acrylic carpet was the worst (4500 piles/dm^2 with a 13 mm pile height) after static loading, as explained in detail in earlier papers [1 - 2]. In this study we lack data to show the behaviour of these carpets after 1000 impacts, and what they would be like in the case of measuring pile recovery over time with no dynamic or static loading. This could be an interesting future work for researchers in this field.

By using the results obtained concerning the mean thickness level and thickness loss values, it is possible to predict mean thickness and thickness loss changes in similar carpet constructions. In other words, the variations exhibited in ***Figures 1*** and ***2*** can be used as models to estimate the behavior of these type of carpets in terms of thickness and thickness loss.

Statistical evaluations of the experimental data showed that the pile material and number of impacts have a significant effect on mean thickness and thickness loss variations.

5. References

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