

Computer-aided statistical module for hand-knotted carpets

D B Shakyawar^a, N P Gupta, P C Patni & R K Arora

Division of Wool Technology, Central Sheep & Wool Research Institute, Avikanagar 304 501, India

Received 22 October 2007; revised received and accepted 5 March 2008

This study deals with the development of equations to predict abrasion loss and carpet hand value (CHV) of hand-knotted carpets. Best-fit equation obtained from regression analysis shows that the abrasion loss depends on fibre diameter and number of medullated fibres present in the yarn as well as pile density of carpet. The regression coefficient is found to be 0.47, which is highly significant ($p < 0.01$). The best-fit equation for CHV reveals that it depends on pile height, carpet thickness and pile density. The coefficient of regression is found to be 0.77, which is significant at $p < 0.01$. Based on these equations, a software is developed using C language which can predict abrasion loss and CHV within the range of error $\pm \sigma$ value.

Keywords: Abrasion loss, Carpet hand value, Hand knotted carpet, Pile height, Wool

IPC Code: Int. Cl. ⁸D04G3/00, G06G

1 Introduction

The design is one of the most important features of carpet manufacturing which decides the value of carpet. Apart from design, other performance characteristics, such as abrasion resistance, resiliency and compressibility, are some of the important characteristics which define the carpet quality and are essentially desired. Since, carpet is a very costly product and made in different sizes according to end-use application, manufacturers always discourage evaluation of carpets by destructive method and prefer subjective evaluation. Moreover, the selection of raw material, yarn structure and construction parameters of a carpet play a vital role in influencing the performance as well as appearance of carpet pile. The carpet manufacturers generally apply their own experience using trial and error method for selection of fibre-mix and constructional parameters. This approach leads to inconsistency and imperfection in carpet making; as a result, carpets of undesirable quality are manufactured. In order to avoid such situation to a larger extent, there is a need to develop some scientific tool using computer-aided statistical management system.

Earlier various researchers made some efforts to study the effect of fibre properties on carpet performance.¹⁻³ Ince and Ryder¹ evaluated carpets made from wool of 48s-36s having 1.1-49%

medullation content and concluded that the correlation exists between medullation and carpet appearance. Gupta *et al.*² reported that the presence of medullated fibres improved resilience, visual appeal and handle of carpets. They further reported that the bulk of carpet showed positive correlation with fibre diameter and medullation.³ The resiliency also has good relationship with fibre diameter and medullation. The correlations between abrasion loss and fibre diameter as well as medullation are found positive. Efforts were also made to analyze the effect of constructional parameters on functional properties and subjective hand value of carpets by Patni *et al.*⁴ They reported that in case of handloom woven carpets, pile density has got direct correlation with performance characteristics. The subjective test is further confirmed by objective test. The pile density plays a key role in affecting the pile thickness loss and its recovery and also the durability of the carpet. Arora *et al.*⁵ reported that the constructional parameters dominate over fibre parameters in affecting the resiliency and compressibility behaviour of the carpets.

In the era of computer and image processing technologies, it is possible to develop database and analyze them rapidly. Presley⁶ studied the appearance retention of carpets using image analysis and correlated with subjective method. He reported that the image analysis is a reliable tool to measure retention of the carpet texture. Mikhailov *et al.*⁷ determined the significance of carpet end-use

^aTo whom all the correspondence should be addressed.
E-mail: dbshakya_67@yahoo.co.in

properties and reported that the abrasion resistance is most important character of carpet. It is mainly determined by pile yarn characteristics, but no matter what kind of pile is used. It can be improved simply by choosing appropriate structural parameters to increase pile density.⁸ Keeping these in views, the present study was undertaken to develop equations for predicting abrasion loss and carpet hand value (CHV) of hand-knotted carpets made of wool and its blends using appropriate database and software.

2 Materials and Methods

The abrasion loss data of total 117 different wool and its blended carpet samples were collected to develop the regression equation. Their fibre characteristics (average fibre diameter and medullation) and constructional parameters (pile height and pile density) were determined using standard procedures recommended by BIS.⁹ Sixty-six carpet samples were assessed for CHV by a panel of judges.¹⁰ The criterion for judgement was feel / touch through sensation for tactile handle. Each carpet sample was evaluated for tactile handle by 10 judges. The judges were asked to give a rank in the scale of 5-excellent, 4-very good, 3-good, 2-average and 1-poor for both tactile handle and aesthetic appeal separately. The average score of each expert's rating is termed as carpet hand value (CHV).

The data were evaluated statistically using SPSS 10.0 window based software. To develop regression equation for predicting abrasion loss, total four independent variables, namely fibre diameter, medullation content, pile height and pile density, were taken for analysis. However, total seven independent variables, namely fibre diameter, medullation content, pile height, pile density, thickness, resiliency and compressibility, were selected to correlate CHV. Using backward method to determine best-fit equation, independent variable was removed step-wise from the equation, keeping probability criterion of $F \geq 0.100$.

Based on these equations, a software was developed to predict abrasion loss and CHV using C language. For testing the software, a set of 20 carpet samples prepared out of commercial yarn was evaluated for fibre characteristics, constructional parameters and their performance properties. The values of abrasion loss and CHV were predicted using the developed software. The absolute and percentage errors between actual and predicted values were also determined.

3 Results and Discussion

3.1 Fibre Characteristics, Constructional Parameters and Carpet Performance

Descriptive statistics of fibre characteristics and constructional parameters along with abrasion loss of carpets are shown in Table 1. The mean values of fibre diameter, medullation, pile height, pile density and abrasion loss are 32.5 μm , 37.2%, 11.1mm, 115.5 knots / inch² and 2.58%, and the standard deviations are 10.5, 26.5, 2.3, 26.5 and 0.96 respectively. The fibre diameter in the carpet sample varies from 15.1 μm to 81.5 μm and medullation ranges between 0% and 97%. The pile density and pile height vary from 46 knots / inch² to 161 knots / inch² and from 5mm to 15 mm respectively. The abrasion loss is varying from 0.33% to 5.00%.

The descriptive statistics of carpets analyzed for CHV, their fibre characteristics, constructional parameters and performance properties are given in Table 1. The mean of fibre diameter, medullation, thickness, pile height, pile density and CHV are 27.8 μm , 20.43%, 13.13 mm, 9.88 mm, 103 knots / inch² and 3.25 respectively. The range variation is found to be 15-50 μm , 0-89.1%, 6.4-21.6 mm, 5.7-16.2 mm, 24-144 knots / inch² and 1.2-4.3 for fibre diameter, medullation, thickness, pile height, pile density and CHV respectively.

3.2 Correlations among Fibre Characteristics, Constructional Parameters and Carpet Performance

The abrasion loss data analyzed for correlation (Table 2) clearly indicates that the abrasion resistance is the property for which pile material characteristics become determinant. Abrasion loss values show positive correlation with fibre characteristics, such as average fibre diameter and medullation content. The correlation coefficients for both these fibre characteristics are 0.34 and 0.46 respectively which are significant at $p < 0.01$ level. However, the constructional parameters such as pile density and height show poor correlations which are non-significant. It reveals that the fibre characteristics dominate over construction parameters for the determination of abrasion loss.

The data analyzed for CHV (Table 2) reveal that the CHV is positively related with pile density, thickness and pile height; the values of their correlation coefficients are 0.60, 0.50 and 0.34 respectively. The correlations are found to be significant at $p < 0.01$. However, the fibre diameter and medullation are negatively correlated with CHV and

Table 1 — Descriptive statistics of abrasion loss and CHV
[No. of carpet samples (N) = 117 (abrasion loss) and 66 (CHV)]

Parameter	Minimum		Maximum		Mean		Std. Deviation	
	Abrasion loss	CHV	Abrasion loss	CHV	Abrasion loss	CHV	Abrasion loss	CHV
Avg. fibre diameter, μm	15.1	15.1	81.5	49.6	32.5	27.8	10.5	6.33
Medullation, %	0	0	97.0	89.4	37.2	20.4	26.5	22.56
Pile height, mm	5.0	5.7	15.0	16.2	11.1	9.88	2.3	2.3
Pile density, knots/ inch ²	46	24	161	144	115.5	103	26.5	24.5
Carpet thickness, mm	-	6.4	-	21.6	-	13.1	-	2.88
Abrasion loss, %	0.33	-	5.0	-	2.58	-	0.96	-
CHV	-	1.2	-	4.3	-	3.25	-	0.68

Table 2—Correlations among abrasion loss and CHV with fibre characteristics and constructional parameters

Property	Fibre diameter μm	Medullation %	Pile height mm	Pile density knots/ inch ²	Thickness mm	N
Abrasion loss	0.34 ^a	0.46 ^a	0.18 ^{ns}	-0.02 ^{ns}	-	117
CHV	-0.13 ^{ns}	-0.20 ^{ns}	0.34 ^a	0.60 ^a	0.50 ^a	66

^a Significant at $p < 0.01$ level (1-tailed).

^{ns} Non-significant.

N—Number of carpet samples.

Table 3—Regression analysis for abrasion loss and CHV

Property	R	R^2	Constant	Coefficients					F-value
				Fibre diameter	Medullation	Pile density	Pile height	Thickness	
Abrasion loss	0.47 ^a	0.22	3.145 ^a	(-) 0.006 ^{ns}	0.019 ^a	(-) 0.003 ^b	-	-	10.40
CHV	0.77 ^a	0.60	0.345 ^{ns}	-	-	0.016 ^a	-0.117 ^a	0.182 ^a	30.9

^aSignificant at $p < 0.01$ level.

^bSignificant at $p < 0.05$ level.

^{ns}Non-significant.

are non-significant. These results reveal that the constructional parameters show predominant effect on CHV than the fibre characteristics.

3.3 Regression Analysis for Abrasion Loss and CHV

Correlation analysis for abrasion loss and CHV shows that either fibre characteristics or constructional parameters predominately affect carpet performance properties. However, it is not acceptable that the constructional parameters do not influence the abrasion loss or fibre characteristics do not affect CHV. It is well understood that both abrasion loss and CHV are influenced by fibre characteristics as well as constructional parameters. The relationships are not linear with any of the parameters, since these are complex in nature and interdependent on each other. Hence, an alternate method to predict the carpet performance by analyzing these data for regression equations was attempted. The detailed statistical analysis of regression equation for abrasion loss is given in Table 3. The best-fit equation, given below,

for abrasion loss shows that the abrasion loss mainly depends on medullation per cent, fibre diameter and pile density of carpet. The regression coefficient is 0.47 which is significant at $p < 0.01$ level.

$$\text{Predicted abrasion loss (\%)} = 3.145 + 0.006 \times \text{Fibre diameter } (\mu\text{m}) + 0.019 \times \text{Medullation (\%)} - 0.003 \times \text{Pile density (knots / inch}^2\text{)}$$

The graph plotted between actual abrasion loss values and calculated values obtained from above equation is shown in Fig. 1. It is revealed that most of the predicted values fall within the range of 95% confidence limit. Therefore, it can be concluded that the developed equation could be used for estimating abrasion loss at the time of selection of raw material and constructional parameters.

The detail of statistical analysis of regression equation for CHV is shown in Table 3. The best-fit equation for CHV, as shown below, obtained from regression analysis indicates that the CHV mainly depends on pile height, carpet thickness and pile

density of carpets. The coefficient of regression is 0.77 which is significant at $p < 0.01$ level.

$$\text{Predicted CHV} = 0.345 - 0.117 \times \text{Pile height (mm)} + 0.182 \times \text{Thickness (mm)} + 0.016 \times \text{Pile density (knots/inch}^2\text{)}$$

The graph plotted between actual CHV and calculated CHV (Fig. 2) reveals that most of the calculated values fall within the range of 95% confidence limit. Thus, it can be concluded that the developed equation could be used for forecasting CHV while selection of constructional parameters. By varying pile height, pile density and carpet thickness, the desired quality of carpets could be developed.

3.4 Development of Software for Forecasting Abrasion Loss and CHV

A software for predicting CHV and abrasion loss of hand-knotted carpet was developed using C language (Fig. 3). The module is capable to forecast the value of abrasion loss (%) and CHV. It can also classify the carpet into five categories such as poor, average, good, very good and excellent, according to CHV.

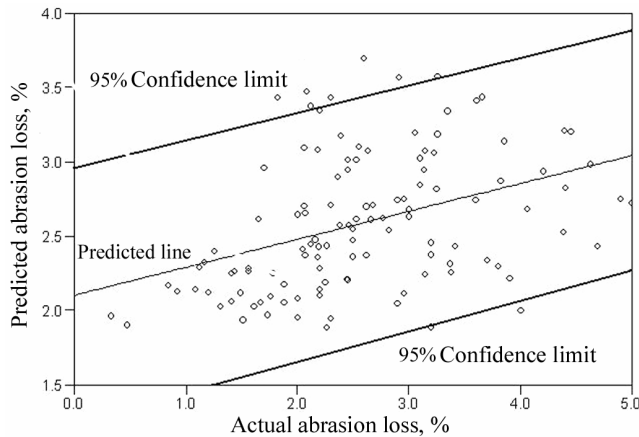


Fig. 1 — Actual vs predicted abrasion loss

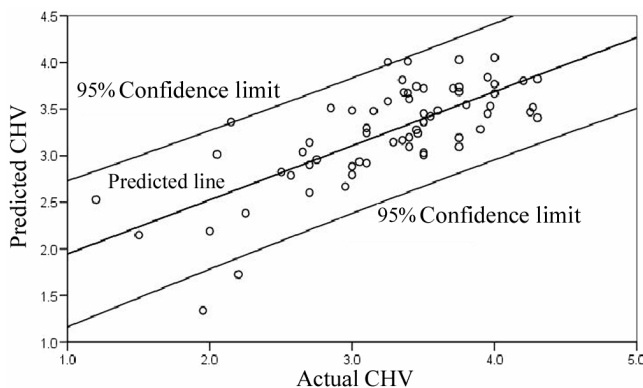


Fig. 2 — Actual vs predicted CHV

Fibre characteristics, such as average fibre diameter & medullation and construction parameters such as pile height, pile density & carpet thickness are prerequisite to predict carpet performance in respect of abrasion loss and CHV.

```

main()
{
int fd,pd,h,m;
float ab,chv;
clrscr();
printf("CAERPET MODULE : FORECASTING OF
ABRASION LOSS AND CARPET HAND VALUE
(CHV)");
printf("\n Enter value of Fibre Diameter (µm) between 20
to 80= ");
scanf("%d",&fd);
printf("Enter value of Pile Density (piles per inch) between
46 to 192= ");
scanf("%d",&pd);
printf("Enter value of pile height (mm) between 4 to 16=
");
scanf("%d",&h);
printf("Enter value of Carpet thickness (mm) between 6 to
22= ");
scanf("%d",&t);
printf("Enter value of medullation (percent) between 0 to
80= ");
scanf("%d",&m);
if(fd>=20 &&fd<=80)
{
if(pd>=46 &&pd<=192)
{
if(h>=4 &&h<=16)
{
if(t>=6 &&t<=22)
{
if(m>=0 &&m<=80)
{
ab=3.145 + (0.006*fd) + (0.019*m) - (0.003*pd);
printf("ABRASION LOSS =%f",ab);
chv=0.345-0.117*h+0.182*t+0.016*pd;
printf("\n CHV =%f ", chv);
{
if(chv>0&&chv<=1)
printf("Poor");
else if(chv>1&&chv<=2)
printf("Average");
else if(chv>2&&chv<=3)
printf("Good");
else if(chv>3&&chv<=4)
printf("Very Good");
else if(chv>4&&chv<=5)
printf("Excellent");
else
printf("invalid");
}
else
printf("INPUT DATA INVALID");
}
getch();
}
}
}
}
}
}
}
}
}
}

```

Fig. 3 — Coding and algorithm used for software

The module was tested using 20 carpets prepared from commercial woollen yarn.¹⁰ The details of fibre characteristics such as fibre diameter & medullation and construction parameters, such as pile height, carpet thickness & pile density of carpet are shown in Table 4. These parameters are used as input data and the values of abrasion loss and CHV are predicted using the developed software. The

actual as well as predicted values of abrasion loss and CHV are given in Table 5. It is observed that the error in predicted values of abrasion loss and CHV is within the limit of $\pm 20\%$. Moreover, the absolute difference in actual and predicted values of abrasion loss and CHV is found within the range of $\pm \sigma$ value, i.e. $\pm 0.96\%$ for abrasion loss and ± 0.68 for CHV.

Table 4—Fibre characteristics and constructional parameters of carpet samples

Code	Fibre mix	Colour	Fibre characteristic		Constructional parameter		
			Diameter μm	Medullation %	Thickness mm	Pile height mm	Pile density knots/inch ²
B1	NZ+CH (50:50)	Orange	30.5	31	16.2	11.8	108
B2	NZ+CH (50:50)	Yellow	28.4	6	14.0	12.0	132
B3	NZ+CH (50:50)	Red	27.4	23	16.8	12.6	100
B4	NZ+CH (50:50)	Yellow	32.0	36	17.0	11.0	100
B5	NZ+CH (50:50)	Red	27.5	2	13.1	9.8	96
B6	NZ+CH (50:50)	Red	28.2	5	13.8	9.6	138
B7	NZ+CH (50:50)	Red	26.9	5	13.2	8.8	120
B8	NZ+CH (50:50)	Red	29.1	5	18.5	13.2	96
B9	NZ+CH (50:50)	Blue	31.7	23	18.0	12.6	96
B10	NZ+CH (50:50)	Brown	31.2	9	18.0	16.2	144
B11	NZ+CH (50:50)	Red	28.2	4	21.7	16.0	92
B12	NZ+CH (50:50)	Red	29.0	12	12.1	8.0	96
B13	NZ wool	Blue	27.1	4	11.4	9.4	134
B14	NZ wool	White	28.8	3	13.4	8.6	126
B15	NZ wool	White	27.2	8	17.7	13.0	96
B16	South African wool	White	26.3	16	12.2	7.9	112
B17	Black yarn	White	31.1	10	9.4	7.1	108
B18	Chokla- Avikalin	White	22.9	13	10.2	6.3	96
B19	Chokla Mutton	White	24.8	12	10.6	9.0	128
B20	CH wool Bikaneri	White	29.2	41	10.5	8.1	84

NZ – New Zealand wool, and CH – Chokla wool.

Table 5 — Carpet performance and calculated values using developed statistical equations

Code	Abrasion loss				CHV			
	Actual	Calculated	Difference	% Difference	Actual	Calculated	Difference	% Difference
B1	3.16	3.23	0.07	2.12	3.36	3.61	0.25	6.85
B2	3.09	2.69	-0.40	-12.86	3.75	3.57	-0.18	-5.08
B3	3.30	3.12	-0.18	-5.53	4.17	3.49	-0.68	-19.59
B4	3.25	3.34	0.09	2.69	3.35	3.72	0.37	10.05
B5	2.72	2.73	0.01	0.37	3.29	3.10	-0.19	-6.25
B6	2.64	2.66	0.02	0.63	3.25	3.90	0.65	16.74
B7	2.68	2.72	0.04	1.45	3.39	3.61	0.22	6.04
B8	2.73	2.78	0.05	1.74	3.71	3.66	-0.05	-1.46
B9	3.29	3.10	-0.19	-5.66	3.50	3.65	0.15	3.98
B10	2.59	2.84	0.25	9.68	3.46	3.20	-0.26	-7.90
B11	2.95	2.78	-0.17	-5.90	3.39	3.84	0.45	11.70
B12	3.14	2.91	-0.23	-7.29	3.35	3.13	-0.22	-7.20
B13	3.17	2.66	-0.51	-16.21	3.60	3.43	-0.17	-4.89
B14	2.26	2.65	0.39	17.31	4.20	3.77	-0.43	-11.42
B15	2.7	2.85	0.15	5.40	3.40	3.53	0.13	3.77
B16	2.44	2.96	0.52	21.11	3.15	3.42	0.27	7.81
B17	2.49	2.82	0.33	13.43	3.05	2.92	-0.12	-4.23
B18	2.78	2.97	0.19	6.71	2.65	2.98	0.33	11.01
B19	3.2	2.84	-0.36	-11.24	3.15	3.25	0.10	3.06
B20	2.96	3.50	0.54	18.14	2.95	2.64	-0.31	-11.94

4 Conclusions

4.1 The abrasion loss mainly depends on fibre diameter and number of medullated fibres present in the yarn.

4.2 The CHV depends on constructional parameters of carpet, such as pile height, pile density and carpet thickness.

4.3 The software can predict abrasion loss and CHV within the range of error $\pm \sigma$ value.

Industrial Importance: The development of software is one of the important outcomes of the study for industrial application. The software can predict carpet performance in terms of abrasion loss and CHV without using destructive method of evaluation. The software will provide CHV based on objectively assessed fibre properties and actual constructional parameters of carpet. It will help to carpet manufacturers in decision-making process for production of desired quality carpets.

Acknowledgement

The authors are thankful to Mr N L Meena and Mr B L Ujenia for their technical assistance in evaluating carpet samples.

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