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Effect of loading behaviour on compressional property of needle-punched nonwoven fabric

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An attempt has been made to understand the effect of different testing parameters on compressional behaviour of needle-punched nonwoven fabric. These parameters are repeated compression-recovery cycles (0-200 kPa), ultimate load (50, 100 and 200 kPa), duration after loading or unloading (up to 6 min with 200 kPa), rate of deformation (1, 5, 10, 15, 20 and 25 mm/min) and testing principles (constant rate of loading or compression). It is found that most of the changes in the compressional properties take place in the first and second compression cycles. In all the cycles, compression parameter (α) and recovery parameter (β) of polypropylene and jute-polypropylene blended fabrics are higher than jute fabric. There is no effect of ultimate compressional pressures selected in this experiment on different compressional parameters. Type of testing principle also affects the extent of compressibility and recovery. As the rate of deformation increases, α, β and energy loss decrease initially and then remain unaltered. When compressional pressure is applied on needle-punched fabric, there is an instantaneous compression and after that thickness loss increases with time in diminishing rate. The thickness loss stabilizes after reaching to maximum which is 55-60% for jute and wet jute, 83% for jute/polypropylene and 92% for polypropylene. Recovery from compression also follows the similar trend. These information will be useful in the real situations where different magnitude and nature of compressional load is applied on needle-punched nonwoven fabrics.

Keywords: Compressional behaviour, Cyclic loading, Jute, Needle-punched nonwoven, Polypropylene

1 Introduction

Needle-punched nonwoven fabrics from synthetic fibre are gaining popularity due to their unique hydraulic properties. Such fabrics made out of low cost, natural, annually-renewable well-established industrial fibre like jute and its blend with synthetic fibre has enormous potential in application of geotextiles, agrotextiles, filtration, insulation (thermal, electrical and sound), etc.[1] . During these applications, fabrics are subjected to compression load and subsequent recovery, affecting their performance[2]. Therefore, study of compressional and recovery behaviour of needle-punched nonwoven fabrics in different conditions of loading is very important.

Different types of nonwoven fabrics have been extensively studied by researchers[3-6] and they suggested various theories and nature of compressional behaviour. Two parameters (α and β), describing compression and recovery curves of different types of spun-bonded fabrics, have been evaluated by Kothari *et al*[5]. In another work[6] , they have studied the compressional behaviour of layered needle-punched nonwoven geotextiles and a relationship has been proposed to predict the compressional behaviour of two nonwoven fabrics in series. Giroud[7] observed that the changes in pore size of needled fabric can be related to compressibility. Wei *et al.*[8] proposed the mechanism of compression, relaxation and stabilization of the fabrics over a selected load range. Mc Gawn *et al.*[9] studied the load-extension behaviour of different types of nonwoven geotextiles under compressive load. Ghosh *et al.*[10] observed lower compressibility and higher recovery with the higher number of passes during needle-punched nonwoven preparation. Jirsak *et al*[11]. suggested and tested a method to characterize the loss of compressional rigidity of high loft materials due to repeated loading during end use. Sengupta *et al.*[12-14] studied the effect of punch density, depth of needle penetration, mass per unit area and dynamic loading on the compressional behaviour of jute-based needled fabric. Debnath *et al*.[15,16] studied compressional behaviour and creep of jute-polypropylene and polyester needle-punched nonwoven fabrics in dry and wet conditions.

Nowadays, successful attempts[17, 18] have been made to apply such fabrics in the areas of geotextiles, e.g. soil stabilization, drainage, filtration, road

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reinforcement, etc. In various geotextile applications, the needle-punched nonwoven fabrics are used under constant or repeatedly changing compressive loads as well as tensile loads of different magnitudes. Recently, jute and allied natural technical fibres have been used successfully in the field of geotextiles[19-20].

During compression of loose fibre mass, Dunlop[21] observed a clear evidence of fibre-to-fibre slippage, resulting in stick-slip nature of curves. The decompression curve, however, was the smooth inverse cube curve, since no slippage was involved in the release cycle of the model. For representation of fibre mass compression, three different models were proposed with series of friction blocks and springs. The friction blocks represent the plastic deformation, i.e. fibre-to-fibre slippage within the structure of the fibre mass during compression, whereas springs represent elastic deformation, i.e. bending of fibres, However, the visco-elastic nature of the fibre mass was not taken into account by any of those models. Hearne and Nossar[22] derived a relationship between bulk density and compressive force within a bed of loose fibres rotating inside a centrifuge. Thompson and Whiteley[23] studied some effects of test specimen preparation procedure on the resistance to compression of cleaned and carded raw wool. Whiteley *et al*.[24] carried out an analysis of the resistance to compression of common marino fleece wools and found that the resistance to compression is highest among fine, short wools.

Batra *et al*.[3] in their study on air-laid thermally bonded nonwoven fabrics have shown that following equations fit excellently with the loading and unloading data respectively of those fabrics, with in a very low pressure range of 0.07 - 3.57 kPa:

$$\sigma = \sigma_0 + \beta\,[(1/\lambda) - 1]$$

$$\sigma = \sigma_0 \exp\,[\alpha\,((1/\lambda) - (1/\lambda_r))]$$

where σ is the stress applied on the fabric; σ_0, the reference stress; λ, the compression ratio i.e. ratio of deformed thickness (t) to the original thickness (t_0); λ_r, the ratio of residual thickness (after complete unloading) to the original thickness (t_0); and α and β, the non-dimensional constants, which would serve as measure of stiffness of the material in lateral compression.

Following three different equations were proposed by Inescu *et al*.[4] to characterize the compressional behaviour of a particular type of nonwoven geotextiles for different ranges of pressure:

$$T_A = \tan\alpha_1 \log\sigma + n_1 \qquad \text{for } \sigma \text{ from 0.5-3 KPa,}$$

$$T_B = k^2/\log\sigma \qquad \text{for } \sigma \text{ from 3-300 KPa,}$$

$$T_C = \tan\alpha_2 \log\sigma + n_2 \qquad \text{for } \sigma \text{ above 300 KPa.}$$

where α_1, α_2, k, n_1, n_2 are the constants and depend on fabric characteristics; T_A, T_B and T_C , the thickness values at different pressure levels; and σ , the pressure level.

It is observed from above-mentioned studies that the testing of compressional behaviour of needle-punched nonwoven fabrics has been done with different magnitudes and nature of testing parameters. But, the compressional behaviour may be influenced by different modes of application and magnitudes of compressive and recovery loads. Hence, the study on the effect of different nature/mode of compressive load on compressional behaviour is necessary. Therefore, in this study, an attempt has been made to understand the effect of repeated compression-recovery cycles, ultimate compressive load applied, duration of applied load, rate of change of load and different loading principles on jute, polypropylene and jute-polypropylene blended needle-punched nonwoven fabrics. It will enrich with the knowledge, how these fabrics will behave on compression under different practical situations.

2 Materials and Methods

2.1 Materials

Tossa Daisee jute of grade TD_3 (IS:271) was used for preparation of needle-punched nonwoven fabrics. Polypropylene (PP) fibre of 120 mm staple length and 1.7 tex linear density was used for the preparation of needle-punched fabric either alone or blended with jute in 1:1 dry weight proportion. The physical properties of jute fibres taken from breaker card and polypropylene were measured. Jute and PP densities are known. PP staple length and linear density have been collected from manufacturer. Jute fibre linear density has been tested by air flow method using JTRL jute fibre fineness tester (IS:7032). Single fibre tensile test has been done with paper window technique in Instron tensile tester using 1 cm gauge length. Coefficient of friction of card sliver has been studied using inclined plane principle[25]. Weighted ring loop method has been used to test flexural rigidity of fibres[26]. All these data are tabulated in Table 1.

Table 1 − Physical properties of fibres

Fabric	Density g/cm^3	Linear density tex	Tenacity cN/tex	Extension at break %	Coefficient of friction	Flexural rigidity dyne-cm^2
Jute	1.46	2.04	33.1	1.53	0.66	5.9
PP*	0.92	1.70	37.3	51.00	0.58	2.6
Jute-PP (1:1)	-	-	-	-	0.51	-

*PP - Polypropylene.

Table 2 − Constructional details of cross-laid experimental fabrics

Sample No.	Fibre	Mass per unit area g/m^2	Needling density punches/ cm^2	Depth of needle penetration mm	Fabric thickness mm	Bulk density g/cm^3
S1	Jute	613	200	13	5.47	0.112
S2	PP	579	200	13	6.53	0.089
S3	Jute-PP (1:1)	584	200	13	5.73	0.102

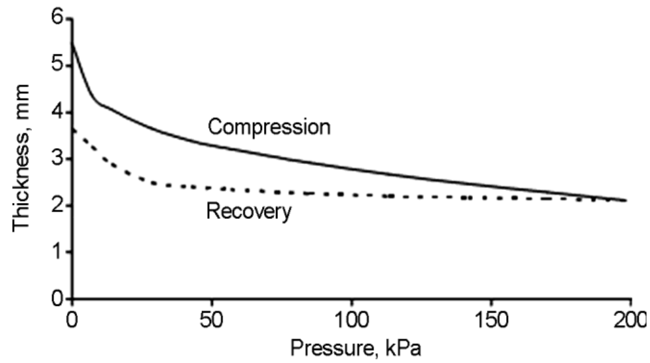

Fig. 1− A typical experimental curve of pressure thickness data of a jute needle-punched nonwoven fabric

2.3 Methods

2.3.1 Preparation of Nonwoven Fabrics

The middle portion of jute reed (after removal of root and tip portion) was subjected to softening treatment. Jute batching oil (a commercial grade, hydrocarbon based mineral oil) in water emulsion was sprayed to maintain an average of 1.5% oil content and nearly 35% moisture on the weight of fibre. The reeds were then kept in bin for piling or conditioning for 24 h as commonly practiced[27] in jute mills. Then it was processed through jute softener and breaker card. The breaker card sliver was fed to Dilo nonwoven plant comprising a card, a camel back cross-lapper and a needle loom (model number OD II/6) to prepare pre-needled web of 50 g/m^2 with 25 punches/cm^2 and 12 mm depth of needle penetration. The fabric mass per unit area was achieved by needling the required number of layers of pre-needled fabric considering mass per unit area loss due to needling [28].

To prepare blended fabric, breaker card jute sliver and polypropylene fibre were opened thoroughly and then mixed in 1:1 dry weight proportion following stack mixing technique. This blend was then processed in Dilo needle-punched nonwoven plant to get the nonwoven fabric. Similarly, polypropylene needle-punched nonwoven fabric was prepared feeding polypropylene staple fibre directly on the conveyor of Dilo card and processed in Dilo loom in the similar way.

Constructional details of jute, polypropylene and jute-polypropylene (1:1) blended needle-punched fabrics, prepared using 25 gauge regular barb needles, are shown in Table 2. The actual mass per unit area was measured following the ASTM standard (D 6242).

2.3.2 Wetting of Jute Fabric

Jute needle-punched nonwoven fabric samples were put in to a tray containing water with 1% anionic wetting agent for 30 min. No pressure was applied on fabric during wetting. After complete wetting, the wet fabrics are taken out and kept on the blotting paper for 10 min and then used for testing immediately[29] .

2.3.3 Measurement of Repeated Compression Recovery Cycles

The compression-recovery of above mentioned nonwoven was carried out for six consecutive load cycles between 0-3532-0 N (0-200-0 kPa approximately) using Instron tensile tester (model no. 5567) with a compression load cell of 10 kN capacity. The needle-punched nonwoven sample was placed between 150 mm diameter stationary anvil and the pressure foot of 150 mm diameter. After starting the test, the pressure foot moves downward in the speed of 2 mm/min. After reaching the maximum compressional load of 3532 N (exerts pressure of about 200 kPa), the pressure foot automatically starts upward movement in the same speed i.e. 2 mm/min. Figure 1 shows compressional load against deformation plots along with a report of compressional deformation in required compressional load (BS 4098:1975). Average of ten such readings was considered.

The compressional parameter (α), recovery parameter (β), energy loss and thickness loss for each cycle have been calculated from the relations given below and the average of ten such tests are reported in Table 3. The parameters α and β are the dimensionless constants, indicating the nature of compression and

Table 3 − Effect of repeated compression-recovery cycles

Sample	Cycle no.	Initial thickness (T_0) mm	Compressed thickness (T) mm	Final thickness (T_f) mm	Compressional parameter (α)	Recovery parameter (β)	Thickness loss (T_L) %	Energy loss (E_L) %
Jute	1	5.480	2.110	3.640	0.08091	0.07174	33.58	72.35
	2	3.640	2.060	3.580	0.05711	0.07271	1.65	45.29
	3	3.580	2.042	3.364	0.05652	0.06568	6.03	39.27
	4	3.364	2.025	3.210	0.05237	0.06061	4.58	39.52
	5	3.210	2.013	3.078	0.04906	0.05587	4.11	38.33
	6	3.078	2.004	3.410	0.04591	0.05396	1.88	38.07
Jute:PP	1	5.730	0.467	4.080	0.12692	0.28517	28.80	62.76
	2	4.080	0.415	2.908	0.12632	0.25615	28.73	54.58
	3	2.908	0.382	2.555	0.12675	0.25002	12.14	47.24
	4	2.555	0.365	2.415	0.12678	0.24860	5.48	45.49
	5	2.415	0.355	2.329	0.12665	0.24748	3.56	46.85
	6	2.329	0.349	2.156	0.12682	0.23957	7.43	47.66
PP	1	6.530	0.230	5.020	0.12084	0.40562	23.12	51.32
	2	5.020	0.200	4.869	0.11818	0.41999	3.01	42.56
	3	4.869	0.180	4.678	0.11428	0.42859	3.92	35.81
	4	4.678	0.170	4.548	0.11277	0.43240	2.78	33.38
	5	4.548	0.170	4.439	0.11222	0.42921	2.40	33.01
	6	4.439	0.160	4.381	0.11185	0.43546	1.31	33.83
Wet jute	1	8.960	3.760	6.010	0.07635	0.04925	32.92	74.35
	2	6.010	3.683	5.781	0.05094	0.04775	3.81	52.78
	3	5.781	3.660	5.629	0.04827	0.04602	2.63	48.32
	4	5.629	3.649	5.568	0.04628	0.04534	1.08	49.95
	5	5.568	3.645	5.546	0.04544	0.04534	0.40	48.33
	6	5.546	3.643	5.539	0.04514	0.04510	0.13	49.17

recovery of the fabric respectively. Higher value of α means higher compressibility and vice versa. β represents the amount of recovery from unit compressed thickness, i.e. the higher the β, the higher will be the recovery and vice versa. A particular fabric will give a unique pair of α and β, irrespective of units of thickness and pressure.

For jute needle-punched fabrics, the following equations were found to be best fit in describing the compression and recovery behavior[12, 30] :

During compression, $T/T_0 = 1 - \alpha / \log_e (P/P_0)$

During recovery, $T/T_f = (P/P_f)^{-\beta}$

where T_0 and T_f are the initial and the final thicknesses at initial and final pressures P_0 and P_f, respectively; and T , the thickness at any pressure P. The energy loss (E_L), after compression and recovery, can be calculated as follows:

$$E_L (\%) = (E_1 - E_2) \times 100/ E_1$$

where E_1 is the potential energy stored during compression; and E_2, the energy recovered during recovery. They are measured as the area under the compression or recovery curves from Instron tester. The loss in thickness (T_L) during compression and recovery is given by,

$$T_L (\%) = (T_0 - T_F) \times 100 / T_0$$

where T_F is the thickness after recovery or final thickness. For any statistical calculations Statistical 7 was used.

2.3.4 Measurement with Different Ultimate Load

Compressional behaviour of nonwoven has been studied with three different ultimate compressional pressures 50, 100 and 200 kPa following the above-mentioned method. For each case, ten tests were carried out and the average was reported (Tables 4 & 5).

2.3.5 Measurement of Thickness Loss after Loading and Unloading with Time

Thickness of jute, polypropylene, jute-polypropylene (1:1) blend needle-punched nonwoven has been measured with 200 kPa compressional pressure applied in 200 mm/min speed. Keeping the fabric under this pressure, the thickness data was collected after every 10 s up to 6 min. Then, recovery

Table 4 – Effect of ultimate load on compressional behaviour

Nonwoven	Ultimate pressure kPa	Initial thickness (T_0) mm	Compressed thickness (T) mm	Final thickness (T_f) mm	Compressional parameter (α)	Recovery parameter (β)	Energy loss %
Jute	200	5.48	2.110	3.64	0.080907	0.071741	72.35
	100	5.51	2.114	3.673	0.081087	0.072679	70.91
	50	5.49	2.112	3.648	0.080951	0.071905	73.22
Jute-polypropylene (1:1) blend	200	5.73	0.440	4.080	0.121461	0.293002	62.76
	100	5.71	0.449	4.228	0.121218	0.295026	63.13
	50	5.70	0.428	3.838	0.121685	0.288595	61.07
Polypropylene	200	6.53	0.190	5.020	0.127735	0.430760	51.32
	100	6.55	0.176	4.541	0.128028	0.427636	50.53
	50	6.56	0.214	5.760	0.127271	0.433201	51.66
Wet jute	200	8.96	3.760	6.010	0.076354	0.049254	74.35
	100	8.91	3.821	6.093	0.075143	0.049058	73.89
	50	8.95	3.787	6.050	0.075895	0.049211	73.82

from 200 kPa pressure in 200 mm/min speed was carried out. The recovery thickness data have also been collected after every 10 s up to 6 min. The thickness loss data of ten tests for compression and recovery are shown in Table 3.

2.3.6 Measurement with Different Rate of Deformation

Six different testing speeds viz. 1, 5, 10, 15, 20 and 25 mm/min have been studied for jute needle-punched nonwoven for compression up to 200 kPa pressure and recovery from that pressure in Instron tensile tester. Compressional parameter (α), recovery parameter (β), energy loss and thickness loss have been calculated and an average of ten such tests are reported in Table 6.

2.3.7 Measurement with Different Principles

Jute needle-punched nonwoven fabric was used for compression up to 100 kPa pressure and subsequent recovery in the following three testing principles:

(i) *Stepwise Increase and Decrease of Load – Constant Rate of Loading (CRL 1)*

Samples were mounted on the Prolific thickness tester and loads were applied at the same place of sample in such a way that pressure exerted was 1, 10, 20, 50 and 100 kPa in increasing steps. Similarly for recovery, pressure has been removed in same steps. The thickness values have been measured after 30 s of application or removal of each load (D 1777-64). This system is denoted as ‘CRL 1’. Percentage of thickness loss has been calculated with respect to the initial thickness at 1 kPa pressure and data (average of 10 tests) are shown in Table 7.

Table 5 − Standard errors of difference of α & β between ultimate pressures 50 and 200 kPa

Nonwoven	Compressional parameter (α)	Recovery parameter (β)
Jute	0.00097	0.00077
Jute-polypropylene (1:1) blend	0.00042	0.00049
Polypropylene	0.00013	0.00024
Wet jute	0.00061	0.00071

(ii) *Application of Different Load as a Whole (CRL 2)*

Sample was mounted on the Prolific Thickness Tester and different pressures i.e. 1, 10, 20, 50 and 100 kPa were applied at different places of the samples separately and subsequently removed to measure compression and recovery for each load (D 1777-64). Their corresponding average thicknesses (of ten tests) are shown in Table 7. The thickness values have been measured after 30 s of application or removal of load. This process is called ‘CRL 2’.

(iii) *Continuous Rate of Compression (CRC)*

The load, under continuous rate of compression and recovery (CRC), has been measured on Instron tensile tester. The average thickness loss has been calculated (average of ten data) in both the cases of compression and recovery (Table 7).

3 Results and Discussion

3.1 Effect of Repeated Compression Recovery Cycles

Table 3 shows the values of initial thickness, compressional parameter, recovery parameter, energy loss and thickness loss of different needle-punched nonwoven fabrics after each compression-recovery

Table 6 – Effect of rate of deformation on compressional behaviour of jute needle-punched nonwoven fabrics

Rate of deformation mm/min	Initial thickness mm	Compressed thickness, mm	Final thickness mm	Compressional parameter (α)	Recovery parameter (β)	Energy loss %
1	5.490	2.149	5.030	0.080064	0.111884	72.67
5	5.500	2.174	4.505	0.079560	0.095860	72.03
10	5.470	2.541	4.172	0.070448	0.065234	70.48
15	5.470	2.795	3.939	0.064339	0.045803	67.34
20	5.480	2.758	3.973	0.065350	0.048023	68.55
25	5.475	2.802	3.946	0.064232	0.045043	67.18

Table 7 − Effect of different testing principles on compression and recovery

CRC			CRL 1			CRL 2		
Pressure, kPa	Comp, %	Rec, %	Pressure, kPa	Comp, %	Rec, %	Pressure, kPa	Comp, %	Rec, %
1	-	33.34	1	-	43.37	1	-	-
7.07	21.52	46.87	10	25.07	50.61	10	12.07	9.06
14.15	28.25	47.48	20	33.46	55.64	20	21.01	16.35
28.30	38.81	52.34	50	49.49	60.86	50	39.73	33.63
42.46	43.76	53.65	100	64.77	64.77	100	51.54	42.62
56.61	47.66	54.69						
84.92	53.40	55.48						
100.00	55.99	55.99						

Comp. − Compression, and Rec. – Recovery.

cycles up to six. A significant difference is observed in the first and second compression cycles, because the maximum slippage between fibres occur in the initial cycles itself as the structure of the fabrics is relatively less dense in this stage. Table 3 also shows a significant effect of properties of fibre. Polypropylene and jute-polypropylene blend show significantly higher α and β values compared to jute and wet jute fabric. This is due to wide difference in properties between jute and polypropylene (Table 1). The flexibility and extensibility of fibres affect the bending and elastic behaviour of fibres as well as compressibility and recovery of needle-punched nonwoven. In wetting of jute nonwoven, fibre diameter increases due to swelling, which results in the increase in compactness of structure and decrease in fibre flexibility and slippage.

The effect of compression-recovery cycles on initial thickness i.e. thickness without any external addition of load is shown in Table 3. The initial thickness shows a sharp fall in the early stages of cyclic loading and then it stabilizes. The deformation due to compression consists of two parts, namely recoverable and irrecoverable. Recoverable part is responsible for bending of fibres and elastic deformation of fibres. On the contrary, irrecoverable part is mainly slippage of fibres due to applied force, which is higher than inter-fibre static frictional force. It decreases the free space between the fibres. In the initial cycles, this irrecoverable part exists. The recoverable part reduces with number of cycles which is evident from the values of initial thickness and final thickness of different cycles. It is observed that jute, polypropylene and wet jute attain their equilibrium initial thickness after 2^{nd} cycle, whereas in jute-polypropylene (1:1) blended fabric, the equilibrium is reached after 4^{th} cycle. This is basically due to frictional property of jute and polypropylene in blend (Table 1).

Table 3 shows the sharp fall in α of jute fabric in the 2^{nd} cycle of compressional loading. A decrease in α in the 2^{nd} cycle has also been observed in the wet jute fabric. In all other cases, α remains almost unchanged at 95% confidence level (calculated t between 1^{st} and 6^{th} cycle < $t_{0.05,18}$ = 2.101 where standard error of difference is 0.00085) with number of cycles up to six. In jute fabric, there is a change in the nature of the compression curve in the 2^{nd} cycle, which is reflected due to fall in α value. Jute fibre is brittle and low extensible in property, which is responsible for change in compression curve in 2^{nd} cycle. In case of jute-polypropylene and polypropylene fabrics, there is almost no change in the nature of curve under cyclic compressional loading due to presence of highly flexible and extensible polypropylene fibre in majority by numbers.

The table also shows percentage loss in thickness of needle-punched nonwoven fabrics on application of compressive load. Except the blended fabric, a major decrease in thickness loss is observed in 2nd cycle. For blended fabric, the major fall in thickness loss continues up to 4th cycle, which is also reflected in initial thickness. As jute-polypropylene blend has very low fibre friction and jute fibre has high rigidity (Table 1), the permanent deformation in the 1st cycle is almost negligible. In this case, permanent deformation starts from 2nd cycle and continues up to 4th cycle.

Table 3 also shows a fall in energy loss in the initial part of cyclic compressional loading and after that it stabilizes. In case of jute, the 3rd cycle brings the energy loss to almost stabilization, and here the fall is much sharper than in polypropylene and jute-polypropylene fabrics. For polypropylene and jute-polypropylene blend, the stabilization of energy loss starts from 4th cycle. This is mainly due to lower coefficient of friction of PP and jute-PP compared to jute. Rigidity of PP is also much lower than that of jute (Table 1).

3.2 Effect of Ultimate Compressional Load

Table 4 shows that there is no significant effect of ultimate compressional pressure on different compressional and related parameters at 95% confidence level ($t_{\text{calculated}} < t_{0.05,\ 18} = 2.101$) when tested at 50, 100 and 200 kPa. Standard error of difference between testing of 50 and 200 kPa for compressional parameter and recovery parameter are in Table 5.

This is true for nonwoven made from jute, jute-polypropylene blend, polypropylene and jute nonwoven in wet condition. As compression is a low load phenomenon, the tested fabrics are reaching to equilibrium in below 50 kPa, further increase in pressure will not show any significant change in thickness load. The compressibility test, therefore, can be carried out up to any ultimate compressional pressure tested here, or an average value of parameters for test carried out up to different pressures may be used to describe the compressional behaviour of nonwoven fabrics.

The instantaneous compression and recovery are basically responsible for bending of hairs and fibres. The time dependant phenomenon is due to slippage between the fibres and deformation in fibres. The compressional and recovery behaviour, which differ between fabrics made from different fibres, is due to the basic fibre surface and bending properties (Table 1).

3.3 Effect of Duration of Loading and Duration after Unloading

Figure 2 shows the nature of thickness loss with duration of loading or duration after unloading. It is observed that there is an instantaneous compression of around 20-25% and after that thickness loss increases with time in diminishing rate. The thickness loss stabilizes after reaching to maximum. For jute and wet jute needle-punched nonwoven, this maximum thickness loss, which is around 55-60% is attained approximately in 30 s. In case of jute-polypropylene blended (1:1) fabric, the maximum thickness loss (83%) has been reached in 70 s, whereas polypropylene attains 92% thickness loss in 130 s. During recovery, maximum reduction in thickness loss is observed in around 75 s for jute and wet jute (19% reduction in case of jute but 14% in case of wet jute), 160 s for jute-polypropylene blend (30% reduction) and 230 s for polypropylene (48% reduction) needle-punched nonwoven fabric. After these limits, there are insignificant changes in thickness and it has ignored.

3.4 Effect of Rate of Deformation

Table 6 shows the effect of rate of deformation on the compressional and related parameters of jute needle-punched nonwoven fabrics up to the ultimate compressional pressure 200 kPa. The compressional parameter, recovery parameter and energy loss of nonwoven fabrics are decreased with the increased

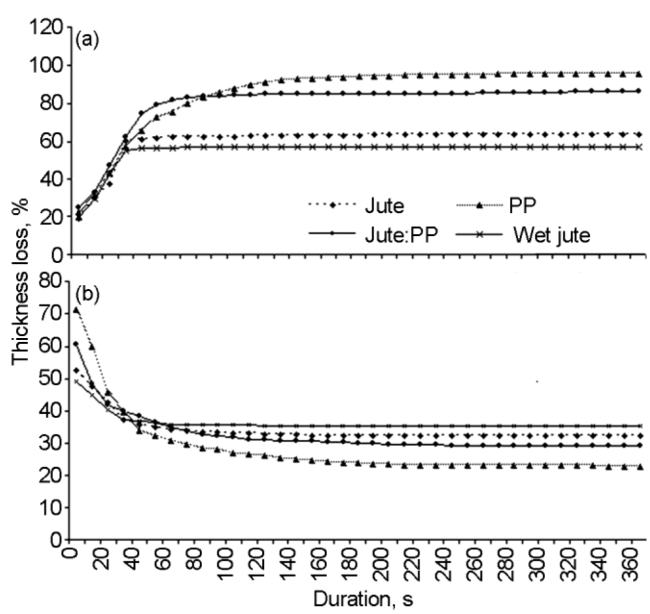

Fig. 2 – Effect of duration during (a) loading and (b) unloading

rate of deformation up to 15 mm/min. The deformation due to load has two parts, namely instantaneous and time dependant. At higher rate of deformation, the instantaneous part is more pronounced than time dependant part because higher testing speed do not allow enough scope for time dependant phenomena, causing lower compressional properties and vice versa. Above 15 mm/min, no significant change in the compressional behaviour is observed.

3.5 Effect of Testing Principles

Table 7 shows the percentage compression and recovery in different principles of testing i.e. CRL 1, CRL 2 and CRC. The significance of this table is that it shows the thickness loss due to application or removal of any specific load on the fabric. It can be seen that the compressibility in CRC test is lower than that in CRL 1. The fabric compressibility is higher when the compression is performed using Prolific thickness tester over a longer time duration due to visco-elastic effect of fibre bending. It also shows that the per cent thickness recovery in CRL 1 is higher than that in CRC testing. This is due to the fact that higher compression and more time available for recovery in case of CRL 1, results in higher recovery. CRL 2 shows lower compressibility than CRL 1 and CRC, because the time available for visco-elastic effect is lower. The recovery is higher in action of higher compressive load.

4 Conclusion

4.1 On repeated compression recovery cycles, most of the changes in the compressional properties take place between the first and the second compression cycles. In all the cycles, α and β of polypropylene and jute-polypropylene blended fabrics are higher than jute fabric. Wetting of jute fabric reduces α and β.**4.2** There is no effect of ultimate pressure of 50, 100, 200 kPa on different compressional and related parameters of needle-punched nonwovens.

4.3 Compressibility and recovery of CRL 1 is higher than CRC, followed by CRL2.

4.4 As the rate of deformation increases in jute needle-punched nonwoven, the compressional parameter, recovery parameter and percentage energy loss decrease initially and then remain unaltered.

4.5 When compressional pressure of 200 kPa is applied on needle-punched fabric, there is an instantaneous compression and after that thickness loss increases with time in diminishing rate. The thickness loss stabilizes after reaching to maximum. Recovery for that load also follows the similar trend. Jute reaches the maximum thickness loss faster than jute-polypropylene blend, followed by polypropylene fabric. The recovery trend is also same. Hence, the selection of raw material is important for the performance of nonwoven in terms of compressibility.

4.6 As the rate of deformation increases in jute needle-punched nonwoven, the compressional parameter, recovery parameter and percentage energy loss decrease initially and then remain unaltered.

4.7 The effect of application and removal of compressional load on wet jute nonwoven is lower than jute or other nonwoven tested in dry condition. In wetting of jute nonwoven, fibre diameter increases due to swelling, which results in increase in compactness of structure and decrease in fibre flexibility and slippage.

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