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Investigation of Tensile Properties of Paddy Straw Geomesh for Slope Erosion Control

[I]Dr. S. A. Halkude, [II]R. C. Katdare

[I]Principal, Walchand Institute of Technology, Solapur, Maharashtra State, India.

[II]Researches Student, Walchand Institute of Technology, Solapur, Maharashtra State, India

Abstract

The present paper deals with the characterization of the tensile strength of a manually prepared Geomesh of 100% Paddy Straw, a Lignocellulosic and agricultural waste byproduct, using plaits prepared by using three or four stalks of Paddy Straw rolled between the palms, and plaits are subsequently weaved manually to form mesh having different thicknesses and apertures proposed for use as slope erosion control material on newly constructed embankment of Canal/Dam till it achieves its full shear strength. The five samples of each 6, 8 and 10 mm thick Geomeshes with different apertures like 12x12, 20x20 and 25x25 mm in dry and wet conditions are taken and tensile strength of each type is calculated using wide width method of finding tensile strength of a Geotextile on textile testing machine as per ASTM D 4595. It has been concluded that the tensile strength of handmade Paddy Straw Geomeshes is influenced by thickness of the strands and aperture size. It is also observed that the behaviour of Paddy Straw is nearly similar to that of elastic material. In either case the maximum tensile strength of paddy Straw Geomesh of 8.03 kN/m in wet condition satisfies the criteria of ASTM (0.1kN/m) required for suitability of natural material for Erosion control.

Keywords

Geomesh, Paddy Straw, Aperture, Tensile strength, Erosion control

I. Introduction

The high cost of petroleum based Geosynthetics has propagated the need to find alternative products developed from naturally available material like Jute, coir, hemp, etc. for use in Geosynthetics applications. However, unlike Jute and Coir, which have become commercially successful, the use of Paddy straw for the same purpose has not yet gained that popularity as its counterpart [1, 2, and 3]. This may be due to its non feasibility of extracting inexpensive fibre and yarn from it.

However, Paddy straw which is considered as a Lignocellulosic waste material has been in use for erosion control since long in various forms like Bales, spreading of loose straw, wattles and blankets which is shown in Figure 1 to 5 below. It is a very well known fact that Paddy Straw is considered as a waste material in the rural areas in India and is often burnt into the field by farmers which unnecessarily creates green house gases emissions and may cause heavy air Pollution and related diseases and therefore the proposed production of handmade Geomesh by villagers may generate rural employment and benefit the society at large.

The created Paddy Straw Geomesh, as per the categorization of Erosion Control Technology Council, USA [4] ,falls into one of the four categories of Rolled Erosion Control Product(RECP) which is called as Open weave Textiles (OWT) And Such Open Weave Textiles (OWTs) are called Erosion controls Meshes (ECMs) in India [5]. As such the proposed mat is now known as Paddy Straw Geomesh. The tensile strength of any natural Geotextile is considered as one of the most important properties along with coverage, Drapability and water absorbency [6]. Accordingly the Geotextile should have sufficient tensile strength to withstand handling, transportation and installation Operation.

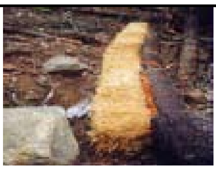

Fig.1: Use as Bales

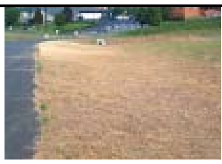

Fig.2: Loose Straw

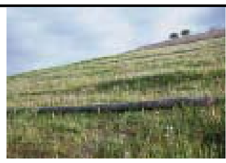

Fig.3:Use as Wattles

Fig.4:Use as Mulch

Fig.5: Erosion control Blanket

Similar observations are also made to identify the properties like percent open area, mass per unit area, thickness, tensile strength, mass of Geotextiles per unit area when wet, design and Drapability which will govern the effectiveness of Geotextile in decreasing soil erosion [7, 8 and 9].The focus of this study is restricted to investigation of tensile strength of the Paddy Straw Geomesh.

It is observed that [10] for effective erosion control the Geotextile may be surface laid (Unlike for reinforcement when it is buried). In this case it does not give strength to the soil in contact with it although it may have its own strength. The strength is however imparted into the soil when the Geotextile begins degrading and its fibres start incorporating into the soil adding strength to it. This is same like the decaying roots that add strength to the soil although the strength added may be very less as compared to its original strength. Therefore it is mentioned that the Tensile strength of the Geotextile as claimed by some manufacturers may not be that important since it is not known that in what way this property helps in preventing soil erosion. The tensile strength also comes into the play when the width or length of the Geotextile is required to be extended by various methods like Overlapping, Sewing, Stapling and gluing etc[11]. While laying Geotextile on soft ground for supporting embankments, the method of overlapping which include holding of parallel sheets of Geotextile is always preferred and possible only if it has sufficient strength to withstand handling. Based on the above requirement the tensile strength of the said Paddy Straw Geomesh of different thicknesses and apertures are tested. The tensile testing of Geotextile is carried out as per standardized procedure of ASTM D4595-09[12] and BSENISO10319:1996 [13] which are called as wide width tensile test in both the Codes.

II. Material And Method

Material composition of Proposed Geomesh for slope erosion control:

The Geomesh proposed to be used in the present study is made from plaits of 100% Paddy Straw which are prepared by using three or four stalks of Paddy Straw and rolled between the palms. The lower palm, usually the left, is open and up, while the right palm rolls the straw into twist. After a part of the length has been twisted, single stalks are added until the original length has been almost used up; then a fresh bunch of stalks is inserted and the operation continues. These Plaits are then weaved manually to form mesh and which is then extended into role of 1.0x1.5 m. and out of which 200 x200 mm size of different thicknesses of 6,8,and 10 mm with apertures such as 10x10, 12x12 and 20x20mm are cut and used for the tensile testing. One of the types is presented in Figure 6, 7 and 8 below.

Sample Size: - 200 x 200 mm size samples (of 6, 8 & 10 mm thickness and 12x12, 20x20 and 25 x 25 mm aperture size.) are prepared for carrying out thickness, mass per unit area and tensile test.

No. of Samples: - 5 Nos. of each type of thicknesses (6.1 page 4 of ENISO10319:1996)

Conditioning of sample: - Moisture equilibrium is not considered since the place where the test has been conducted has a dry climate.

Instruments Used : While Standard Thickness gauge and Calibrated electronic balance was used to calculate the physical properties like Thickness, Mass per unit area of the Paddy straw Geomesh samples as per the standard procedures described in ASTM D5199 and ASTM D5261/ISO 9864 respectively, the Tensile tests experiments on paddy straw Geomesh are proposed to be conducted on Star India manufactured Geotextile Tensile testing machine available with Garware Wall Ropes, Bhosari, Pune who have kindly permitted to encourage this Research activity. The said machine has got computer interface to give direct values of maximum load, break load, % elongation, Fabric Strength, etc. Special jaws with nut bolts are provided to the said machine to provide firm griping of paddy straw specimen and to avoid damage of the specimens. The speed of the machine can be controlled to maintain constant strain rate. The gauge length of the specimen is considered as175 mm.

Fig.6: 6 mm thick paddy straw Geomesh with 12x12 mm aperture size.

Fig.7: 8mm thick paddy straw Geomesh with 12x12 mm aperture size.

Fig.8: 10 mm thick paddy straw Geomesh with 12x12 mm aperture size.

Fig. 9:Closer view of finally mounted Paddy Straw Geomesh 200x200 mm size on Tensile Testing Machine

Fig. 10: Geomesh fitted into clamps with 50 mm grip on either side to make effective size of 200x100 mm for the test

III. Experimental Method

Initialization: Tensile strength of the Paddy Straw Geomesh specimen is calculated by testing done as per ASTM 4595-09, using the method of wide-width tensile test on a tensile testing machine, Manufactured by Star India Co., Mumbai, India and is shown in Figure 9, and 10 above. The tensile test of Geotextiles (Paddy Straw Geomesh in this case) is carried out initially at strain rate of 10% (ASTM4595-09, 10.3) to ascertain the variation in its tensile strength [14] and the results are tabulated in Table 1 below.

Table 1: Tensile strength of Paddy Straw Geomesh calculated as per ASTM 4595-2009.

S.N.	Samples Size #	% Strain Rate			
		2%	5%	10%	25%
		Tensile Strength (kN/m)			
1	S-1	0.78	1.764	8.28	7.05
2	S-2	0.71	1.854	8.03	6.87
3	S-3	0.81	1.964	7.81	7.12
4	S-4	0.69	1.71	7.98	6.89
5	S-5	0.75	1.94	8.02	7.34
# 6mm thick, 200x200 size and 12x12 mm Aperture					

From the Table 1 above, it is observed that the tensile strength of Geomesh samples at 10% strain rate are showing higher values

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than that calculated at lower strain rate of 2% and 5% and at higher strain rate of 25%. Although it would have been more logical to calculate tensile strength of same Geomesh at intermediate strain rate between 10% and 25% but is not possible due to limitation of machine constraint. Therefore 10% of strain rate is adopted for testing purposes. In addition to this the following conditions are adopted additionally.

i)Test specimen size 200x100 (Actual size is kept as 200x200 mm with 50 mm going for the grips on both sides of the jaws . ii) Looking at the stiffness of the material the specimen are not Subjected to initial pretension load (may be 5.0 N) as is given while testing the Geotextiles.

iii) The Geomeshes are designated as G6-12, G6-20, G6-25, G8-12,G8-20 etc and their nomenclature is explained in the foot note in Table 2 below.

Actual Method: About 5 no. of each G6-12, G6-20 and G6-25 test specimen of size 200 x 200 mm in dry and wet conditions at about 28^0 C are tested for tensile strength and the average reading of each type is tabulated in the Table 2. Similar procedure is adopted for finding tensile strength of remaining samples of G8-12, G8-20, G-25, G10-12, G10-20 and G10-25, and the average value of each type is also tabulated in Table 2.

Now since the sample G6-12 shows maximum tensile strength in both dry and wet condition, its test data is used to plot a curve between values of Maximum Load in kN and % Elongation for both dry and wet condition and are shown in Figure 11 and 12. Similarly a standard stress-strain curve for metal with different X and Y axis values than for curve of Sample G6-12 in wet and dry condition is shown in the Figure 13.

In order to study the elastic behaviour of Paddy Straw Geomesh by using generalised stress strain curve, it is necessary to plot the same using same values of X and Y axis as used for G6-12 sample in dry and wet condition. For this purpose curves shown in Figure 11,12, and 13 are digitized using "Get data" Software which is freely available on Internet and are presented in Figure 14, 15, and 16 on subsequent pages. Now all these three curves have same X_{min} and X_{max} and Y_{min} and Y_{max} values..

Similarly a combined curve using values of Figure 14, 15 and 16 is drawn for instant analysis and is presented in Figure 17. The same procedure is adopted for other Samples G6-20 and G6- 25 and the combined curve for them is drawn and presented in Figure 18 and 19 respectively.

Table 2: Different properties of Paddy Straw Geomesh obtained from tensile testing.

Property	Designation of Sample									Remark
	G6-12	G 6 - 20	G6-25	G8-12	G8-20	G8-25	G10-12	G 1 0 - 20	G 1 0 - 25	* The warp and weft is not considered f o r handmade Geomesh # Max. Value of particular sample. ## Max. Values of Tensile Strength
*Thickness(mm)	06	06	06	08	08	08	10	10	10	
*Aperture(mm)	12x12	20x20	25x25	12x12	20x20	25x25	12x12	20x20	25x255	
Mass/Area(Dry)	15.2#	14.59	11.03	16.67#	15.61	12.44	17.04 #	15.97	13.06	
Max Load (kN) (Dry)	1.489	1.058	1.291	1.136	1.019	0.988	1.023	0.992	0.879	
Elongation (%) (Dry)	16.1	16.1	20.7	20.2	18.4	21.21	21.89	19.45	23.01	
Tensile strength ,kN/m (Dry)	7.468 ##	5.292	5.39	5 . 6 8 ##	5.096	4.94	5.12 ##	4.76	4.27	
Mass/Area(Wet)	15.91#	15.46	11.56	17.83 #	16.37	13.11	18.12 #	17.87	13,99	
Max Load (kN),(Wet)	1.617	1.215	1.479	1.546	1.460	1.328	1.41	1.33	1.19	
Elongation (%),(Wet)	18.7	16.7	16.2	28.95	30.4	26.62	29.05	32.1	27.54	
Tensile strength,(kN/m) (Wet)	8.085 ##	6.076	7.399	7.73 ##	7.301	6.64	6.99 ##	6.43	6.14	
G = Geomesh, 6 = Thickness in mm, 12 = 12x12, 20 = 20x20 and 25 = 25x25 mm aperture size, Dry = without soaking in water and Wet = after soaking in water for 10 minutes.										

IV. Result And Discussion

Tensile strength: The Table 2 shows that the Paddy Straw Geomesh of 6 mm thick with different apertures shows maximum tensile strength among Geomeshes of other thicknesses of 8 and 10 mm with same three apertures sizes of 12x12, 20x20, and 25x25 mm. Therefore these results are used for further analysis of behaviour of Paddy Straw Geomesh. And these results further indicate that although the values of mass/area of sample G6-12, G8-12 and G10-12 are found in the ascending order 15.2, 16.67 and 17.04 gms/sq.m, the values of tensile strength for Sample no.G6-12, G8-12 and G10-12 in dry condition are found respectively to be 7.468, 5.68 and 5.12 kN/m in descending order.

Similar trend is observed when the same type of Samples (G6-12, G8-12 and G10-12) are tested for tensile strength in wet condition in which the tensile strength increases in descending Order i.e. 8.085, 7.73 and 6.99 kN/m while mass/area increases in ascending order i.e. 15.91, 17.83 and 18.12 gms/sq.m. The difference in tensile strength value of these three types of Geomeshes is not considerable.

However, this trend may be attributed to making of Paddy Straw plaits of lower thicknesses (like 6 mm against 8 and 10 mm), in which more twist is given to the plaits and thus the reduced cross sectional area of the plaits along the width might impart better strength into it as compared to plaits of higher thickness with reduced or negligible twist.

Variation in tensile strength and elongation: The coefficient of variation in the tensile strength and elongation of these Geomeshes designated as G6-12 and G8-12 in both dry and wet conditions which is worked out using statistical functions in EXCEL SHEETS is calculated in Table 3 blow.

Table 3: Shows the variation in the experimental properties like tensile strength and %Elongation of Paddy straw Geomesh

Sample Designation	Tensile Strength (kN/m)			Elongation (%)		
	Range	Median	Variance	Range	Median	Variance
G6-12 Dry	6.92-7.44	7.27	0.0389	22.58-24.23	23.7	0.38367
G8-12 Dry	7.61-8.08	7.77	0.0317	16.61-18.26	17.84	0.44013
G6-12 Wet	4.99-5.68	5.21	0.0853	17.8-20.2	18.96	0.66928
G8-12 Wet	6.97-7.73	7.185	0.1048	23.1-28.95	26.14	5.33127

Interpretation of Table 3:

From the Table 3 above it is observed that the coefficient of variation in the tensile strength of Paddy Straw Geomeshes G6-12 and G8-12 in both dry and wet conditions worked out to be 0.0389, 0.0317, 0.0853 and 0.1048 respectively. These results indicated that there is a fair level of uniformity in the specimens, Despite the variation that could be expected in a natural material. Also the coefficient of variation in the tensile elongation of these Paddy Straw Geomeshes G6-12 and G8-12 in both dry and wet conditions worked out to be 0.38367, 0.44013, 0.66928, and 5.33127 respectively. Barring exception of G8-12 wet, the remaining results indicate that there is a fair level of uniformity in the specimens, despite the variation that could be expected in a natural material.

Elastic behaviour of Paddy Straw Geomesh:

In order to understand Elastic behaviour of Paddy Straw Geomesh from the nature of curves drawn between Maximum load in kN and % elongation for the values of samples G6-12, G6-20 and G6-25 x20 in both Dry and Wet condition, is compared with digitized general elastic Stress Strain Curve which is redrawn using "Getdata" Software using Values of $X_{min\ \&\ max}$ and $Y_{min\ \&\ max}$ of those samples. The nature of these three curves drawn in Figure 17 should nearly resemble in its nature in which case it may ascertain to possess elastic properties as well. Similarly Combine curves of Samples G6-20 and G6-25 are studied to confirm the elastic behaviour of Paddy Straw Geomesh.

Comparison of actual stress strain curve of Paddy Straw Geomesh 6x12 mm in dry and wet condition with general elastic stress strain curve

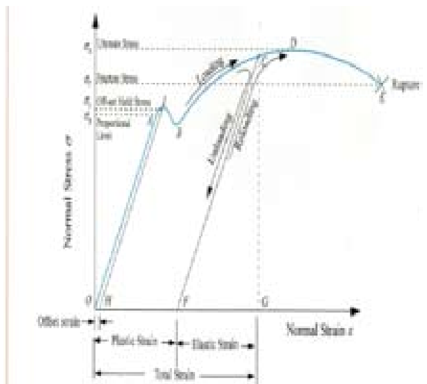

Figure 11: Scanned copy of general elastic stress strain curve

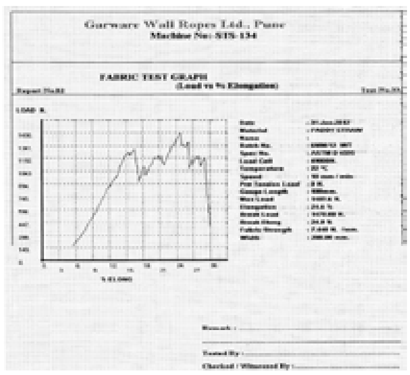

Figure 12:Scanned copy of actual stress strain curve of Paddy Straw Geomesh G6-12 mm in dry condition

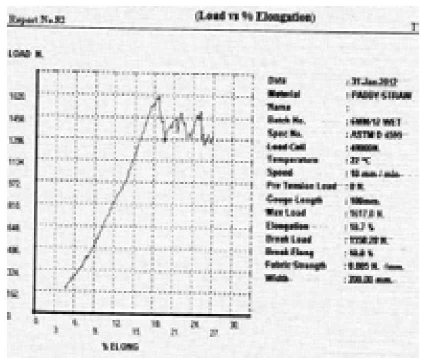

Figure 13:Scanned copy of actual stress strain curve of Paddy Straw Geomesh G6-12 mm in wet condition

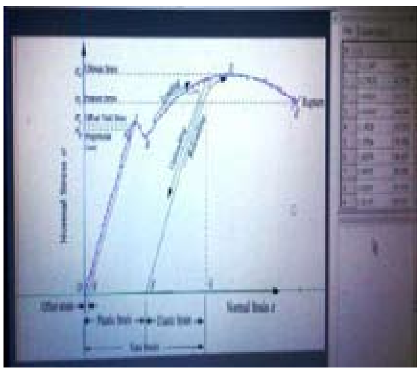

Figure14: Digitized copy of Figure 11 using $X_{min}= 0$ & $X_{max}= 30$ and $Y_{min}= 0$ & $Y_{max}= 1620$.

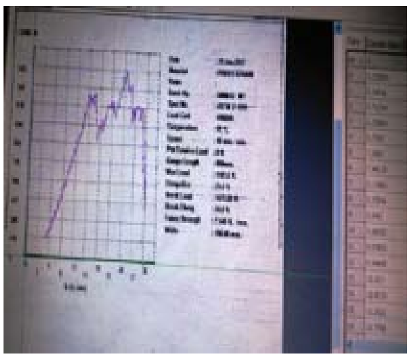

Figure15: Digitized copy of Figure 12 of using values of $X_{min}= 0$ & $X_{max}= 30$ and $Y_{min}= 0$ & $Y_{max}= 1620$.

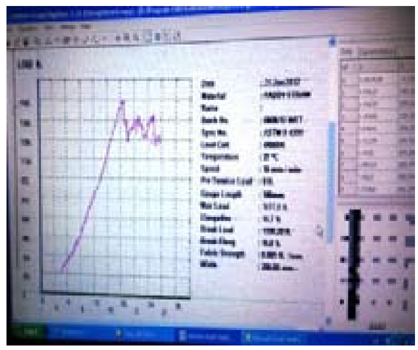

Figure16: Digitized copy of Figure 13 using values of $X_{min}= 0$ & $X_{max}= 30$ and $Y_{min}= 0$ &$Y_{max}= 1620$.

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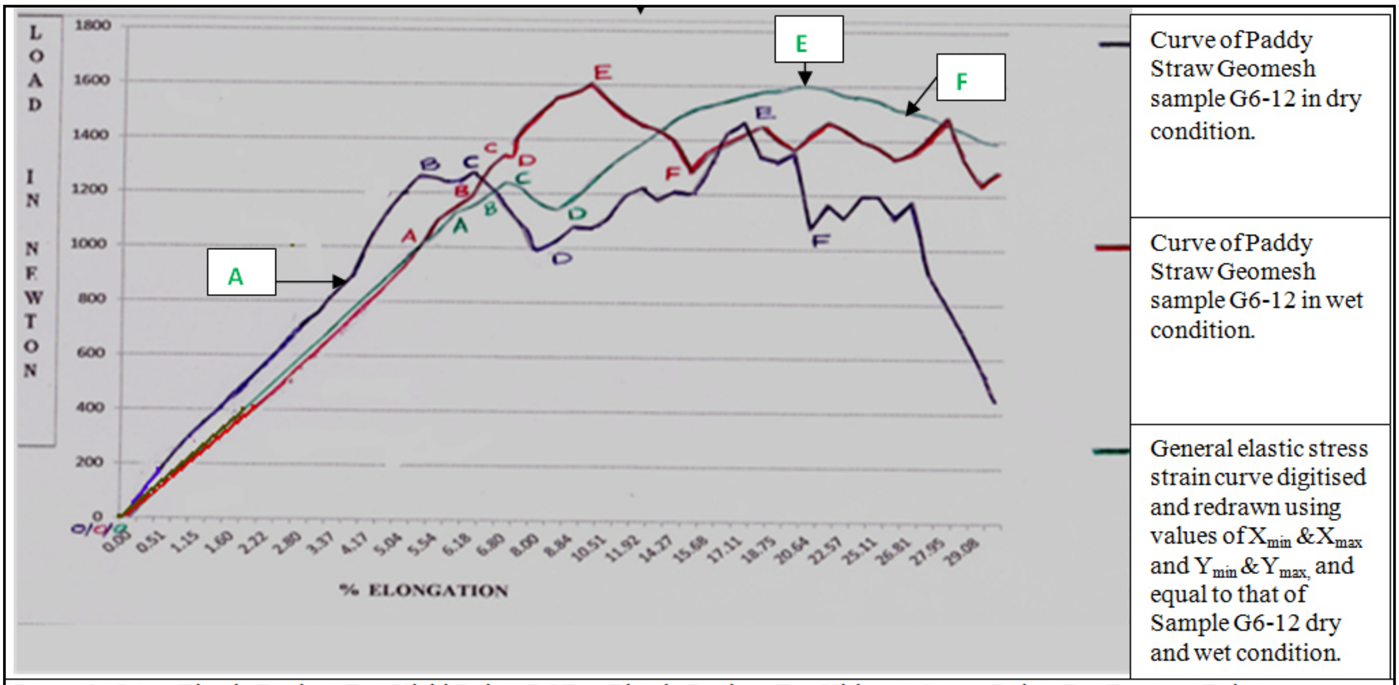
Comparison from combined stress strain curves of Geomesh G6-12 Dry (Blue colour) and G6-12 wet (Red colour) with digitized general elastic stress strain curve (Green colour) .



Legend: OA = Elastic Region; B = Yield Point; BCD = Plastic Region; E = Ultimate Stress Point; F = Fracture Point.

Figure17: Combined stress strain curves of Geomesh G6-12 Dry (blue colour) and G6-12 Wet (Red colour) with digitized general

Interpretation of curves of Paddy Straw Geomesh sample G6-12 dry (blue colour), with general elastic stress strain curve (green colour):

The initial 'OA' portion of the curve for sample G6-12(dry) in Figure 17 shows linear elastic behaviour up to point 'A' and the magnitude of elastic limit of this is much lower than that or general elastic stress strain curve. It indicates that the Paddy Straw possesses elastic properties within the range 'OA' only. This elastic property of paddy straw will enable the said Geomesh to have sufficient flexibility in rolling and laying operation on the artificial slopes for proposed erosion control.

The nature of 'AB' portion of the same curve indicates that the strain in that portion of the curve increases faster than stress at all points after point A. The portion BC and CD beyond the yield point 'B' indicates that the material should not be loaded in this plastic region to avoid permanent deformation of the material. The 'DE' portion indicates the marching of the curve for sample G6-12(dry), without much increase in the stress up to ultimate stress point 'E'. However the magnitude of ultimate stress or tensile strength of the said Paddy Straw sample in this case, may not be compared with generalized stress strain curve since it is used only as a reference for comparison of behavioural pattern only.

The 'EF' portion of the curve indicates the deformation of the sample until point of fracture 'F' which shows the failure of material once it reaches the ultimate stress. The magnitude of the tensile strength of said Paddy straw sample is found as 7.43 kN/m with 16.1% elongation and which is found to be much more than the minimum tensile strength of the Geomesh as prescribed by ECTC for effective erosion control is 0.1 kN/m and elongation less than 50% only. During the field use when it is not possible to measure the on field tensile strength, the said curve would become useful to find out % elongation (measurable in the field) corresponding to 0.1 kN/m of tensile strength and help in deciding on field durability of the product.

Comparison of curve of Paddy Straw Geomesh sample G6-12 wet (red colour), with generalized elastic stress strain curve (green colour) and similarities observed with respect to G6-12 dry sample as above.

The general behaviour of curve for Paddy Straw Geomesh sample G6-12(wet) in Figure 17 also behaves like a general elastic stress strain curve and therefore is called to possess elastic properties. However the magnitude of the elastic limit of the said sample G6-12(wet) appear to be higher than G6-12(dry) sample and hence the sample in wet conditions (which are the field conditions), due to enhance elastic properties, will be more suitable for use as erosion control material.

This enhanced property of sample G6-12 wet can be attributed to the effect of water since the sample is immersed in water for 10 minutes and then is tested. While testing, the joints of the sample due to wetness might have become wider and under the application of load must have resulted into elongation of the sample. This elongation would be the cause of shifting of elastic limit of the sample from moderate to higher value.

This increase in elastic limit however will be helpful during folding and stretching operations of the bundles of rolled Geomesh while laying on the slope for erosion control.

Effect of Elongation: Since the ductility is a measure of the plastic deformation that has been sustained at fracture, the % elongation at point E, for all three curves viz. Std. stress strain curve, Graph of G6-12 dry and G6-12 wet was observed and found to be 17.23, 29.84 and 30.75 % which is much more than the criteria of 5% for ductile material.

Interpretation of curves of Paddy Straw Geomesh sample G6-20 dry, G6-20 wet with standard stress strain (Figure 18):

From the Figure 18, the nature of curves of samples of Paddy straw Geomesh designated G6-20 dry and G6-20 wet condition respectively, when compared with generalised elastic stress strain curve, the behaviour appears to be exactly similar to what has been described under behaviour of Paddy Straw Geomesh samples G6-12 in both dry and wet condition Figure 17.

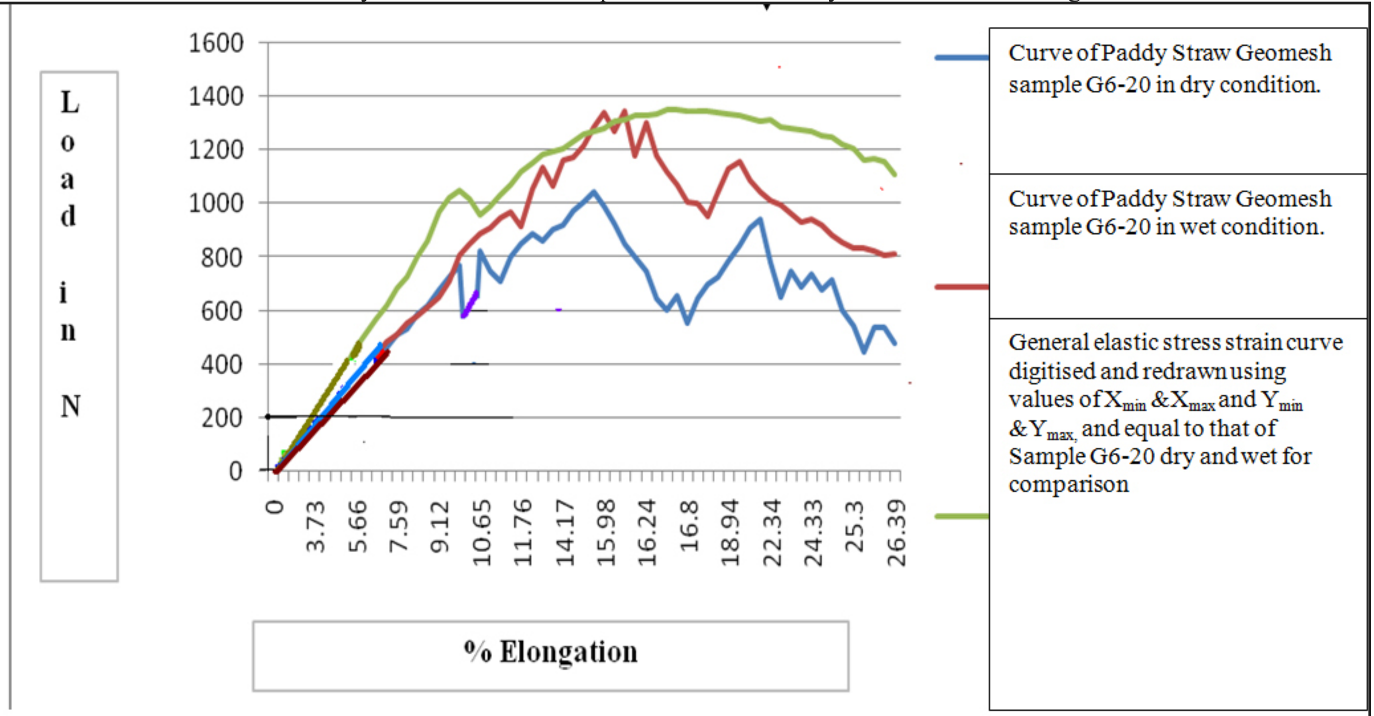


Fig.18: Comparison of Actual stress Strain Curve of Paddy Straw Geomesh G6-20 in Dry and Wet condition with general elastic Stress Strain Curve

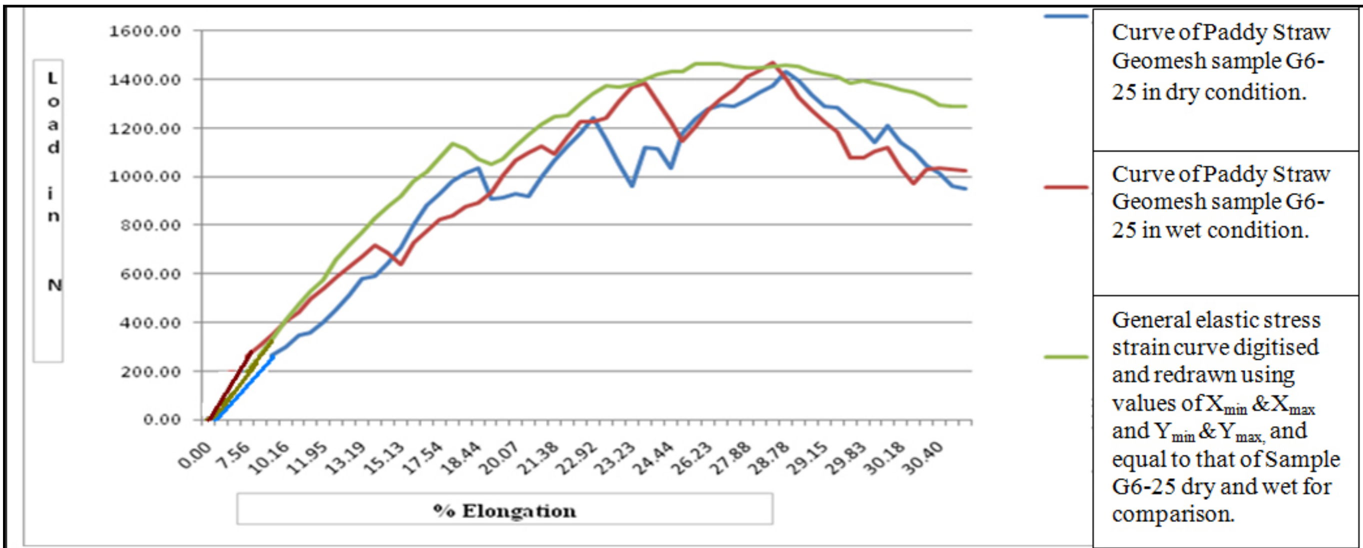


Fig.19: Comparison of Actual stress Strain Curve of Paddy Straw Geomesh G6-25 mm in Dry and Wet condition with general elastic Stress Strain Curve.

Interpretation of curves of Paddy Straw Geomesh sample G6-25 dry and G6-25 wet with general elastic stress strain (Figure 19):

The comparison of curves of the samples of Paddy straw Geomesh designated G6-25 dry and G6-25 wet condition respectively with general elastic stress strain curve shows exactly similar behaviour as described for Paddy Straw Geomesh samples G6-12 in both dry and wet condition in Figure 17.

Effect of water:

The effect of water on the Paddy Straw is worth noting from the fact that when the meshes are immersed in water for 10 minutes there is increase in its original weight to the tune of 10% (Table 1). Similarly the tensile strength of the all samples i.e. G6x12, G6x20 and G6-25 in wet condition are found to posses more strength than the same samples in dry condition.

One possible reason for the marginal increase in case of samples in wet conditions may be due to slippage of knots of plaits of Geomesh during the loading process on testing machine. And another reason which is also mentioned in the literature that usually in case of Geotextile made from natural fibre, the wet strength decreases and strain increases. However, in the paddy Straw Geomeshes, the behaviour is found to be just reverse. The Plaits are prepared manually, and hence the reproducibility is a question, however the trend of the curve shows identical behaviour in tension test. This is being confirmed with more tests.

V. Conclusion

The Paddy Straw Geomesh nearly behaves like a linear elastic material and 6 mm thick handmade Paddy straw Geomesh (with 12x12 mm, 20x20 mm and 25x25 mm aperture size) shows slightly more tensile strength than that of the Geomeshes of 8 and 10 mm thickness (with 12x12 mm, 20x20 mm and 25x25

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mm aperture size) .The better twisted strands of lower thickness (like 6 mm) as compared to less twisted strands (8 and 10 mm) due to difficulty in twisting thicker elements by hand could be the reason for exhibiting more tensile strength of 6 mm thick sample. The following conclusions are drawn

i) The Paddy Straw in the form of Geomesh behaves like an elastic material within a certain range of elastic limit which would add to its suitability considering it has to undergo stretching and rolling during installation on slopes for erosion control
ii) The Elastic limit of Paddy Straw Geomesh(G6-12 wet) in wet condition is higher than that in dry condition (G6-12 dry)
iii) The Paddy Straw Geomesh in both dry and wet conditions should not be loaded beyond respective elastic limit to avoid permanent deformation.
iv) From the curve of sample G6-12 wet the % elongation proportional to allowable tensile strength 0.1 kN/m of Geomesh for erosion control can be found for testing the onsite durability. However as per E.C.T.C., the criteria for suitability of such type of material (Paddy Straw Geomesh) for slope erosion control remains to be the properties like elongation less than 50% and minimum tensile strength of 0.1 kN/m.
v) The other required properties like Drapability and field erosion studies are under investigation.

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