Durability of Erosion Control Geomesh of Paddy by 'Accelerated Biodegradation Test'

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ABSTRACT: Paddy straw is abundantly available as crop waste and has a sacrificial quality to biodegrade early, which can be advantageously utilized to develop a low-cost Paddy Straw Geomesh (PSG) to control rain-induced surface erosion of a newly constructed embankment for the critical period of few months of the rainy season. The present study reports employing, 'Accelerated Biodegradation Test' to quickly estimate the test time of PSG specimens in the laboratory to reach its durability in comparison with the field test time which is generally longer due to slow disintegration of organic material in climatic conditions. This acceleration is achieved by increasing fungi spore concentration with respect to field fungi concentration, using various concentrations ranging from 3.29×10^5 through 3.29×10^9 spores per gram of soil while taking 'Accelerated Biodegradation Test'. The findings of 'Accelerated Biodegradation Test' report 40% decrease in test time of PSG in a laboratory, using higher fungi spore concentration in soil embodiments, as compared to those in the field.

KEYWORDS: Accelerated biodegradation test, Laboratory embedment, Paddy straw geomesh, Fungi spore concentration, Tensile strength.

1. INTRODUCTION

The slopes of newly constructed embankments undergo substantial rain-induced surface erosion. During the surface erosion, the raindrop impact on the surface of embankment acts as a splash of water and dislodge soil particles from its position and slides away in the form of sheets from its position. This flow creates reels and gullies on the slope surface of an embankment to cause the generation of surface runoff, and if this process continues then, the surface erosion gets converted into mass erosion and internal erosion to cause the failure of a slope. Such surface erosion of the embankments can be controlled by placing natural Rolled Erosion Control Products (RECPs). Generally, the erosion control requirements of newly constructed slopes are limited to the few months of monsoon. Sometimes, RECPs made of market established materials like jute and coir are used for erosion control. However, the use of jute and coir is cost-prohibitive as well as it has many possible better uses. The good quality yarn is produced from the jute and coir having higher tensile strength. Also, the RECPs made from these materials have longer durability ranging from 1 to 2 years. Thus, this longer durability of RECPs of jute and coir becomes unnecessary for a rain-induced surface erosion control purpose, which is also at a higher cost.

Alternatively, to have a cost-effective solution, we have designed and developed a handmade Paddy Straw Geomesh (PSG) produced from the stems of paddy for erosion control. As the tensile strength of Paddy stems is very less, these are rolled into plaits to attain the required tensile strength of PSG, just adequate for erosion control over one rainy season. Thus, the sacrificial quality of PSG is advantageously utilized for erosion control for one rainy season. In the present study, the durability of Paddy Straw Geomesh (PSG) is found using laboratory 'Accelerated Biodegradation Test', which involves the creation of accelerated biodegradation conditions while simulating field condition in the laboratory. The results of durability of PSG by the accelerated test are correlated with that of field test using suitable 'Acceleration Factors'.

2. REVIEW OF LITERATURE

The chemical composition of natural RECPs made of lignocellulosic fibres of jute, coir, and paddy straw etc., generally comprise of cellulose and lignin in different proportions. While laying on the embankment for erosion control, microbes and fungi present in the soil, attack cellulose and lignin in RECPs to cause a reduction in its tensile strength and continuous degradation.

ASTM G160 (1998), Blackburn, R.S. (2005), and Carneiro, J. R. et al. (2018) have described that the damage occurred in RECPs during the degradation tests is often determined by monitoring changes in their tensile behaviour over a passage of time.

Paulo César de Almeida Maia et al. (2017) have carried out the field test on Geosynthetic by exposing it to the local climatic conditions and other possible exogenous actions. The European Standard, recommends 'Soil Burial Test' of finding the resistance of Geosynthetics to microorganism & fungi to know its field durability (BS EN 12226:2012). However, the durability in both cases is quantified by measuring the reduction of the tensile strength of Geosynthetic over a period of time.

In the present case, the Paddy Straw Geomesh (PSG) needs to be laid on the embankment surface, and this condition is different from soil burial. Therefore, this 'Field durability test' is performed by laying PSG specimens on canal embankment under ambient atmospheric conditions and its durability is found by observing time at which its tensile strength reduces to its minimum required tensile strength of 1 kN/m."

The minimum tensile strength requirement of biodegradable RECP in the form of Open weave Geotextile/'Geomesh is standardized to be equal to 0.1 kN/m width of the specimen (Erosion Control Technological Council, ECTC, 2017). It means, the durability of a PSG specimen, in this study, having an average tensile strength of 7.5 kN/m of width, is found equal to the time elapsed till its residual tensile strength reduces to 0.1 kN/m of width (i.e. about 1.34% of the original strength) by virtue of biodegradation.

However, in the present case, the yardstick value of minimum tensile strength requirement of PSG is increased from 0.1 kN/m to 1.0 kN/m for ensuring additional safety to sustain tensile stresses during handling of PSG. Accordingly, the durability of the PSG under test is identified as the time, when it shows its residual tensile strength equal to 1.0 kN/m width of the specimen (i.e. about 13.34% residual strength).

Michael Crewdson (2006) has mentioned that the accelerated laboratory testing is preferably used to provide data on the long-term outdoor durability of many products. Hsieh et al. (2006), Carneiro et al. (2017) and Carneiro et al. (2018), have also described that, the 'Field Test' is generally time-consuming and hence 'Accelerated Biodegradation Tests' are carried out to study long-term behavior and estimate the durability of a RECPs made of lignocellulosic material like jute and coir. The same philosophy was used in the legendary work done by Balan, K. and Venkatappa Rao, G. V. (1996) while finding durability of coir geotextiles. They placed the coir geotextiles specimens in different mediums like acidic, alkaline and fungal and found out the durability in terms of loss of tensile strength to a yardstick value of 1.0 kN/m of width. Agarry, S. and

Jimoda (2013), observed that the Paddy straw, amended with Nitrogen and Phosphorus is effectively biodegradable using two cellulolytic and one ligninolytic fungi viz. Aspergillus awamori, Trichoderma reesei, and Phanerochaete Chrysosporium, respectively.

Halkude, S.A. and Katdare, R.C. (2014), carried out biodegradability test of PSGs kept under three specific pH (acidic, neutral and alkaline) conditions, blended with nutrients and fungi culture for effective biodegradation of PSGs. Their findings report that the rate of biodegradation is the highest in the embedments containing fungi (Aspergillus awamori and Trichoderma viride) in neutral range and which was quantified in terms of reduction in tensile strength of PSGs to the yardstick value 1.0 kN/m width of the specimen (ECTC Manual 2017).

Findings from the study carried out by Suleman, A. R. (2014), on use of Paddy straw for erosion control suggest that the use of Paddy straw is popularly done in the form of a blanket, which is a non-woven product with limited application in the agricultural field. However, no experimental data on the use of Paddy Straw in the form of handmade Geomesh for erosion control is available. Due to abundant availability of Paddy straw and non-availability of any profitable option of its disposal, the farmers tempt to burn the straw in the field, thereby causing severe air pollution resulting into endangering the health of people. Therefore, the proposed development of Paddy Straw Geomesh would not only solve the disposal problem of straw but being a green product, would be widely used for erosion control operation.

The handmade manufacturing of Paddy Straw Geomesh would also generate rural employment for semi-skilled workers to support the rural economy. So, we feel that the present study of the development of PSG with durability is sufficient enough to survive the rain-induced erosion of newly constructed embankments for one rainy season and therefore is a useful novel contribution.

The present research aims to explore the possibility of reducing the time of 'durability test' of PSG specimens made out of paddy crop. The details of the development are given below.

3. DEVELOPMENT OF PADDY STRAW GEOMESH

The PSG is developed using the property of Paddy straw stems, which can be weaved when these are made wet but would turn brittle after their drying out. Therefore, the Paddy straw stems are soaked in water, and then 3 to 4 stems are taken in hand and are rolled between the palms. The lower palm, usually the left, is open and up, while the right palm rolls the straw into a twist. After a part of the length has been twisted, single stalks are added until the original length has been almost used up; then afresh bunch of stalks is inserted, and the operation continues. The meshes produced for the present work are of 6 mm thick with 12 mm x 12 mm aperture size and 200 mm x 200 mm specimen size. The making of these meshes and its specimens are shown in Figure 1 and Figure 2.

Figure 1 Hand-weaving of PSG

Figure 2 PSG specimens of 6 mm thickness and 12 mm x12 mm aperture and 200 mm x 200 mm size

The research work of exploring the possibility of reducing the time of 'durability test' of PSG is done by carrying out accelerated biodegradation of PSG specimens in the laboratory by simulating field conditions. The durability of PSG specimens found in this way is then correlated with the field durability on the basis of fungi spore concentration present in the soil in laboratory embedments and field soil. Thus, early estimation of the durability of PSG and other similar erosion control products having longer field durability is achieved by carrying out 'Accelerated biodegradation test'.

4. CHARACTERIZATION OF FIELD SOIL

The characterization of field soil is done by performing the 'Pour Plate Test' on the field soil sample, to find its fungi spore concentration. The 'Pour Plate Test' is standardized by the International Organization for Standardization, ISO 4833-1:2013 (En), 'Microbiology of the food chain'. In 'Pour Plate Test', successive dilutions of the inoculum (serially diluting the original specimen of old broth culture, field soil in the present case) are added to the sterile Petri plates containing the melted and cooled (40°C - 45 °C) agar medium and thoroughly mixed by rotating the plates which are then allowed to solidify. After incubation, the plates are examined for the presence of individual colonies growing throughout the medium and counted.

4.1 'Pour Plate Test'

The test comprises of preparation of a series of dilutions of the field soil sample expected to contain a fungi spore concentration between 30-300 CFU/ml (Colony Forming Unit). For this, initially, 1:10 dilution (10^1) is prepared by mixing 1 g of field soil with 10 ml of 0.85% sterile saline water (NaCl). Next1:100 (i.e.10^2) made up dilution is obtained by mixing 1 ml of the made-up solution of (i.e. 10^1) with 9 ml of sterile saline water (NaCl). Similarly, subsequent dilutions are carried out to obtain 10^3, 10^4, 10^5 level dilutions. The inoculum of 1 ml from every five dilutions is poured into a Petri dish in triplicate which is made sterile and cooled at 45 ºC. Each Petri dish is then added to 20 ml of molten Martin Rose Bengal agar and the fungal colonies developed are counted considering their dilutions and 'Final Colony Count' per gram of soil is found to be 3.29 x 10^3 spores per gram of soil.

5. FIELD DURABILITY TEST

The durability test of PSG in the field is carried out on the slope of the newly constructed canal embankment of 'Pench canal' near village Khat, Tahsil and District: Nagpur, Maharashtra state, India. The canal embankment is constructed using soil, which is classified as a 'Well Graded Gravel and Sand Mixture (GW-SW)'. The soil is compacted to form a slope of 1V:2H.

Three sets of test specimens with 30 PSG specimens in each set (Each specimen of size 200 mm x 200 mm, 6 mm thick and 12 mm x12 mm aperture size) are placed on embankment surface and are well anchored using mild steel bar staples, at four corners intermittently. The ultimate tensile strength of all specimens is ensured to be @7.5 kN/m of width. The schematic and actual field arrangements of placing PSG on an embankment slope as an erosion control product is shown in Figure 3 and Figure 4, respectively.

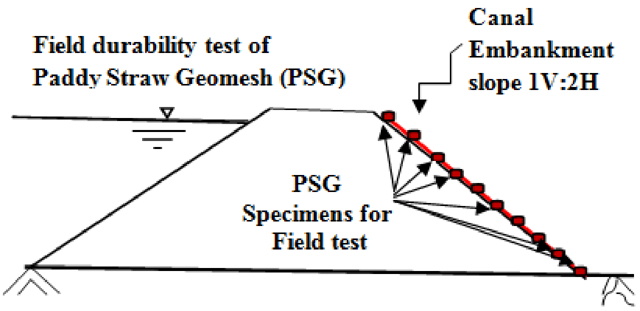

Figure 3 Placing PSG specimens on the embankment

Figure 4 PSGs, being laid on Canal slope

The PSGs laid on the embankment undergo natural biodegradation due to the organism present, chiefly fungi, which start digesting their cellulose contents and results in the reduction in the tensile strength of PSGs.

5.1 Durability Field Test- Results and Discussions

The biodegradation is quantified by taking out a total of 3 specimens (1 from each set) after a cycle of three days and testing of their residual tensile strength. The procedure is continued until the ultimate residual tensile strength of the specimen in all three sets reduces to the value of 1.0 kN/m of the width of the specimen, which is a measure of durability of a specimen in a number of days.

The residual tensile strength of all 3 specimens undergoing biodegradation is plotted against time elapsed in days. The plot in Figure 5 shows the residual ultimate tensile strength of PSGs with respect to time elapsed in number of days.

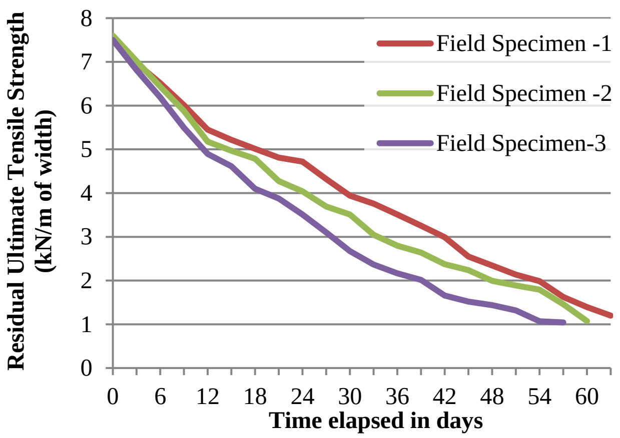

Figure 5 Residual ultimate tensile strength of PSG v/s Time in days in 'Field Test'

The 'Field durability' of specimens 1, 2, and 3 are found to be 63, 60, and 57 days, respectively. The difference in durability values of three specimens is attributed to the small variation in micro flora and the variations in the field conditions due to moisture, temperature, sunlight, etc. The average works out to 60 days, which is considered as the durability of PSG in the field durability test.

5.2 Benchmarking of Laboratory Test with Field Test

The durability of PSG, found out to be 60 days, in 'Field Durability Test' is now compared & verified by carrying out a 'Laboratory Durability Test' by simulating same field conditions which existed in the 'Field Durability Test' for benchmarking.

Accordingly, one embedment of three containers, designated as E-3.29 x 10^3, is prepared in the laboratory. The contents of the said embedment are PSG specimens, disinfected field soil blended with Nutrients (N-P) which are same as that of five embedments described in details under 'Accelerated Biodegradation Test', except for the fungi concentration, which in this case, is kept as 3.29 x 10^3 spores/g (i.e. equal to the concentration of spores in the field durability test).

The biodegradation process in embedment E-3.29 x 10^3 is quantified by taking out 1 specimen, after a cycle of three days and testing its residual tensile strength until it reaches to 1.0 kN/m of the width of the specimen. Thus the observation of the 'Durability Test' in the laboratory is used to plot a graph between residual ultimate tensile strength v/s time elapsed in days and is shown in Figure 6.

Similarly, the average of the observed values of Residual Ultimate Tensile Strength (kN/m of width) and Time elapsed in days, of three specimens in 'Field Durability Test' is worked out. Using said observations, a single graph of durability of PSG in 'Field Durability Test' is drawn and is superimposed over a graph of a 'Laboratory Durability Test' already drawn in Figure 6.

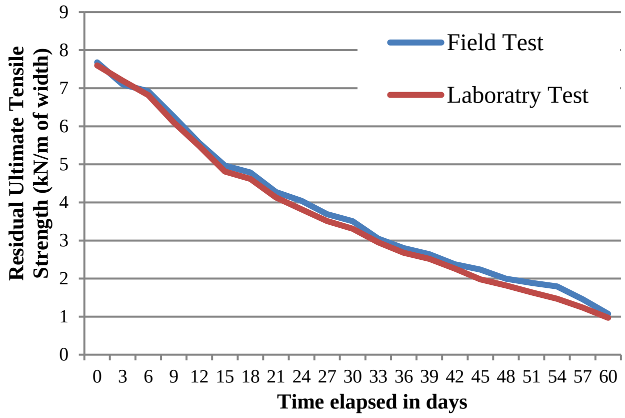

Figure 6 Durability of PSG, in field and laboratory

The study of Figure 6 shows that both the graphs reasonably coincide with each other and give the same durability value of PSG equal to 60 days for the same condition. It also establishes that among several degrading agents that are present in the field conditions, as well as in laboratory conditions (since same soil is used) the process of biodegradation is predominantly carried out by fungi only. Therefore, these two alike durability values (60 days) of PSG in field and laboratory test, for the fungi concentration of 3.29 x 10^3 spores/g of soil, establish the benchmark of the results. Hence, now with this benchmarking test, it is proposed to carry out the 'Accelerated Biodegradation Test' in the laboratory.

6. 'ACCELERATED BIODEGRADATION TEST' ON PSG

Five sets of test specimens, with 30 PSG specimens in each set, are placed in five different embedments (Containers) by simulating field soil conditions except fungi spore concentration. Each embedment comprises of 3 containers, each in the shape of an inverted frustum of a square pyramid, of the top size of 450 mm x 450 mm, bottom size of 350 mm x 350 mm and depth of 300 mm. Each container is capable of accommodating 10 PSG specimens embedded but separated by 20 mm layers of disinfected field soil blended with Nutrients (N-P) and different fungi spore concentration.

Accordingly, three containers of the first embedment, designated as E-3.29 x 10^5 are prepared as described above with the fungi spore concentration of 3.29 x 10^5 spores/g of soil. The fungi concentration used in this case is higher than the concentration of 3.29 x 10^3 spores/g of field soil for accelerated biodegradation of PSGs.

In the same manner, other four embedments are prepared using same field soil blended with N-P nutrient, except that the fungi spore concentration added in each of these four embedments is in the increasing order of 3.29 x 10^6, 3.29 x 10^7, 3.29 x 10^8, and 3.29 x 10^9, respectively. The typical details of 1st embedment are shown in Figure 7.

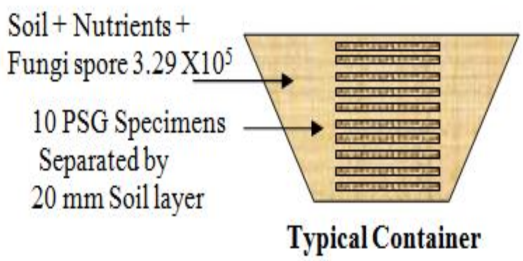

Figure 7 Typical container details of 1st embedment for Accelerated Biodegradation Test'

In the same manner total five embedments are prepared using same field soil blended with N-P nutrient, except that the fungi spore concentration added in each of these four embedments is in the increasing order of 3.29 x 10^6, 3.29 x 10^7, 3.29 x 10^8, and 3.29 x 10^9, respectively.

The Photographs of embedment preparation of PSG Specimens is shown in Figure 8(a) to Figure 8(d). Similarly, Figure 8(e), 8(f) and 8(g) shows the biodegraded PSG specimen at different times in the laboratory test.

Figure 8 (a) - (d) Photographs of Embedment, and (e) - (g) Extent of biodegradation of PSG specimens at the: (e) start of expt. (f) end of 30 days, and (g) end of 48 days

6.1 Biodegradation Process

Due to different fungi spore concentrations, all the six embedments undergo biodegradation at different rates. The test is continued till the tensile strength of each specimen from all five embedments, tested after a cycle of three days, reduces up to 1.0 kN/m of width, which is considered as the durability of PSG specimen in a number of days. From the recorded observations, five plots between the 'Residual ultimate tensile strength of the PSG specimens v/s Time taken' for 'Accelerated Biodegradation Test' is drawn for all 5 laboratory embedments. Also, the curve of durability of PSG in a laboratory test with fungi spore concentration of 3.29 x 10^3 spores/g of soil, which is used for benchmarking with field test is also drawn on the same graph. The combined graph is shown in Figure 9.

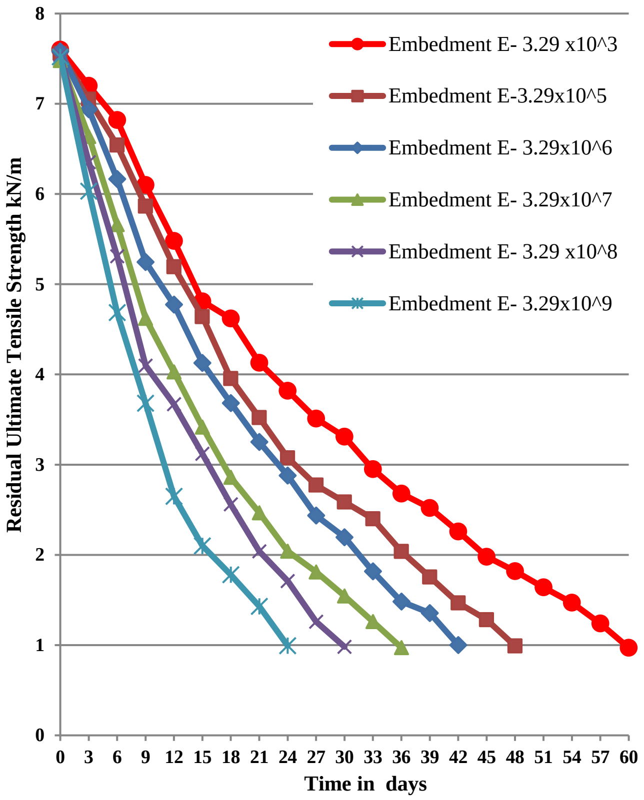

Figure 9 Durability of PSGs, by 'Accelerated Biodegradation Test'

6.2 Results and Discussion of 'Accelerated Biodegradation Test'

From the graph in Figure 9, it is observed that the nature of biodegradation of all PSGs in 'Accelerated Biodegradation Test' performed in the laboratory does not differ from what is found in the field test in Figure 6.

The benchmarking of the durability values of PSG in laboratory and field test, with same fungi concentration 3.29 x 10^3 spores/g of soil, is already established in section 5.2, through comparison as shown in Figure 6. This benchmark test result enables authors to correlate the durability results of PSG in 'Accelerated Biodegradation Test' with 'Field Durability Test' based on their fungi concentration.

It is also observed that the increase in fungi spore concentration of 3.29 x 10^9 spores/g of soil in one of the embedments, reduces the test time for PSG specimen to attain its durability in 24 days, as against test time of 60 days in 'Field Test' with fungi spore concentration of 3.29 x 10^3 spores/g of soil.

In a similar way, the time taken by PSG specimens to reach their respective durability value in another four Embedments with fungi spore concentration ranging from 3.29 x 10^5 to 3.29 x 10^8 spores/g of soil is found to be 48, 42, 36, and 30 days, respectively.

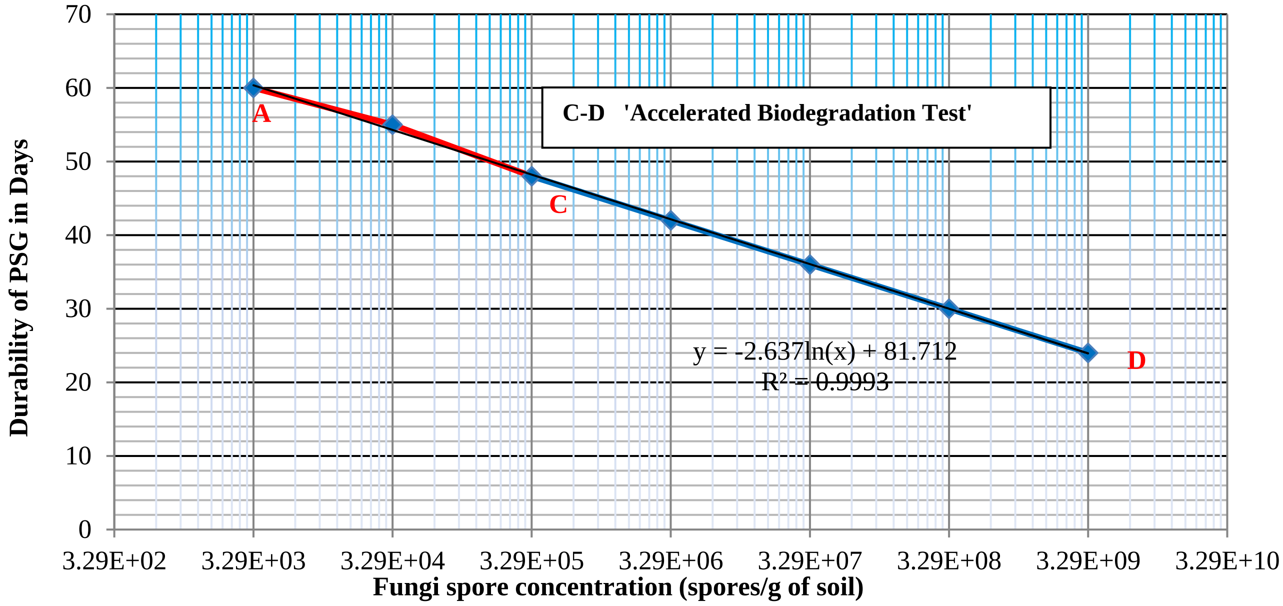

Figure 10 'Accelerated Biodegradation Test' of PSG specimens

7. CORRELATION OF FUNGI SPORE CONCENTRATION & DURABILITY

It is established in Figure 9 of section 6.1 that the fungi spore concentration and durability can be now correlated to predict the nature of the biodegradation process of PSGs. This is done by plotting six fungi spore concentration v/s Durability in days on semi-log graph paper since the increase in fungi spore concentration is exponential and is shown in Figure 10.

The nature of the plot of Fungi spore concentration v/s Durability in days, drawn on semi-log graph paper in Figure 10 is a straight line. It also shows that the increase in fungi concentration ranging from 3.29 x 10^5 to 3.29 x 10^9 spores/g, is a major factor for reduction in test time of laboratory accelerated durability test time.

Curve 'C-D' in Figure 10 is the portion, plotted on the basis of increasing fungi spore concentration for accelerated biodegradation in the laboratory and the durability of PSG in days is a straight line in nature. The line 'C-D' is extrapolated up to point 'A', which indicates a durability period observed in the field test. The purpose of this extrapolation is to find out the fungi spore concentration corresponding to field durability of 60 days which is observed to be 3.29 x 10^3 spores/g. Therefore, spore concentration obtained by extrapolation from Figure 10 is exactly same as that of field spore concentration. Therefore, it is confirmed that fungi spore concentration and the time to reach durability value in days are correlated as observed in the field.

The correlation between fungi spore concentration and durability of PSGs is also established by using the equation of the line 'C-D', which is obtained by using standard curve fitting feature of Microsoft Excel and is found as:

$$Y = -2.602\, Ln(X) + 81.035 \quad (1)$$

where, Y = Fungi spore concentration and X = Durability in Days

Using Eq. (1) and value of durability, Y as 60 days, the Fungi spore concentration works out to nearer to 3.22 x 10^3 Spores / g of soil as against field fungi concentration of 3.29 x 10^9 spores/g in field soil. It is therefore observed that the durability values of PSG calculated by 'Accelerated Biodegradation Test' are in conformity with the 'Field Test' result.

8. CALCULATION OF 'ACCELERATION FACTOR' FOR DURABILITY OF PSG

'Acceleration Factors' are used to correlate durability of PSGs in laboratory embedments with the field test. The comparison of the time degradation curve of 'Accelerated Biodegradation Test' and 'Field Test' (Figures 5 and 6), identifies the time required to reach the same level of degradation in both the tests. Therefore, the 'Acceleration Factors', which are expressed as the ratio of field durability period (of 60 days) to the different periods of durability in 'Accelerated laboratory conditions', are calculated and are shown in Table 1.

Table 1 'Acceleration Factor' for finding field durability of PSG

Name of the laboratory embedment	Quantity of fungi spores per g. of soil	Durability in accelerated condition (Days)	Acceleration Factor = Durability outdoor / Durability accelerated
E-3.29 x 10^5	3.29 x 10^5	48	1.25
E-3.29 x 10^6	3.29 x 10^6	42	1.42
E-3.29 x 10^7	3.29 x 10^7	36	1.67
E-3.29 x 10^8	3.29 x 10^8	30	2.50
E-3.29 x 10^9	3.29 x 10^9	24	2.60

9. CONCLUSIONS

It is concluded that there exists a possibility of using different fungi spore concentration in increasing order, as a predominant biodegrading medium for carrying out the 'Accelerated Biodegradation Test' in the laboratory for reducing the laboratory test period. It is also possible to reduce the test time of 'durability test' of PSG up to 40% by adopting 'Accelerated Biodegradation Test', using suitable higher fungi spore concentrations. The

'Accelerated Biodegradation Test' carried out on Paddy Straw Geomesh can also be extended to the other natural erosion control products made of lignocellulosic material like jute and coir. This is because all three viz. paddy straw, jute and coir have the same chemical composition in the form of Lignin and Cellulose, responsible for imparting resistance to biodegradation and tensile strength respectively to these natural fibers. The estimated durability of 60 days as found by 'Field Test' under ambient atmospheric conditions are considered for use in all erosion control applications.

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