

# The Effect of Polypropylene Fibre and Lime on CBR and Permeability Properties of Granular Sub-base Material

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**ABSTRACT:** In the flexible type pavement, the granular sub-base (GSB) is placed on top of the sub-grade and beneath the base course in a road structure, its function is to drain out the water which might enter because of stripping of asphalt as well as to transfer the wheel load to the sub-grade layer. The GSB material is mixed with different percentages of lime and polypropylene fibre. Initially, physical properties of GSB materials were ascertained to judge its suitability. Performance related test like maximum dry density (MDD) and optimum moisture content (OMC), soaked California bearing ratio (CBR) and permeability of GSB material were performed in the laboratory with and without lime and polypropylene fibre. Addition of lime improves CBR but decreases the permeability of the GSB material. Incorporation of polypropylene fibre enhances the reinforcing effect of GSB materials due to which a significant improvement on the strength of the GSB composites were obtained. Also, the permeability of the GSB composites were improved by the addition of polypropylene fibre. On the basis of the result, it was found that polypropylene fibre is the best additive along with sub-base material as it provides good strength to the GSB material and increases the permeability of GSB material.

**KEYWORDS:** Granular Sub-base (GSB), California Bearing Ratio (CBR), Maximum Dry Density (MDD), Optimum Moisture Content (OMC), Permeability.

## I. INTRODUCTION

Aggregates are crystalline or granular rocks that are extracted for use in the construction as well as roads works. These can be either primary aggregates (extracted from the ground in quarries) or secondary aggregates (recycled from construction waste). Aggregate materials that are widely used in road construction and maintenance applications to replace unsuitable soil, prepare pavement working platform, or construct flexible pavement foundation layers are becoming increasingly scarce and expensive in many parts of Assam and northeastern region, particularly in urban areas. Such local shortages or depletions of aggregates, especially “standard” or traditional high quality crushed ones, around those areas result from multifaceted obstacles. Firstly, geographical distribution of natural deposits of high-quality aggregates needed for road construction is uneven in nature and not found in some areas; secondly, in areas where high-quality aggregates exist, gravel mines and rock quarries are being either lost to other land uses or restricted from mining due to public perception and conservation efforts. As a result, road construction/maintenance applications have been hindered in certain regions both financially and logistically.

In India, more than 98% of the roads are of flexible type. The pavement structural section is a costly element of the highway system and its premature failure is of great concern. Water damage is the most important factor which affects adversely the performance of flexible pavements. Water enters into the pavement section through cracks, joints, pavement infiltration and fluctuation of water table. Some of the effects of water, when trapped within the pavements structure are: a) Reduction in strength of sub-grade and base/sub-base, b) Hydraulic pumping action under effect of traffic which causes disintegration of aggregate particles in different pavement layers, c) Differential swelling in expansive sub-grade soils, d) Stripping of asphalt in flexible pavements, e) Frost heave and reduction of strength during frost melt, and f) Movement of fine particles into base or sub-base course materials resulting in a reduction of the

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coefficient of permeability. There are two approaches to reduce water infiltration into the pavement. First, pavement joints and cracks should be sealed to reduce infiltration. Second, water can be removed either vertically through the sub-grade or laterally through the drainage layer into a system of pipe collectors. In most areas, vertical drainage is not adequate because the coefficient of permeability of sub-grade materials is usually very low. Therefore, lateral drainage is needed to carry free water away from pavement structure. A system of lateral drains uses a drainage layer to carry the infiltrated water to a collector system, which consists of longitudinal or transverse drains. A drainage layer generally consists of highly permeable materials. Therefore, laboratory determination of the permeability of sub base materials is the most important factor for assessing the drainage capability. Granular Sub-base (GSB) is above the sub-grade soil and serves as the foundation for the overall pavement structure. The GSB layer is divided into two parts: i) The upper GSB functions as drainage layer ii) The lower GSB functions as filter layer to prevent intrusion of sub-grade soil into the pavement. The main functions of the sub-base layer in pavements are as follows: 1) It is a structural layer which will accept greater compressive stresses than the sub-grade. 2) It provides a working platform on which the paving materials can be transported, laid and compacted. 3) It reduces the intrusion of fines from the sub-grade in the pavement structure. 4) It provides adequate drainage for the infiltration of rain water through cracks and joints.

## II. RELATED WORK

In recent years, discrete fibres have been added and mixed into soils to improve the strength behavior of soils (Mandal and Murti, 1989; Prabakar and Sridhar, 2002). Li et al. (1995) reported that there were notable increases in shear strength, toughness and plasticity of a cohesive soil after reinforcement with discrete polypropylene fibre. The results of Cai et al. (2005) indicated that fibre reinforced soils took on the strain-hardening ductile failure characteristics. In addition, some investigators (Pera and Ambrois, 1998; Savastano et al. 2003; Kaufmann et al. 2004) found that the use of discrete fibre increased significantly the toughness and led to further improvement of the strength behavior of cement. The reports on the use of discrete fibre for improving the toughness and strength of lime-stabilized soils have been studied by Yi Cai et al. (2006). In order to understand the effect of polypropylene fibre content, lime content and curing time on the strength behavior of a clayey soil investigated, a great number of untreated and treated soil specimens were subjected to unconfined compressive tests and direct shear tests.

The inclusion of randomly oriented discrete fibres significantly improved the unconfined strength when optimum fibre was 51 mm, fibre dosage rate between 0.6 % and 1 % of dry weight and minimum silt dosage was 8 %. Hoover et al. (1982) reported that the soil and fibre composites were more effective in improving California bearing ratio values of sandy soil as compared to silty/clayey soil. Lindh and Eriksson (1990) observed the performance of road stretches where a sub-base of sand has been reinforced with 0.25 % and 0.55 % by weight of discrete plastic fibres. It was reported that the test stretches have been performing well, with no rutting of the road surfaces after about 2 years of traffic use. Tingle et al. (2002) concluded from full-scale study that fibre stabilized sands were a viable alternative to traditional road construction material for rural roads. Maher et al. (1990) proposed a model based on the results of triaxial compression tests for randomly distributed discrete fibre-reinforced sand. The model predicted the orientation and the quantity of fibres at any chosen plane. The increase in strength of fibre-reinforced soil was estimated by limit force-equilibrium method.

Maher and Ho (1994) carried out a series of unconfined compression test on kaolinite using polypropylene fibre content varies (1-5) % by weight. Addition of polypropylene fibres improves the unconfined compressive strength linearly. Fibres increase the unconfined compressive strength and reduce the post peak loss in strength.

Charan (1995) conducted multiple triaxial and CBR test on different sands (silty-coarse) reinforced with polypropylene fibres ranging from (0.5-3) %. Optimum value of fibre content was found to be 2%. Gain in shear strength was found to be 2.4 times at all optimum values of fibres. Similar extensive study was carried out by Nataraj and McManis (1997), used fibrillated polypropylene fibres on sand and carried out compaction, unconfined compression, direct shear and CBR tests. The test results indicated that optimum fibre content is 0.3% of the dry unit weight of the soil specimen.

Consoli et al. (2002) conducted unconfined compression test and drained triaxial tests on sand with fibre inclusion of polyethylene tetraphalate (PT) fibres. Fibre inclusions improve both the peak strength and ultimate strength for cemented and un-cemented sands. Also fibre length strongly improved the unconfined compressive strength, specially improves the peak failure stress. Compaction, unconfined compression, unconsolidated undrained and consolidated drained triaxial test were conducted on fly ash with polyester fibres (Kaniraj and Gayatri (2003)). They observed that

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fibre inclusion of 1% did not affect the maximum dry density (MDD) and optimum moisture content (OMC) in case of a particular fly ash; however another fly ash variety showed that fibre inclusion of 1% increased the MDD and decreased the OMC.

Kumar, Wallia and Bajaj (2007) did extensive reinforcement study on black cotton soil with varying amounts of fly ash, lime and randomly oriented fibres. Investigation was made by 7 conducting series of standard proctor test, unconfined compression tests and split tensile strength tests. The addition of 1.5% of 6 mm plain fibres or 1% of 6 mm crimped fibres to fly ash-soil lime-fibre mixtures (at 8% lime content and 15% fly ash content) increases unconfined compression strength by about 74% as compared to that of same mixture without fibres.

### III. COLLECTION OF SAMPLE AND MATERIAL USED IN THE STUDY

The samples were collected from different sites of Arunachal Pradesh and Assam. The various properties of the GSB samples (SL) are given in Table 1. In this study, polypropylene fibre was used as an additive in sub-base layer. The diameter of fibre was 0.3 mm. The fibre was cut into piece of 4 cm giving the value of aspect ratio (aspect ratio is the ratio of length of fibre to diameter of fibre) as 133.33. The fibre was mixed in GSB mixes in different percentages of 0.5%, 1.0%, 1.5% and 2.0% by dry weight of mix. Lime can permanently stabilize fine-grained soil employed as a sub-grade or sub-base to create a layer with structural value in the pavement system. Sub-base stabilization is used for new road construction and reconstruction of worn-out roads, and generally requires adding 3 to 6 percent lime by weight of the dry soil. In-situ "road mixing" is most commonly used for sub-base stabilization, although off-site "central mixing" can also be used. Lime is also used to improve the properties of soil/aggregate mixtures in "full depth recycling." In this studies lime which is used has specific gravity of 2.69. The lime was mixed in GSB mixes in different percentages of 2%, 3%, 4%, 5% by dry weight mix.

Table 1: Physical properties of GSB material

Sl no	Properties	Samples								
		SL 1	SL 2	SL 3	SL 4	SL 5	SL 6	SL 7	SL 8	SL 9
1	Liquid limit ( $W_L$ ), %	16.64	15.89	19.1	18.21	15.72	17.52	15.54	17.37	13.47
2	Plastic limit ( $W_p$ ), %	Can't be determined	Can't be determined	Can't be determined	Can't be determined	Can't be determined	Can't be determined	Can't be determined	Can't be determined	Can't be determined
3	P.I ( $W_L - W_p$ ), %	Non-plastic	Non-plastic	Non-plastic	Non-plastic	Non-plastic	Non-plastic	Non-plastic	Non-plastic	Non-plastic
4	Aggregate crushing value, %	15.57	13.21	18.54	13.24	13.12	23.61	21.42	27.42	29.13
5	Impact value, %	19.70	17.21	17.47	16.54	14.21	19.26	21.16	28.17	27.36
6	Abrasion value, %	29.51	27.26	30.12	24.21	20.01	33.13	32.11	37.11	36.21
7	Specific gravity	2.63	2.69	2.62	2.64	2.68	2.60	2.61	2.37	2.51
8	Water absorption value, %	0.42	0.34	0.46	0.32	0.22	0.82	0.78	0.79	0.73

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## IV. EXPERIMENTAL RESULTS

The compaction characteristics of the GSB samples used in the study have been established by using standard proctor compaction procedure as per IS 2720 (part 7)-1980. The compaction characteristics i.e. maximum dry density (MDD) and optimum moisture content (OMC) of untreated samples and treated with polypropylene fibre and lime are listed in Table 2. CBR is the measure of resistance of material to the penetration of standard plunger under known moisture content and density conditions. The CBR test were performed as per IS 2720 (Part 16) - 1987. Soaked CBR were done in which the untreated GSB samples and treated GSB samples with fibre were cured for four days and GSB samples treated with lime were cured for seven days. The CBR values of various samples are given in Table 2. Falling head permeability test were done on all the nine samples and with fibre and lime treated GSB samples as mentioned in test methodology as per IS 2720 (Part 17) -1986. In case of lime treated GSB, initially the samples were cured for three days and then the permeability values of the lime-GSB composite were determined.

Table 2: Engineering properties of GSB material.

SL No.	Properties								
	Sample ID	OMC, %	MDD, g/cm <sup>3</sup>	CBR, % (Untreated)	CBR, % (Fibre treated)	CBR, % (Lime treated)	Permeability, cm/sec (Untreated)	Permeability, cm/sec (Fibre treated)	Permeability, cm/sec (Lime treated)
1	SL 1	10.50	2.010	21.46	26.67 (for 1% fibre)	28.39 (for 4% lime)	5.226 x 10 <sup>-3</sup>	7.262 x 10 <sup>-3</sup> (for 1% fibre)	1.624 x 10 <sup>-3</sup> (for 4% lime)
2	SL 2	10.01	2.118	22.83	25.75 (for 1% fibre)	27.89 (for 4% lime)	4.278 x 10 <sup>-3</sup>	6.216 x 10 <sup>-3</sup> (for 1% fibre)	1.926 x 10 <sup>-3</sup> (for 4% lime)
3	SL 3	8.20	2.011	23.44	26.57 (for 1% fibre)	26.42 (for 4% lime)	6.261 x 10 <sup>-3</sup>	7.012 x 10 <sup>-3</sup> (for 1% fibre)	1.711 x 10 <sup>-3</sup> (for 4% lime)
4	SL 4	8.33	2.122	27.85	35.54 (for 1% fibre)	36.21 (for 4% lime)	3.661 x 10 <sup>-3</sup>	6.017 x 10 <sup>-3</sup> (for 1% fibre)	1.814 x 10 <sup>-3</sup> (for 4% lime)
5	SL 5	9.58	2.113	26.54	33.65 (for 1% fibre)	34.46 (for 4% lime)	3.842 x 10 <sup>-3</sup>	5.112 x 10 <sup>-3</sup> (for 1% fibre)	1.021 x 10 <sup>-3</sup> (for 4% lime)
6	SL 6	10.21	1.792	15.53	22.61 (for 1.5% fibre)	23.11 (for 4% lime)	9.721 x 10 <sup>-3</sup>	1.615 x 10 <sup>-2</sup> (for 1.5% fibre)	2.792 x 10 <sup>-3</sup> (for 4% lime)
7	SL 7	10.40	1.821	16.40	22.76 (for 1.5% fibre)	23.41 (for 4% lime)	9.221 x 10 <sup>-3</sup>	1.687 x 10 <sup>-2</sup> (for 1.5% fibre)	4.021 x 10 <sup>-3</sup> (for 4% lime)
8	SL 8	11.21	1.790	15.11	21.01 (for 1.5% fibre)	22.81 (for 4% lime)	7.417 x 10 <sup>-3</sup>	9.875 x 10 <sup>-3</sup> (for 1.5% fibre)	4.623 x 10 <sup>-3</sup> (for 4% lime)
9	SL 9	12.21	1.699	13.21	20.57 (for 1.5% fibre)	22.10 (for 4% lime)	9.574 x 10 <sup>-3</sup>	1.245 x 10 <sup>-2</sup> (for 1.5% fibre)	5.121 x 10 <sup>-3</sup> (for 4% lime)

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## V. OBSERVATION AND ANALYSIS

From the Figure 1, it can be observed that with the increase in fibre content the optimum moisture content increases but dry density decreases. The decrease in dry density may be due to reduction of average unit weight of solids in soil-fibre mixture per unit volume. The increase in moisture is due to the addition of fibre to the GSB which increases the required amount of moisture content due to the increase in surface area of the fibre, so that the composite material becomes workable under the load. Addition of water results in a thin lining of water around the fibre which ultimately increases the OMC of GSB composite.

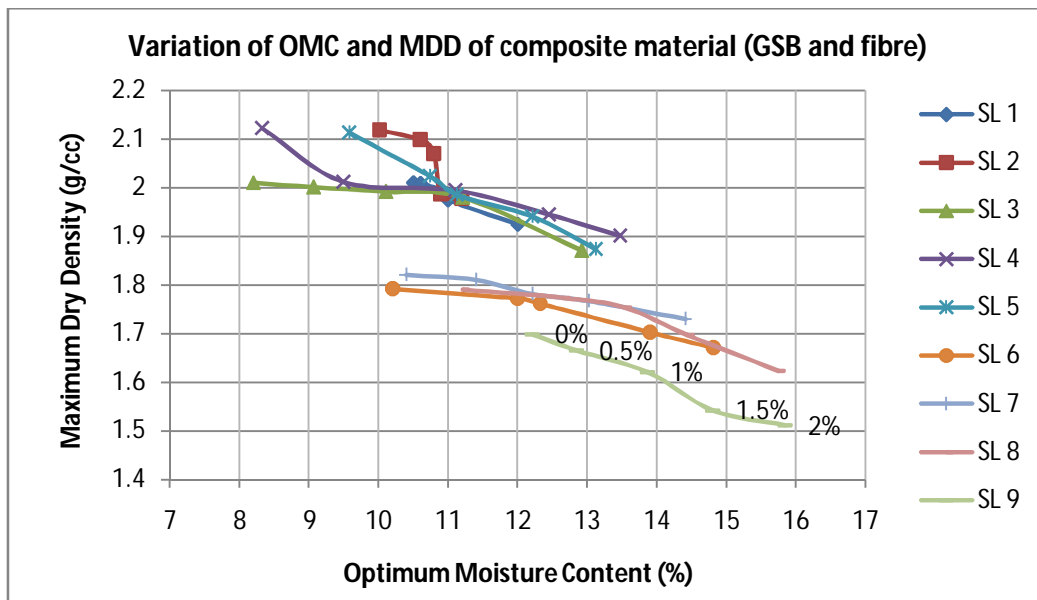


Fig 1: Maximum dry density vs optimum moisture content for fibre mixed composite

From the Figure 2, it can be observed that with the increase of lime content the maximum dry density increases, this is because the particle of lime occupies the pores of the GSB material which leads to the higher compact of composite and hence a higher dry density of composite material. On the other hand, with the increase in lime content, the optimum moisture content also increases; this is because as the lime comes in contact with GSB material, the lime takes up the moisture from the GSB material and thereby reducing the moisture content of GSB material and hence increasing the tendency of GSB material to absorb more water and in the course of time, lime releases much energy in the form of heat which can also dry the GSB material.

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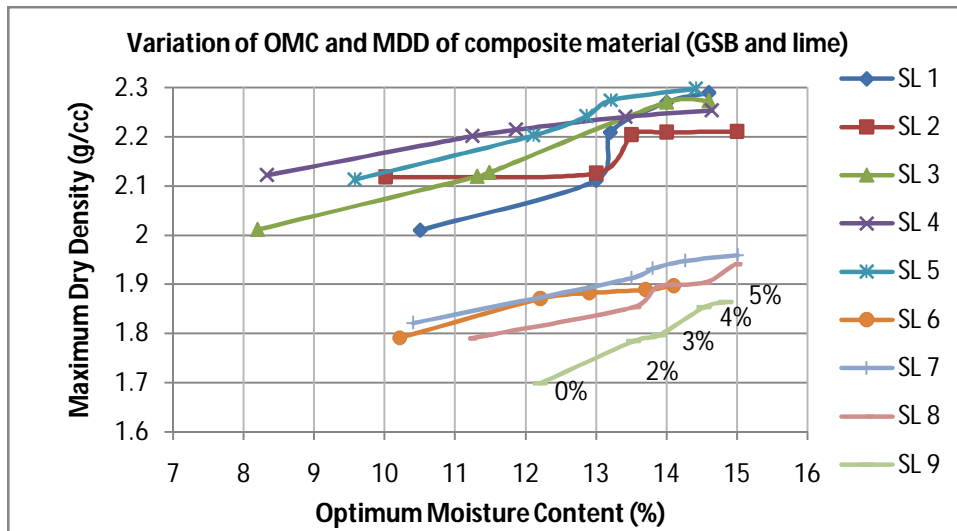


Fig 2: Maximum dry density vs optimum moisture content for lime mixed composite

The Figure 3, shows the variation of CBR with different amount of fibre content, the graph shows the variation of 9 samples among which, the 5 samples (i.e. SL 1, SL 2, SL 3, SL 4, SL 5) which are relatively stronger GSB samples the optimum amount of fibre content at which CBR value is maximum is 1% and the remaining 4 samples (i.e. SL 6, SL 7, SL 8, SL 9) which are relatively weaker GSB samples the optimum amount of polypropylene fibre is 1.5%.

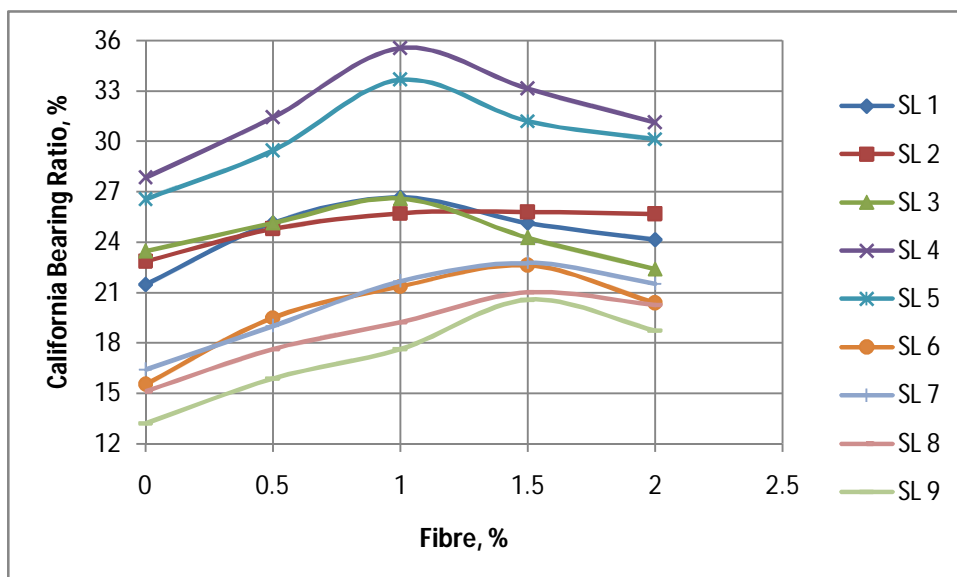


Fig 3: California bearing ratio for fibre mixed composite



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However, the Figure 4 shows the variation of CBR with different amount of lime content, it can be observed that the optimum amount of lime content at which maximum value of CBR obtained is 4% irrespective of the GSB samples.

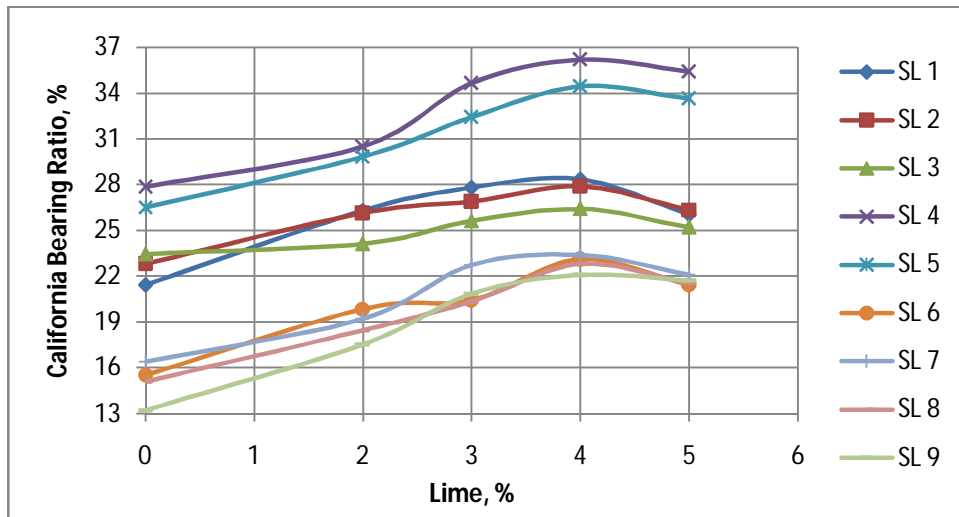


Fig 4: California bearing ratio for lime mixed composite

Variation of permeability with different amount of fibre content is shown in Figure 5. From the graph it can be observed that with the increase in fibre content the permeability also increases, this is because the fibre forms the connecting passage for the flow of water along with the pore of the sub-base material.

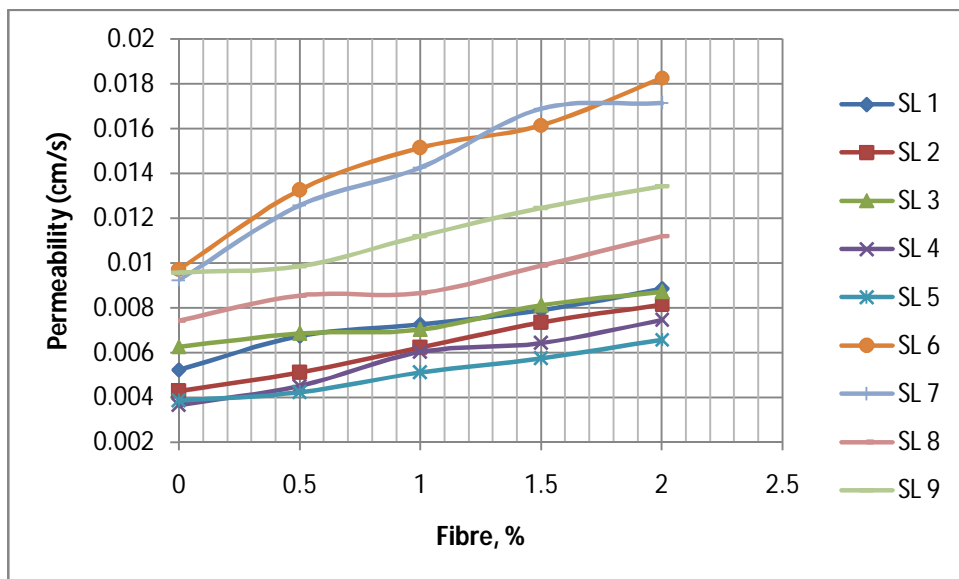


Fig 5: Permeability vs fibre content for fibre mixed composite

However the variation of permeability with different amount of lime content is shown in Figure 6, from the graph it can be observed that the permeability decreases with increase in lime content, this is because the particle of lime occupy the voids of the sub-base material.

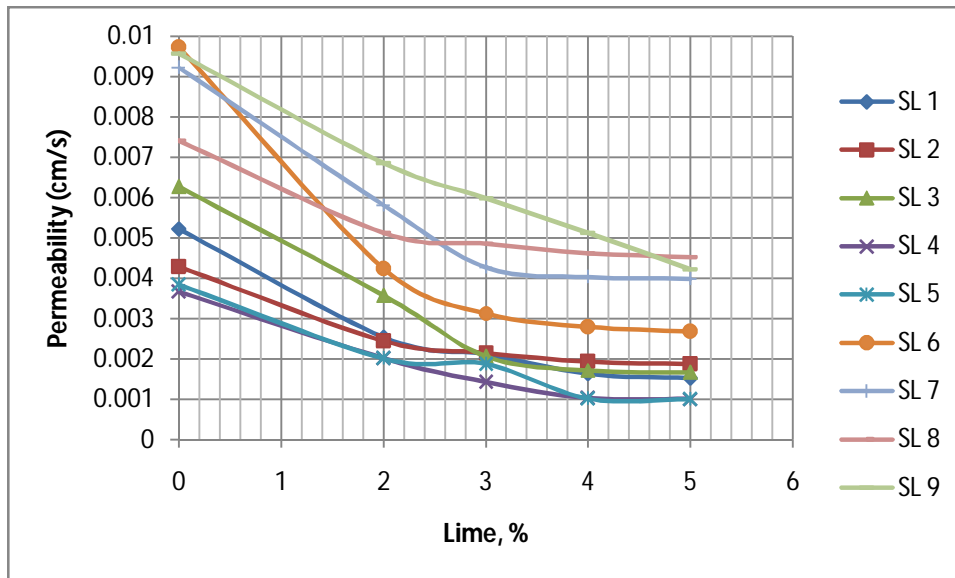


Fig 6: Permeability vs lime content for lime mixed composite

## VI. CONCLUSION

From the detailed analysis of both untreated GSB and treated GSB with polypropylene and lime, it is found that the fibre and lime can be used in road construction field. Addition of few percentage of fibre in GSB material can increase the value of CBR and hence thickness of the pavement decreases, which help in economy in the road project. Addition of polypropylene fibre also increases the permeability of GSB material which enhances the drainage of the water from the sub-base layer of road and hence amount of degradation to the road can be reduced. On the other hand addition of lime increases the value of CBR, which decreases the thickness of pavement layer but addition of lime, decreases the permeability of the GSB material which may obstruct the drainage of water, leading to the degradation of road before its life span. The following are the salient observation: The optimum content of polypropylene fibre is found as 1.5% for relatively weaker GSB sample (SL 6, SL 7, SL 8 and SL 9) at which the increase in CBR value is 45.58% and increase in permeability is 66.13%, whereas for relatively stronger GSB sample (SL 1, SL 2, SL 3, SL 4 and SL 5), the optimum polypropylene fibre content is 1% at which the increase in CBR value is 24.27% and increase in permeability is 38.95%. The optimum content of lime is found as 4% at which the composite gives maximum CBR. The increase in CBR value of composite treated with lime is 32.29% and decrease in permeability is 68.92% when optimum lime content is 4%.

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