Laboratory Investigation of Black Cotton Soil – Fly Ash – Steel Slag Mixes

Mangesh Subhash Ambekar [1] and Hrishikesh Ashok Shahane [2[0000-0003-3339-2234]]

[1] Assistant Professor, Department of Civil Engineering, MET's Bhujbal Knowledge City, Nashik, Maharashtra-422003, India.
[2] Doctoral student, Applied Mechanics Department, S. V. National Institute of Technology, Surat, Gujarat-395007, India.
ambekarmangesh107@gmail.com;shahane.hrishi@gmail.com

Abstract. Black cotton soil is one of the major soil deposits in India. They exhibit high swelling and shrinking when exposed to changes in moisture content and hence has found to be most troublesome from engineering considerations. In this study, geotechnical characteristics of black cotton soil with the addition of fly ash (FA) and steel slag (SS) mixes were investigated. FA and SS were added in the varying percentage of 5, 10, 15 and 20% of the weight of black cotton soil. Atterberg's limit tests illustrated that 5–20% addition of FA and SS in the black cotton soil considerably reduces the volume change potential of the black cotton soil. Addition of FA and SS in black cotton soil also helps in reducing its swelling and shrinkage potential. The strength gain of the mixes not only depends on fly ash and steel slag content but also on mix gradation. The angle of internal friction for all mixes and the cohesion part of the shear strength was higher than that of the black cotton soil owing to strong bonding between steel slag and fly ash particles. Apart from the experimental results the use of fly ash and steel slag has proven to be an eco-friendly material thereby reducing the dumping and disposal problems associated with fly ash and steel slag.

Keywords: Black Cotton soil, Fly Ash, Steel Slag, Swelling, Shrinkage

1 Introduction

The expansive soils occur all over the world. India has large tracks of expansive soil known as black cotton (BC) soil. These soils are suitable for growing cotton and black or blackish-grey in color due to the presence of titanium oxide in small concentration. This soil has a high percentage of Montmorillonite clay mineral which is mainly responsible for expansive characteristics of the soil. This soil increases in volume on absorbing water during rainy seasons which results in swelling and softening of soil. Also, the volume of soil decrease when water evaporates from it in the summer season. Due to alternate swelling and shrinkage property, the construction of the foundation for structure over a black cotton soils poses a challenge to the civil engineers. To overcome this effect many locally available materials and industrial waste such as coir waste, quarry dust, lime, fly ash, copper slag, murum, etc. (Poh et al. 2006; Osinubi 2006; Raut et al. 2007; Consoli et al. 2011; Kumar et al. 2014; Kartik et al. 2014; Joe et al. 2015; Jayshree et al. 2015) were used in combination of black cotton soil

and the geotechnical properties of BC soil were enhanced. The use of the optimum amount of additives is mainly dependent on the mineralogical composition of the soils and additives. Utilization of industrial wastes in the geotechnical engineering field is the best method for improving the performance of BC soil.
Extensive research was carried out by the geotechnical investigators to reduce the swelling and shrinkage and enhance geotechnical properties of expansive soils by using industrial wastes. Nwaiwu et al., (2012) reported that quarry dust can be successfully used for road construction containing black cotton soil area. However, the mixture does not become non-plastic after addition of quarry dust content. Partial addition of shredded tire waste with black cotton soil changed the geotechnical properties which were advantageous to engineering applications and greatly decreases the swelling potential of the black cotton soil (Srivastava et al. 2014). Poh et al. (2016) showed that the use of basic oxygen steel (BOS) slag fines produce enhancements in strength and durability, and also a reduction in expansion characteristics. Fly ash due to its pozzolanic properties beneficial in combination with lime in improving properties of soil. With the increase in the percentage of fly ash keeping amount of lime as a constant, strength of the respective soil-lime mixture was increased (Kumar et al. 2007). Miao et al., (2017) presented a method of geopolymerizing black cotton soil (BCS) to ascertain its potential use in subgrades.

2 Materials and Methodology

In this study laboratory investigation of BC soil, fly ash and steel slag with different proportions was carried out. BC soil was collected from the nearby area of Nashik. Geotechnical properties of BC soil are given in Table 1. It was observed that the liquid limit and plastic limit of soil sample was greater than 50% and 30% respectively. Therefore, according to Casagrande's A-line chart soil was classified as CH soil.

Table 1. Geotechnical Properties of Black Cotton Soil

Sr. No	Parameters	Results
1	Specific Gravity	2.67
2	Liquid limit (%)	58.40
3	Plastic limit (%)	30.37
4	Plasticity Index	28.03
5	Shrinkage limit (%)	18.93
6	IS classification	CH
7	Free Swell Index (%)	103
8	OMC (%)	24.50
9	MDD (gm/cc)	1.53
10	UCS (kg/cm2)	0.29

Fly ash (FA) for the present investigation was collected from the coal-based thermal power plant located at Eklahare, Nashik. FA in dry form was transported in airtight double polythene bags. The chemical constituents of FA are given in table 2 and it is classified as Class F fly ash as per ASTM C 618 (ASTM 2018). Steel Slag (SS) was collected from the electric arc-based Bhagawati Steel Cast PVT Ltd. located in Malegaon MIDC, Sinnar, Nashik, chemical constituents of steel slag are given in table 2.

Table 2. Physical Properties and Chemical Composition of the Fly Ash and Steel slag

Sr. No.	Constituents	Fly Ash	Constituents	Steel Slag
1	Silica	58.66%	Loss of Ignition at 900ºC	5.20%
2	Magnesium Oxide	1.82%	Silica	44.25%
3	Sulphur trioxide	0.76%	Alumina	9.10%
4	Sodium dioxide	0.62%	Iron oxide	24.10%
5	Total Alkalies	92.56%	Calcium Oxide	4.60%
6	Total chloride	0.03%	Magnesium Oxide	0.40%
7	Loss on Ignition	1.94%	Chromium oxide	Nil
8	Moisture content	0.25%	Total Alkalis	2.80%
9	Specific gravity	2.43	Manganese Oxide	8.10%
10			Phosphorus Pentoxide	0.32%
11			Specific Gravity	2.85

Series of laboratory tests were carried out to find the geotechnical characteristics of black cotton soil, fly ash and steel slag mixes. Details of the combination used are shown in table 3.

Table 3. Details of Black cotton soil-Fly Ash- Steel slag Mixture for Test Conducted

$W=W_{BC}+W_{FA}+W_{SS}$	Variation of W_{BC} (% by total dry weight)	Variation of W_{FA} (% by total dry weight)	Variation of W_{SS} (% by total dry weight)
Combination 1	100, 95, 90, 85, 80	0, 5, 10, 15, 20	0
Combination 2	100, 95, 90, 85, 80	0	0, 5, 10, 15, 20
Combination 3	85, 80, 75, 70	10	5, 10, 15, 20

For evaluation of various geotechnical properties of black cotton soil, fly ash and steel slag mixes following laboratory tests were performed. During this study the standard procedures and precautions have been implemented as per IS 2720 Part-3 Sec I (2016) for Specific Gravity, IS 2720 Part-4 (2015) for Grain size analysis, IS 2720 Part-5 (2015) for liquid limit and plastic limit, IS 2720 Part-6 (2016) for Shrinkage limit, IS 2720 Part-40 (2016) for Free swell Index, IS 2720 Part-8 (2015) for Compaction test and IS 2720 Part-10 (2015) for Unconfined Compression Test.

3 Test results and Discussion

Fig.1 shows the effect of fly ash, steel slag, and combinations of the fly ash and steel slag on the liquid limit of black cotton soil. It was observed that as the additive content increases the LL value decreases. The LL of black cotton soil has been found as 58.4% for 0% additives. This is a reference datum to study the effect of additives namely fly ash and steel slag on LL of black cotton soil. In Present case, the LL is decreased by 1.35% for 5% FA, 2.675% for 5% SS and 3.86% for combination of 10% FA+ 5% SS. So this reduction in LL is found to be reduced gradually with the increase in the percentage of additives. Finally, at 20% gross additives consisting of 80% BC with 20% FA gives 8.59% reduction in LL. In the case of 80% BC with 20% SS gives 11.49% reduction. Whereas, for 70% BC +10% FA+ 20% SS up to 14.84% reduction in LL was observed.

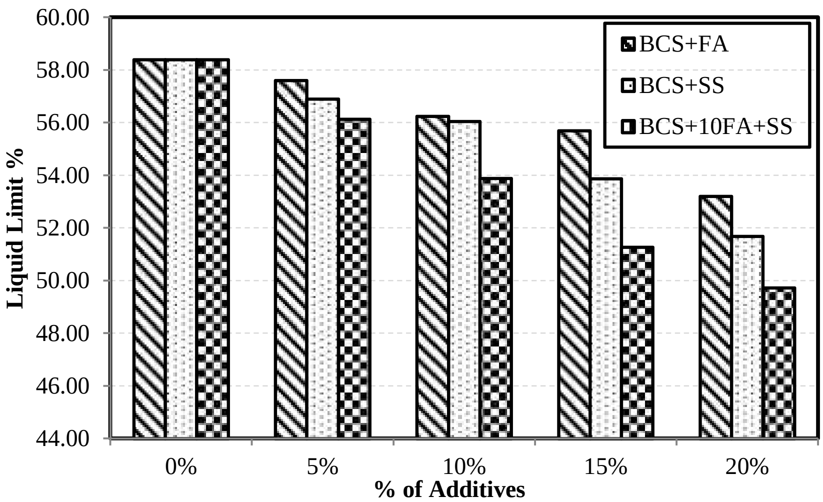

Fig. 1 Comparative effect of FA, SS and FA+SS on Liquid limit

Fig. 2 shows the variation of the plastic limit for different proportions of BCS+FA+SS mixtures. It was observed that PL of 30.37% has found for 0% additives. In Present case, the PL is decreased by 0.72% for 5% FA, 35% for 5% SS and 2% for a combination of 10% FA+ 5% SS. Similar observation as that of LL has been observed in a reduction in the PL of mixes as it reduced gradually with the increase in the percentage of additives. It is due to the reduction in the percentage of clay content in the mix (Srivastava et al., 2014).

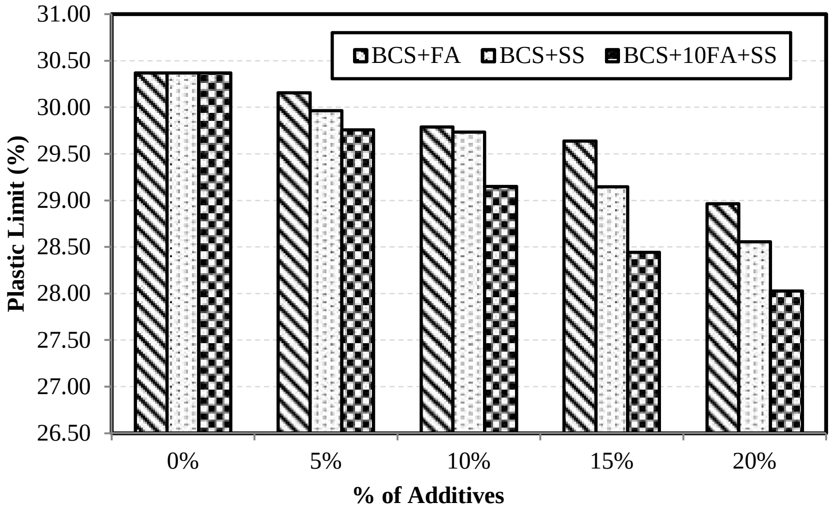

Fig. 2 Comparative effect of FA, SS, and FA+SS on Plastic limit.

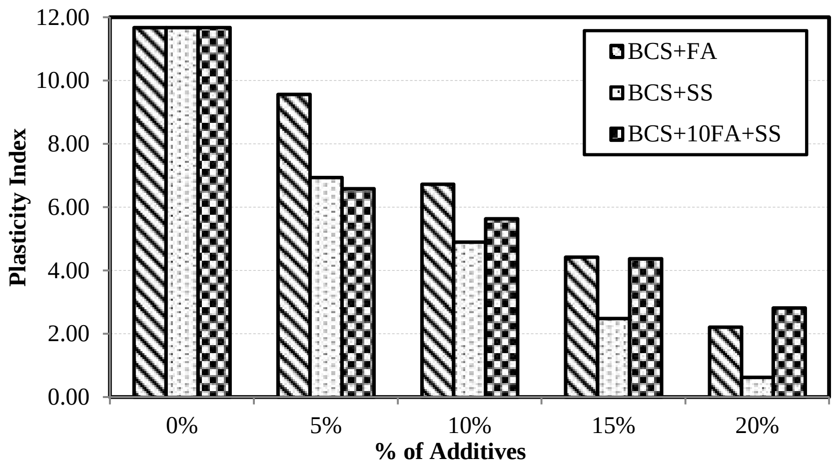

Fig. 3 Comparative effect of FA, SS, and FA+SS on Plasticity Index

From fig. 3 it has been observed that the plasticity index of only black cotton soil is 28.03%. It was evident that the PI was decreased very rapidly with the addition of FA and SS. PI was decreased by 2.03% for 5% FA, 3.88% for 5% SS and 5.88% for the combination of 10% FA+ 5% SS. Finally, for the combination of 80% BC with 20%, SS gives the highest reduction in PI of 17.49%. Liquid limit, plastic limit well as PI values, decreased consistently at higher fly ash and steel slag contents, similar observations were observed by Nwaiwu et al., (2013) and Srivastava et al., (2014).

The shrinkage limit of natural soil mainly depends on the grain-size distribution of the soil. Even though clay-sized particles play an important role in the shrinkage phenomenon, there is an optimum clay content at which the shrinkage limit of soil becomes lower. From the fig. 4 it was observed that the shrinkage limit of 18.93% has found for 0% additives in BC soil. As FA and SS content increases the SL increases. Finally, at 80% BC with 20% FA gives 47.43% increase in the SL. In case of 80% BC with 20% SS gives 56.89% increase in SL. However, for 70% BC +10% FA+ 20% SS up to 20% increase in SL was noticed. In BC soil the clay content reduced due to the addition of fly ash and steel slag resulting in increasing the shrinkage limit.

These results clearly show potential for reducing the shrinkage behavior of black cotton soil when mixed with FA and SS. It was also observed that the addition of coarser SS waste provides relatively higher values of shrinkage limit when compared to the corresponding values obtained for FA mixed with black cotton soil. Hence, the addition of coarser category waste material is more advantageous for controlling the shrinkage behavior of black cotton soils (Srivastava et al., 2014).

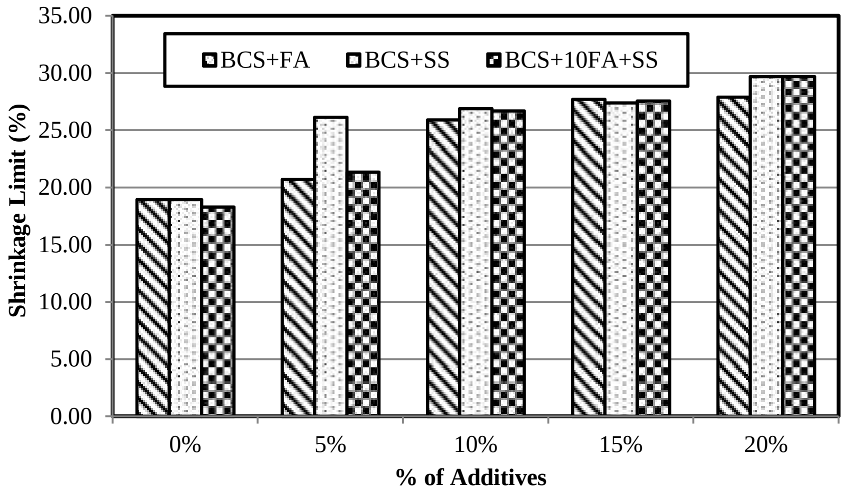

Fig. 4 Comparative effect of FA, SS, and FA+SS on Shrinkage limit

Addition of FA and SS to black cotton soil causes a reduction in the free swell Index. In Fig 5, it is shown that additions of up to 20% FA and SS caused a reduction in free swell Index from 104% to 60%, this represents a reduction of up to 40%. The reduction in FSI was found to be reduced gradually with the increase in the percentage of additives. These trends suggest that FA and SS, which are the granular material can be used to reduce the swelling potential of expansive clay soils. The possibility of using fly ash and steel slag to reduce the swelling potential of expansive soils offer an opportunity for a reduction in the volume of this waste product which would otherwise establish an environmental problem.

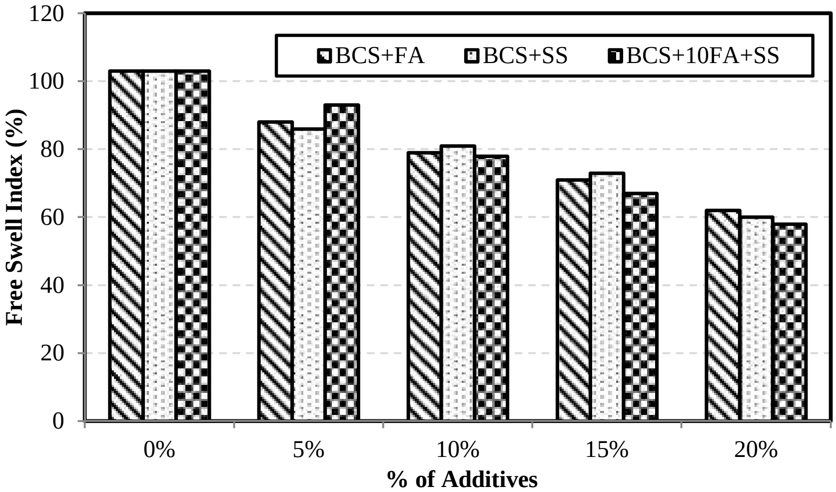

Fig. 5 Comparative effect of FA, SS, and FA+SS on Free Swell Index

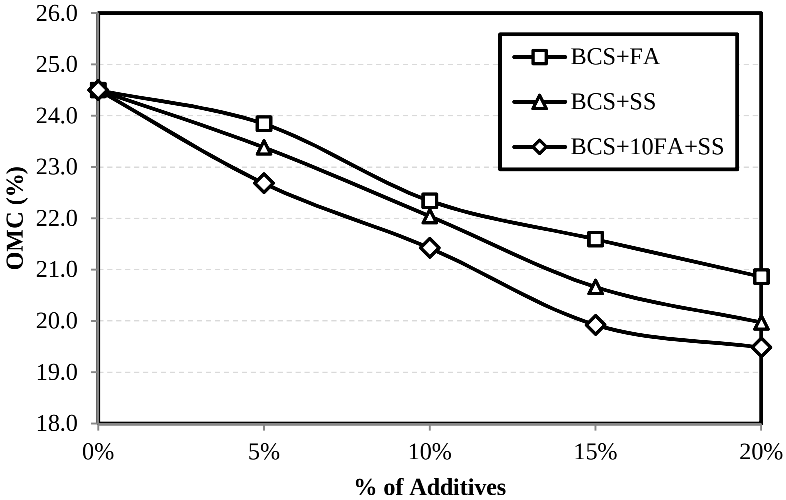

Fig. 6 Comparative effect of FA, SS and FA+SS on OMC

Fig.6 shows the variation of OMC with additive content. From the results, it is clear that OMC decreases with the addition of FA and SS. OMC of 24.5% has been found for 0% additives content i.e. for black cotton soil only. The OMC was decreased by 2.69% for 5% FA, 0.48% for 5% SS and 7.42% for combination of 10% FA+ 5% SS. So this reduction in OMC was found to be reduced gradually with the increase in the percentage of additives. Also in case of 70% BCS+10%

FA+ 20% SS up to 14.61% reduction in OMC was observed. From the results, it was evident that as the percentage of clay from the BC soil reduces the amount of moisture required also reduces.

Fig. 7 show the variation of maximum dry density for different proportions of BCS-FA-SS mixtures. It has been observed that the maximum dry density of all mixes increased with additive content. From the results, it was observed that with an increase in fly ash content, the MDD of BCS-FA mixes increases and after 10% FA content MDD value decreases. The rise in density is more significant at lower percentages of FA. However, increasing trend of MDD value was observed in the case of BCS+SS and BCS+10FA+SS combination. The MDD was increased by 1.96% for 5% FA, 3.26% for 5% SS and 6.53% for combination of 10% FA+ 5% SS. Finally, at 10% FA and 90% of BCS gives MDD value of 1.64 gm/cc. In case of 85% BCS with 15% SS gives 18.95% addition of MDD i.e. 1.82 gm/cc. Also in case of 75% BCS +10% FA+ 15% SS MDD value observed as 1.75 gm/cc. In BC soil the clay content reduced due to the addition of steel slag resulting in increasing the coarser particles and increase in the maximum dry density for BCS+SS mixes.

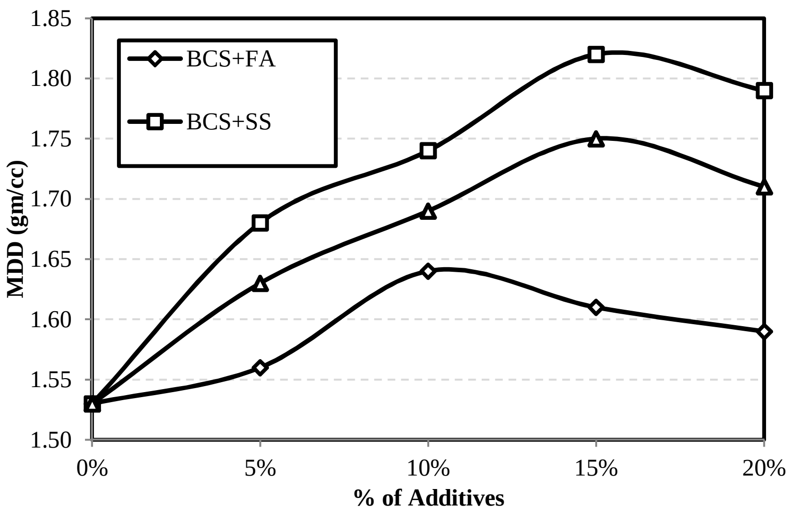

Fig. 7 Comparative effect of FA, SS, and FA+SS on MDD

The UCS tests were carried out on the cylindrical specimens BCS+FA+SS mixes (38mm X 76mm) to for different mix proportion without curing. The test is un-drained based on the assumption that there is no moisture loss during the test. The mixture was compacted in three layers to achieve the required MDD of the mix. Increase in the fly ash and steel slag content increased the cohesive and frictional property of black cotton soil. The 75% BC soil + 10% fly ash + 15% steel slag content found the optimum combination among all combinations. The UCS value black cotton soil sample was 0.291 Kg/cm^2 and it was increased up to 0.552 kg/cm^2 after addition of FA+SS as shown in fig. 8.

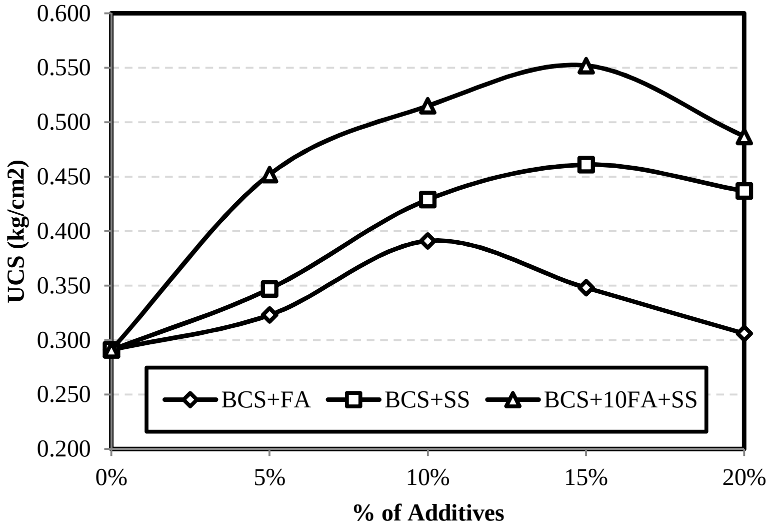

Fig. 8 Comparative effect of FA, SS, and FA+SS on UCS

4 Conclusions

From the Atterberg's limit tests, it was observed that 5–20% addition of FA and SS in the black cotton soil considerably reduces the volume change potential of the black cotton soil. Addition of FA and SS in black cotton soil also helps in reducing its swelling and shrinkage characteristics. From the combined observation of compaction tests and UCS test results, it can be noted that addition 10FA and 20% SS in black cotton soil will provide a mix having higher shear strength.

According to the test results, it appears that fly ash and steel slag can be used as an admixture in the BC soil to improve its properties. Utilization of fly ash and steel slag also has the advantages of reusing an industrial waste by-product without adversely affecting the environment and solve the dumping and disposal problems of industrial waste.

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