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# Behavior of Fly Ash at Different Mix Ratios with Plastic Recycled Polymers

Tushar Vasant Salunkhe
*Civil Engineering Department, Indian Institute of Technology, Delhi, India*

**Abstract:** Fly ash is a waste produced from burning of coals in thermal power stations. The staggering increase in the production of fly ash and its disposal in an environment friendly manner is increasingly becoming a matter of global concern. Many efforts have been made to use the fly ash in various geotechnical applications viz. embankment, roadway, railway, backfill material. In this study, PRPs (plastic recycled polymers) were mixed with fly ash at different mix ratios so as to inspect its influence on the geotechnical properties of fly ash. In this regard, the laboratory study includes Atterberg limits, compaction characteristics, unconfined compressive strength, direct shear test, Triaxial shear test and X-ray fluorescence test. Tests were carried out on only fly ash and treated fly ash with PRPs. Results indicate increase in MDD (maximum dry density) and also in shear parameters of the fly ash with inclusion of PRPs.

**Key words:** Fly ash, PRPs, X-ray fluorescence, shear parameters.

## 1. Introduction

Thinking about the stability of either new slopes formed by earthworks or of naturally occurring slopes is of great and obvious importance in the field of civil and geotechnical engineering. While constructing for example railways, highways, canal and excavations, analysis of related slopes must be carried out and possibly remedial work done to the slope [1]. Bahareh et al. [2] carried an experimental work on stabilization and erosion control of slopes using cement kiln dust.

Pandian [3] studied fly ash characterization with reference to geotechnical applications. Coal-based thermal power plants all over the world face serious problems of handling and disposal of the ash produced. The high ash content (30%-50%) of the coal in India makes this problem complex.

Safe disposal of the ash without adversely affecting the environment and the large storage area required are major concerns. Hence, attempts are being made to utilize the ash rather than dump it. The coal ash is utilized in bulk only in geotechnical engineering applications such as construction of embankments, fills, landfill liners [4]. Shenbaga et al. [5] have carried out experimental study to investigate the influence of randomly oriented fiber inclusion in fly ash.

Plastic recycling or plastic waste recycling is the process of recovering scrap or waste plastic material into useful products. As for example, the spare soft drink bottles, refrigerator, coolers, air conditioners, mobiles, spare parts of computers and televisions can be melted down and recycled to another plastic products. Basically all types of plastic can be recycled except those made from recycled plastics, often unrecyclable. Besides, a plastic cannot be recycled into the exact plastic it was before. Before recycling, the plastics are sorted according to their resin type. Different types of plastics need different types of recycling process; that is why we can see a single digit ranging from 1 to 7 and surrounded by a triangle made of clockwise arrows right at the bottom of the plastic containers. The identification coding system follows Indian Standard IS: 14534-1998 Part III, “The Guidelines for Recycling Plastic” [6].

**Corresponding author:** Tushar Vasant Salunkhe, associate director. Research field: construction engineering.

## 2. Material Description

The PRPs (plastic recycled polymers) as shown in Fig. 1 were collected from R.J. Plastic Enterprises Pvt. Ltd., Mumbai. The dimensions, specific gravity and density of the plastic polymers are mentioned in Table 1. These are produced from shredding of the polymer wastes like computer accessories, mobile phones, television sets, washing machine, air conditioners, refrigerators, air cooler, polymers accessories in car, chairs, tables, electronic chips, etc.

The fly ash was collected from Tata Thermal Power Plant, Trombay, Mumbai. Table 2 represents the physical properties of fly ash. The chemical compositions of fly ash were found out by conducting X-ray Fluorescence test and reported in Table 3. It can be observed that the fly ash mainly consists of $SiO_2$ (71%), $Al_2O_3$ (32%) and $Fe_2O_3$ (6%). The CaO content (0.626%) is very low and thereby it is classified as Class F fly ash according to ASTM C618-08a (2008) [7].

**Fig. 1 PRP.**

**Table 1 Specification of recycled polymers.**

| Type and color | Diameter (mm) | Length (mm) | Specific gravity (G) | Density (kg/m$^3$) |
|---|---|---|---|---|
| Polymers (orange and white) | 2.98 | 4.0 | 2.154 | 0.62 |

**Table 2 Physical properties of fly ash.**

| Properties | Value |
|---|---|
| Water content | 22.35% |
| Specific gravity | 2.154 |
| Liquid limit | 23.6% |
| Plastic limit | NP |
| MDD (maximum dry density) | 1,220 kg/m$^3$ |
| OMC (optimum moisture content) | 18.6% |
| $D_{10}$ | 0.0030 mm |
| $D_{30}$ | 0.01 mm |
| $D_{60}$ | 0.45 mm |
| $C_u$ | 15 |
| $C_c$ | 1.45 |
| Cohesion ($c$) | 23.14 kPa |
| Angle of internal friction ($\phi$) | 20.4 ° |

**Table 3 Chemical compositions of fly ash.**

| Chemical composition | Content (%) |
|---|---|
| CaO | 0.626 |
| $Fe_2O_3$ | 5.908 |
| $K_2O$ | 0.962 |
| MnO | 0.034 |
| $P_2O_5$ | 0.349 |
| $SO_3$ | 0.039 |
| SrO | 0.056 |
| $TiO_2$ | 1.776 |
| $Al_2O_3$ | 32.077 |
| MgO | 0.819 |
| $SiO_2$ | 71.046 |
| $Na_2O$ | 0.136 |

## 3. Materials and Methodology

First, the fly ash was oven dried at approximately 40 ℃ for 24 h. To prepare the fly ash-PRP mixture, the required amount of fly ash and PRPs were measured and mixed together in dry or wet state. The recycled polymers were mixed at different percentages of the dry weight of the fly ash. As the PRPs have tendency to lump together, it requires considerable care to get an even distribution of the polymers in the mixture. Then, required amount of water was mixed with the dry mix. Proper care was taken to prepare homogeneous mixture. PRPs could be mixed with fly ash in the moist state as in dry state the fly ash particles tend to fly.

## 4. Result and Discussion

The laboratory experimental study was carried out by mixing fly ash with PRPs considering 0%, 25%, 50% and 75% weight of PRPs by weight of fly ash. The blending operation was carried out manually by hand mixing and proper care was taken to obtain homogeneous mixture. The homogeneous mixture so formed was tested for Standard Proctors test to find OMC and MDD.

*4.1 Standard Proctor Test*

Standard Proctor compaction tests on fly ash were conducted using Standard Proctor mould with varying percentage of PRPs and fly ash mixes. IS light compaction tests were carried out on different mix proportions of PRPs and fly ash as per IS: 2720 (Part VII) 1980/87 to study their MDD and OMC. As per IS: 2720 recommends, a mould of 1,000 mL capacity having internal diameter of 100 mm and an internal effective height of 127.5 mm should be used. The rammer has a mass of 2.6 kg with a drop of 310 mm.

Fig. 2 shows typical dry density (kg/m$^3$) versus water content (%) relationship obtained for fly ash. Also it shows that fly ash having MDD is 1,220 kg/m$^3$ and OMC is 18.6%.

A standard Proctor compaction test was also carried out on different mix proportions of PRP and fly ash (i.e. 0, 25%, 50% and 75%). Fig. 3 shows the compaction curves for different mixing proportions.

The MDD and OMC values are increased initially up to a mix proportion of 50% and then it decreases for 75%. It may be due to the increase in the PRP which creates voided space owing to its geometry that causes decreased MDD and OMC. The optimization values for mixtures of PRPs and fly ash are shown in Table 4.

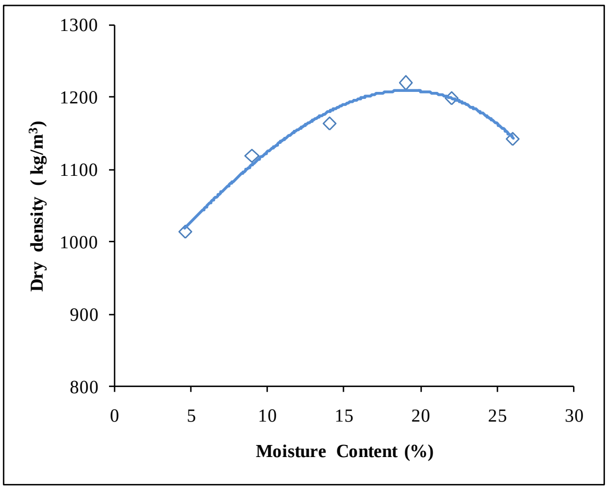


**Fig. 2 Standard Proctor test compaction curve for fly ash.**

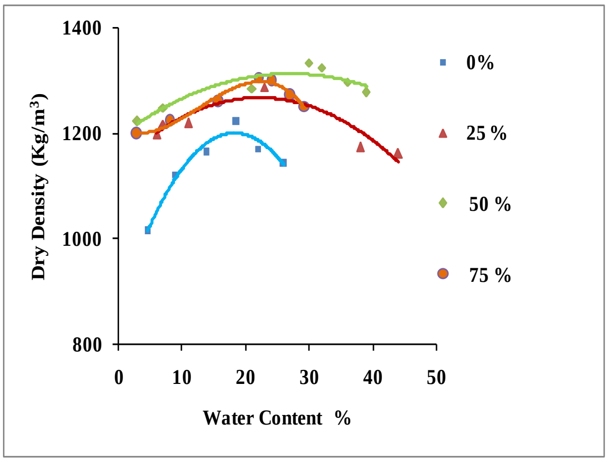


**Fig. 3 Compaction curve for fly ash mixed with different percentage of recycled polymer.**

**Table 4 Optimization of recycled polymers contents (%) with MDD and OMC.**

| PRPs (%) | MDD (kg/m$^3$) | OMC (%) |
|---|---|---|
| 0 | 1,220 | 18.6 |
| 25 | 1,280 | 23.0 |
| 50 | 1,330 | 30.0 |
| 75 | 1,300 | 22.0 |

*4.2 Shear Strength Characteristics*

4.2.1 Direct Shear Test

CD (consolidated drained) direct shear test was carried out on 60 mm × 60 mm × 20 mm specimens as per IS:2720 (Part 13)-1986 [8]. The test was carried out on specimens prepared from fly ash and PRP mixes compacted on their corresponding OMC. The normal stress varied in the range of 50 kPa, 100 kPa and 150 kPa. The specimens were sheared at a constant strain rate of 0.125 mm/min under saturated condition.

Fig. 4 shows the shear stress and horizontal displacement behavior of fly ash tested for different normal stresses. Cohesion ($c$) and angle of internal friction ($\phi$) obtained from CD direct shear test are found to be 23.14 kPa and 20.4° respectively as shown in Table 5.

Failure plane in case of fly ash and mixture of fly ash with PRPs 50% is shown in Figs. 5 and 6 respectively. When fly ash mixes with PRPs contents in different percentage, the optimum value for angle of internal friction ($\phi$) is obtained at PRP content about 50%.

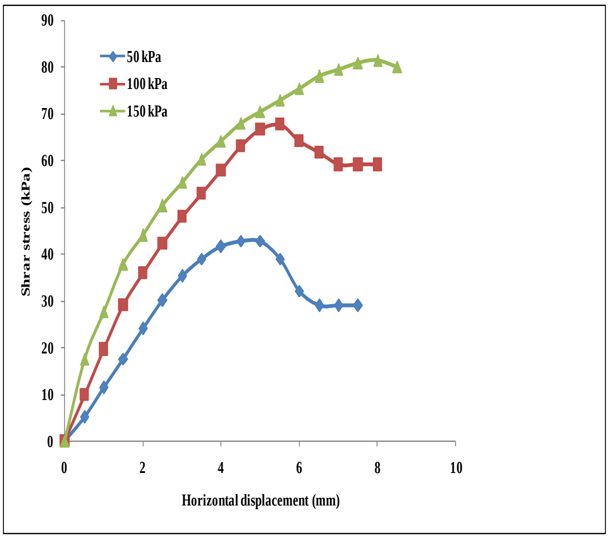


**Fig. 4** **Shear stress vs. horizontal displacement for fly ash.**

**Table 5** **Direct shear test results for fly ash and mixture of fly ash with PRPs in different percentage.**

| Plastic recycled polymer percentage (%) | Cohesion ($c$) (kPa) | Angle of internal friction ($\phi$) (°) |
|---|---|---|
| 0 | 23.14 | 20.4 |
| 25 | 17.65 | 27.5 |
| 50 | 12.94 | 39.5 |
| 75 | 16.47 | 29.4 |

**Fig. 5** **Failure of fly ash.**

**Fig. 6** **Failure on fly ash with 50% PRP.**

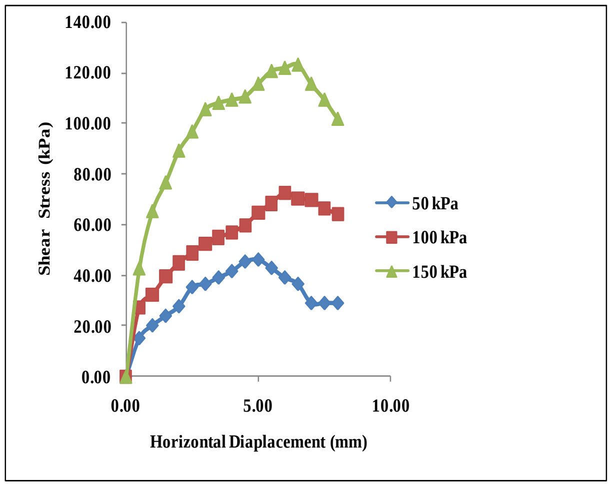


**Fig. 7** **Shear stress vs. horizontal displacement for mixture of fly ash with PRPs 50%.**

The variation of stress and percentage strain is shown in Fig. 7. For this optimum percentage, angle of internal friction ($\phi$) and cohesion ($c$) are 39.5° and 12.94 kPa respectively.

*4.3 UCS (Unconfined Compression Strength) Test*

In laboratory, UCS tests were carried out on height of the sample 7.62 cm with diameter of the sample 3.82 cm, having an area and volume of specimens of 11.4 $cm^2$ and 87 $cm^3$.

Minimum three specimens were prepared for each combination of variables at a deformation speed rate of 0.125 mm/min specimens as per IS: 2720 (Part 10) 1973 [9]. According to their respective mixture fly ash and PRPs, MDD and OMC for the preparation of samples are used.

The test was carried out on specimens prepared from fly ash and fly with PRPs mixes and compacted at their corresponding OMC to MDD.

The PRP’s inclusion had a significant effect on the stress-strain behavior. The fly ash specimens attained distinct failures but PRPs with fly ash specimens exhibit a highly ductile behavior. Fig. 8 shows that UCS test for the mixture of fly ash and fly ash with PRPs (50%).

**Fig. 8 UCS test: fly ash + PRPs 50%.**

**Table 6 UCS test.**

| | Fly ash | Fly ash + 25% PRP | Fly ash +50% PRP | Fly ash +75% PRP | Fly ash +100% PRP |
|---|---|---|---|---|---|
| UCS (qu) kPa | 31.77 | 44.69 | 51.84 | 43.00 | 30.10 |
| Cohesion (*c*) kPa | 15.88 | 22.34 | 25.92 | 21.50 | 15.05 |

UCS tests were carried out on fly ash and mixture of fly ash with PRP and the values of cohesion (*c*) are shown in Table 6.

The percentage strain with deviators stress variation is shown in Fig. 9 and also the optimization of UCS values is shown in Table 6 and Fig. 10.

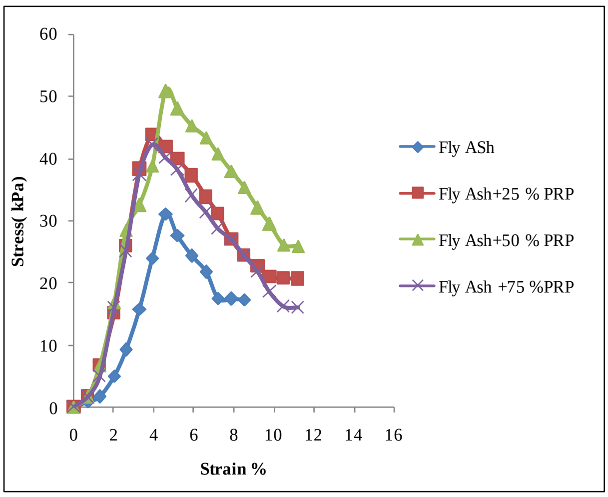


**Fig. 9 Percentage strain vs. stress for fly ash and PRP.**

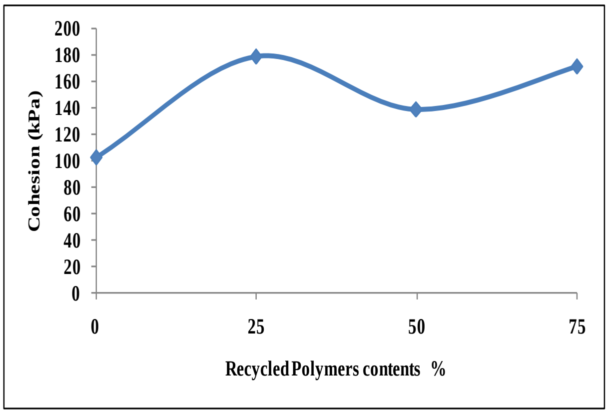


**Fig. 10 Variation of UCS value with PRP content percentage.**

*4.4 UU (Unconsolidated Undrained) Test*

In laboratory, UU triaxial shear tests were carried out on height of the sample 7.62 cm with diameter of the sample 3.82 cm, having an area and volume of specimens of 11.4 $cm^2$ and 87 $cm^3$. Minimum three specimens were prepared for each combination of variables (50 kPa, 100 kPa, 150 kPa ) at a deformation rate of 0.125 mm/min specimens as per IS: 2720 (Part XI)-1993 [10]. According to their respective mixture of fly ash and PRP's MDD and OMC for the preparation of samples for both the cases fly ash and mixture of fly ash with PRPs are used. The failure pattern in both case of fly ash and mixture of fly ash with PRPs (50%) is shown in Fig. 11.

The normal stress varied in the range of 50 kPa, 100 kPa, and 150 kPa. Specimens were tested under the saturated condition. This may be a manifestation of the ductile behavior induced by both the confining pressure and the fiber inclusions. For determination of the total stress shear strength parameters $C_{uu}$ and $\O_{uu}$, the variation of stress versus percentage strain is shown in Figs. 11 and 13.

The variation of PRPs in different percentage gives the variations of cohesion (*c*) and also angle of internal friction (*ø*) are shown in Table 7.

Fig. 11 UU test samples.

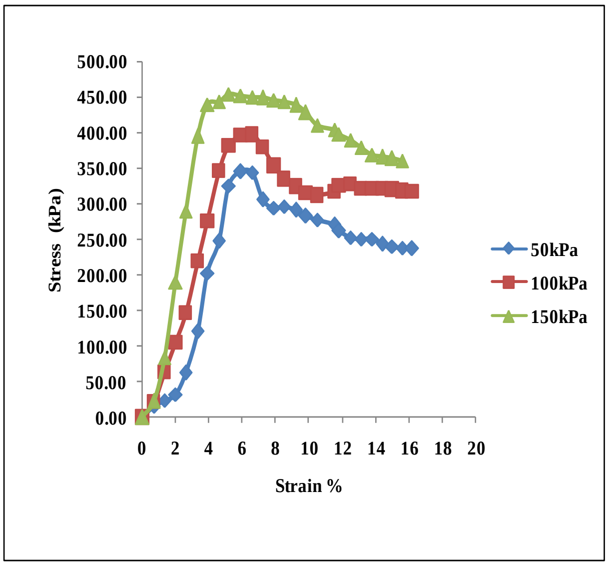


**Fig. 12 Stress strain variation of UU test on fly ash.**

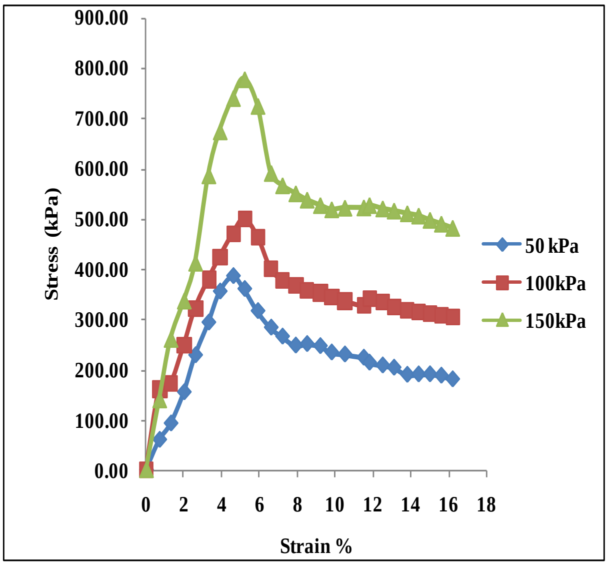


**Fig. 13 Stress strain variation (UU) test on fly ash with PRPs 50%.**

**Table 7 UU test.**

| PRP's percentage (%) | Cohesion ($c$) (kPa) | Angle of internal friction ($\phi$) (°) |
|---|---|---|
| 0 | 29.00 | 20.04 |
| 25 | 36.73 | 35.55 |
| 50 | 16.11 | 40.10 |
| 75 | 34.81 | 31.20 |

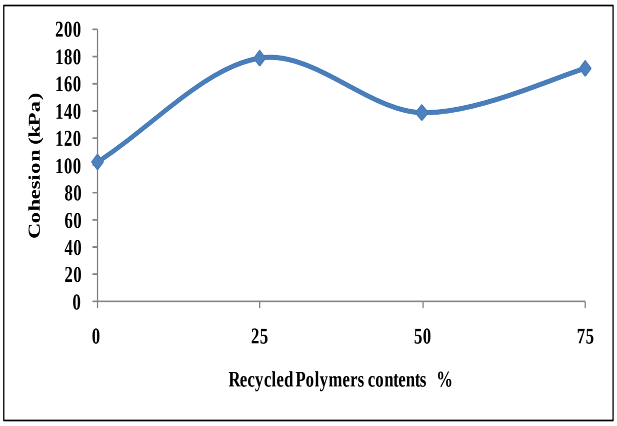


**Fig. 14 PRP percentage vs. cohesion ($c$) (kPa).**

The variation of angle of internal friction ($\phi$) and cohesion ($c$) with respect to PRP's content in percentage is shown in Fig. 14 respectively.

This is because of partially saturated fly and mixture of fly ash with PRPs that is why the angle of internal friction has been taken into consideration.

## 5. Conclusions

Fly ash is a waste material imposing hazardous effect on environment and human health. Also it cannot be disposed of properly and its disposal is not economically viable but if it is mixed with other materials like PRPs then it can be used best for construction of embankments. This feasibility study is aimed at improving the properties of fly ash to be suitable for embankment's construction. Based upon the above study following conclusions can be drawn:

(1) In light compaction test (Standard Proctor) compaction characteristics of the fly ash with PRPs in different mixing proportion shows that PRP's inclusions increased the MDD beyond 50% mixes after MDD was decreased.

(2) In the case of the UU tests, the deviator stress attained a peak value at axial strains in the range of 4%-8% and thereafter remained almost constant. This may be a manifestation of the ductile behavior induced by both the confining pressure and the PRP's inclusions. In unconfined compression tests, the raw fly ash specimens attained a distinct axial failure stress at a strain. The PRP's inclusions increased the failure deviator stress and the shear strength parameters $C_{uu}$ and $Ø_{uu}$.

(3) The increase in shear strength parameter was also found in the case of direct shear test for fly ash and fly ash with PRPs having different mix proportions.

(4) In addition to increasing content of PRPs in fly ash, MDD of mixtures initially increases then it starts decreasing and OMC of fly ash increases in addition to increasing content of PRPs in it. The MDD was found to be at 50% mixing proportion of fly and PRPs.

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