Chapter 4

STRENGTH CHARACTERISTICS OF CYLINDER, BLOCK AND MASONRY

4.1 General

This chapter deals with the analysis of experimental investigations conducted to ascertain the influence of combinations and compositions of Soil, Cement, Fibre and Moulding pressure, on the strength characteristics of cylinder, block and masonry. Experiments were conducted for different Moulding pressures, Cement content, types of Fibre, their length and volume to determine the Density, Compressive strength, Tensile strength. The role of each ingredient and its properties, on these variables was investigated. Determination of the Masonry strength has been done using Masonry prisms. Results of the experiments by varying the constituents, their proportions, properties and Moulding pressure are analysed to
understand the behaviour of Plastic Fibre Reinforced Soil blocks and that of the masonry system made out of these blocks.

4.2 Density

Dry density of samples with different composition (three samples for each composition) is determined after drying it in an oven at a temperature of 105°C. The results are analysed for the effect of Moulding pressure, Cement content, Fibre type, its length and volume as described below.

4.2.1 Effect of Moulding Pressure

Fig 4.1 shows the effect of Moulding pressure on the dry density. For given Cement content, as Moulding pressure increases, the dry density increases. The marked increase in density witnessed in modified specimens could have been due to the following factors like (i) Pore filling effect (ii) Increased homogeneity (iii) Improved bonding and also (iv) Reduced voids. The measured Density was found to vary between 1.846 to 1.958g/cc. These values are in conformity with the desirable limit, for producing a stabilized mud block, which is specified as 1.8 to 1.85g/cc (Jagadish, 2007). The density was found to be 1.805 to 1.894g/cc, in the preliminary studies on the mud blocks, which were made, using ASTRAM. In the present study, these values correspond to a Moulding pressure of 1.25MPa. There is an increase in density about 6 % when the Moulding pressure is increased from 1.25 to 7.5MPa.
4.2.2 Effect of Cement Content

The effect of Cement content on dry density was investigated, for given Moulding pressure and different Fibre properties. The curves are shown in Fig 4.2(a) which corresponds to a low Moulding pressure of 1.25MPa and for Kit fibres. Fig 4.2(b) corresponds to that of Bottle fibres. The fibres do not contribute much for the improvement of density. Higher the length of fibre or its content, the value of density is reduced. However this reduction is compensated by increasing the Moulding pressure. The rate of increase in density is pronounced when the moulding pressure is increased.
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Fig 4.2 (a) Effect of Cement content on dry density
(Moulding pressure 1.25MPa; Kit fibre)

Fig 4.2 (b) Effect of Cement content on dry density
(Moulding pressure 1.25MPa; Bottle fibre)
Fig 4.2(c) reveals the effect of Moulding pressure as high as 7.5MPa and for the Kit fibre properties on the Density. The effect of the Bottle fibre properties on density is shown in Fig 4.2(d). From these figures, it is evident that increase in the Cement content enables the fibres to recoup density, but not that much as in the case of increase in the Moulding pressure. When the Cement content was increased from 0 to 15%, there was an increase of 2.2 to 3.7% in the density. Choudhary (2004) in a study has reported that Cement content has little effect on the block density. The small increment attained in the study may be due to the higher specific gravity and the use of 43grade Cement.

![Fig 4.2 (c) Effect of Cement and fibre content on dry density (Moulding pressure 7.5MPa; Kit fibre)](image-url)
4.2.3 Effect of the Type of Fibre, its Length and Content

From Fig 4.2, it is evident that any addition of fibre reduces the density and Table 4.1 gives the percentage reduction in the density, for different type, length and quantity of Fibre. It is clear from the table that effect of the Fibre content was less pronounced on the density of the specimens. However there is only a small decrease in the density, over a range of 0 to 1.87%. This is because of the low specific gravity of the Fibres, the values being 1.10 for Kit fibre and 1.17 for Bottle fibre. Similar type of observation is made by Chee-Ming Chan [2011] in a study using natural fibres in clay bricks. It can be observed from Fig 4.2 and
Table 4.1 that, a maximum reduction of 1.87% in density occurs at a higher content of Bottle fibre, for a low Moulding pressure of 1.25MPa and without Cement. For a higher Moulding pressure of 7.5MPa and a Cement content of 15%, there was no reduction in density. The loose state of fibres at low Moulding pressures and for low Cement content may be the reasons for the decrease in density.

Low moulding pressure, leaves behind air spaces in the specimen, makes the specimens loose and less dense. Higher compacting energy enables the particles to come closer reducing, the voids. The specimens thus become denser. Due to this, the bond between the Fibres and the Soil would be increased in the presence of Cement.

**Table 4.1 Percentage Reduction in Density for different Fibre content and length**

<table>
<thead>
<tr>
<th>Cement content (%)</th>
<th>Moulding pressure (MPa)</th>
<th>Type of fibre</th>
<th>Reduction in density (%) for fibre length</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 cm (0.1%), 2 cm (0.2%)</td>
</tr>
<tr>
<td></td>
<td>1.25</td>
<td>Kit</td>
<td>0.16, 0.64</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bottle</td>
<td>0.64, 1.02</td>
</tr>
<tr>
<td>0</td>
<td>7.5</td>
<td>Kit</td>
<td>0.47, 0.73</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bottle</td>
<td>0.57, 0.94</td>
</tr>
<tr>
<td>15</td>
<td>1.25</td>
<td>Kit</td>
<td>0.31, 0.21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bottle</td>
<td>0.14, 0.31</td>
</tr>
<tr>
<td></td>
<td>7.5</td>
<td>Kit</td>
<td>0.2, 0.39</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bottle</td>
<td>0.39, 0.25</td>
</tr>
</tbody>
</table>
4.3 Compressive Strength of Cylindrical Specimens

Cylindrical samples of diameter 101.5mm and height 117mm were prepared and the tests have been carried out. The tests were conducted on cylindrical samples to correlate the values of Compressive strength with that of Tensile strength (by Split Tension test). The sample will be a relevant replica, on the engineering properties of the soil, as the value of dry density and OMC has been found out using Proctor mould for light compaction.

4.3.1 Effect of Moulding Pressure

The effect of Moulding pressure on Compressive strength is shown in Fig 4.3.

![Fig 4.3 Effect of Moulding pressure on Compressive strength](image-url)
In general, as the Moulding pressure is increased, the Compressive strength increases. About 20 to 50% increase in the Compressive strength was observed when the Moulding pressure was increased from 1.25 to 7.5MPa. A study reported by Riza et al. (2011) concluded that by increasing the compacting pressure from 5 to 20MPa, improves the Compressive strength up to 70%. Bahar (2004) in his study reported that dry Compressive strength increases with the Static applied stress. About 60% increase of the dry Compressive strength was obtained when the applied Static stress was increased from 2.1 to 7.3MPa (Bahar, 2004). For given Compaction pressure, as the Cement content is increased, there resulted an increase in the Compressive strength. Effectiveness of Cement content was more at higher Moulding pressures compared to the lower pressures. However, for a Moulding pressure more than 5MPa, the rate of increase in strength reduces. This may be due to a reduced water for the hydration of Cement as it was observed that some water in the samples comes out at higher Moulding pressures. It is seen that, the Compressive strength can be improved from 2.5 to 3.7MPa by increasing the Moulding pressure and with addition of 10% of Cement.

### 4.3.2 Effect of Cement Content

Fig 4.4 shows the variation of Compressive strength of the specimens with Cement content, for different Moulding pressures. There was an increase in the Compressive strength, with an increase in the Cement content for any Moulding pressure. Due to the Cement addition
alone, there was an increase of 38 to 58% in the Compressive strength, for Moulding pressures of 1.25 to 7.5MPa. For given Cement content, as Moulding pressure increases, Compressive strength also increases. This increase in Compressive strength is more significant for Cement content up to 10% and beyond 10%, the effectiveness of Cement addition was not substantial for any Moulding pressure. This may be due to the lesser Fibre Cement ratio in the Soil Cement matrix. The final strength of the specimens appears to be more sensitive to changes in Cement content than Moulding pressure. This improved strength may be attributed to the (i) Pore filling effect (ii) Increased homogeneity and (iii) Improved bonding.

![Fig 4.4 Effect of Cement content on Compressive strength](image)
4.3.3 Effect of Type of Fibre

The effect of the fibre type on the Compressive strength is shown from Fig. 4.5(a) to Fig. 4.5(c). Fig 4.5(a) reveals that, any addition of fibre in the raw soil reduces the strength, as all the lines are below the thick line which corresponds to the specimens without fibre, up to a Moulding pressure of 5MPa for Bottle fibres and up to 2.5 to 3.7MPa for Kit fibres. However at higher Moulding pressures, the addition of these fibres improves the strength. There seems an inhibition on the part of fibres, in assisting the soil to take more Compression at low Moulding pressures. The reduction in strength may be due to the lack of proper bond between the fibres and the Soil at low pressures. It also affects the Soil homogeneity, which would have caused a reduction in the strength.
As Moulding pressure increases, the bond is improved and the strength has increased correspondingly. In the case of specimens stabilised with Cement, all fibres performed better even at lower Moulding pressures which are evident from Fig 4.5(b) and Fig 4.5(c). This may be attributed to an increased bond between the Soil and the Fibres in the presence of Cement. Cement contributes much, for an increase in the Compressive strength. This strength gain is again supported by increasing the Moulding pressure. The presence of fibres adds to the value of Compressive strength, with the help of Cement and Moulding pressure. Even though the role of fibres in increasing the compressive strength is subsequent to that of Cement and Moulding pressure, it contributes a substantial percentage of increase in compressive strength, especially at higher Moulding pressure, and with optimum quantity of Cement.

![Fig 4.5 (b) Effect of fibre and Moulding pressure on Compressive strength (7.5 % Cement)](image-url)
Regarding the type of Fibres, those made out of carry bags (Kit fibres) are found to be more effective. Fig 4.5(a) to Fig 4.5(c) establishes this fact. This may be due to the fact that, these fibres are flexible and while making the specimens, they bend and cause better bond in the Soil Cement matrix (Fig 4.6). Lesser efficiency of fibres made out of Bottle (Fig 4.7) may be due to the following reasons: i) The type of surface finish which results in lack of bond with Soil ii) Due to the stiffness of the fibres, during mechanical compression, the soil particles may laterally move apart, leaving behind air spaces between the Fibres and the Soil. This may result in the formation of weaker planes.
This relaxation of Fibres may be reduced by moulding the block at higher Moulding pressures and the stabilization of Soil using Cement, as seen from the test results.

Fig 4.7 Effect of type of Fibre and Cement content on Compressive strength
4.3.4 Effect of length of the Fibre and its Quantity

The effect of length of the fibre and its quantity on the Compressive strength, for different Moulding pressures is shown in Fig 4.8(a) and Fig 4.8(b). From these figures, it is evident that, the fibres having a length of 2 cm and a weight of 0.2% by the weight of Soil, adversely affect the Strength performance of the specimens considerably. Further, the presence of higher percentage of longer Bottle fibres showed inconsistent results.

![Graph showing the effect of fibre content and length on compressive strength](image)

**Fig 4.8 (a) Effect of fibre content and length on the Compressive strength (7.5% Cement and Bottle fibre)**

The Fibres made out of carry bags (Kit fibres) showed better performance when the length is increased. This may be due to the fact
that, as the length of fibre is increased from 1 to 2cm, the bond between Fibres and the Soil is increased. This increase in bond is attributed to the fact that, while making the specimens they bend and cause better bond in the Soil Cement matrix, as these fibres are more flexible in nature. For the Kit fibres at higher volumes, there was a reduction in strength even though the behaviour is consistent. This reduction may be due to non-uniform distribution of the large quantity of fibres present in the specimens, thus leading to the formation of weaker planes.

Fig 4.8 (b) Effect of fibre content and length on Compressive strength (7.5% Cement and Kit fibre)

4.3.5 Percentage Increase in Strength

The Compressive strength of the specimens after 28 days of curing, was found to vary from 1.99 to 4.40MPa for different
combinations of the stabilisers (Cement and Moulding pressures), the type of fibres, the length of fibres and their volume. The variation in the Strength in percentage, by the effect of Stabilisation, the addition of Fibres, and the Moulding pressure with respect to that of the raw Soil samples are shown in Table 4.2. The table displays the extremities of values, considering the worst case of using Bottle fibres, 2cm long, 0.2% by weight of the dry Soil and an ideal case of using Kit fibres, 2cm long, 0.1% by weight of the dry Soil.

Table 4.2 Percentage increase in the Compressive Strength

<table>
<thead>
<tr>
<th>Moulding pressure (MPa)</th>
<th>% increase in Strength compared to raw Soil specimens (1.99MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fibre Content and Length</td>
</tr>
<tr>
<td></td>
<td>Cement C (%)</td>
</tr>
<tr>
<td></td>
<td>0 5 7.5 10 15</td>
</tr>
<tr>
<td>Lower P (1.25)</td>
<td>Nil 0 13 20 26 38</td>
</tr>
<tr>
<td>2B2</td>
<td>-16 -17 -15 9 25</td>
</tr>
<tr>
<td>2K1</td>
<td>- 6 20 59 64 73</td>
</tr>
<tr>
<td>Higher 6P (7.5)</td>
<td>Nil 25 49 50 86 97</td>
</tr>
<tr>
<td>2B2</td>
<td>23 18 22 52 71</td>
</tr>
<tr>
<td>2K1</td>
<td>50 70 89 118 121</td>
</tr>
</tbody>
</table>

P→ Moulding pressure of 1.25MPa
2B2→ Bottle fibre 2cm long, 0.2% weight of Soil
2K1→ Kit fibre 2cm long, 0.1% weight of Soil

The role of Cement is significant, at this context, as it acts as an internal reactive stabilizer to enhance the Compressive strength (Primary stabilisation). The applied Compacting or Moulding pressure increases the strength, by acting as an external active stabiliser (Secondary stabilisation). The Fibres could increase the strength, only in the presence
of Cement and Moulding pressure, hence they act as internal embedded passive stabilisers (Tertiary stabilisation).

Compared to the raw Soil specimens, the Fibre reinforced stabilised Soil samples have shown an apparent increase of 20 to 121% in the Compressive strength. However in reality, the effect of fibres is pronounced in Kit fibres having 2cm length and 0.1% by weight of the dry Soil. An optimum Cement content of 7.5% by weight of the dry Soil is required to meet the minimum requirement of strength. The maximum quantity of Cement may be limited to 10% by weight of the dry Soil, considering the rate of increase in the strength and the cost. The practical combinations of the variables are given in Table 4.3.

<table>
<thead>
<tr>
<th>Cement Content (%)</th>
<th>Moulding Pressure(MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.25</td>
</tr>
<tr>
<td>0</td>
<td>-6(NA)</td>
</tr>
<tr>
<td>7.5</td>
<td>59</td>
</tr>
<tr>
<td>10</td>
<td>64</td>
</tr>
</tbody>
</table>

Compared to the stabilised samples, the Fibre reinforced stabilised samples showed an increase of 59 to 89 % in the Compressive strength, for a Cement content of 7.5% and 64 to 118%, in the case of a Cement content of 10%, for the range of Moulding pressures from 1.25 to
7.5MPa. The Kit fibres exhibit consistent behaviour and produce reliable results on the Soil, which was selected for the study.

Based on the wet Compressive strength, stabilised blocks may be classified in to three grades viz. (i) Grade 4 with strength range 4 to 5MPa (ii) Grade 3 with strength range 3 to 4MPa (iii) Grade 2.5 with range 2.5 to 3MPa (Jagadish, 2007). Stabilised samples and Fibre reinforced stabilised samples at higher Moulding pressure showed strength values of 3.5 to 4.40MPa, a value which is in conformity with that of minimum Compressive strength of 3.5MPa, for a well burnt brick as per BIS 1077-1992. As per BIS 1725-1982, the blocks which are to be used in general building construction when tested in accordance with the procedure laid in the standards, viz. BIS 3495 (Part I), 1976 shall have a minimum average Compressive strength of not less than 20kgf/cm² for Class 20 and 30kgf/cm² for Class 30.

4.3.6 Effect of Density

Fig 4.9 shows the variation of Compressive strength with the density of the specimens at service condition. Obviously, the Compressive strength increases with the density. For given density, specimens containing fibres made out of carry bag (Kit fibres) showed higher strength compared to those with Bottle fibres. The specimens without fibres showed the least strength for given density. But at lower density level, specimens with Bottle fibres showed lower strength than
those without fibre. But specimens containing Kit fibres performed better than other types, for all density level. This observation once again points towards the better performance of Kit fibres compared to that of the Bottle fibres.

![Graph showing variation of strength with density](image)

**Fig 4.9 Variation of strength with density**

### 4.4 Compressive Strength of Blocks

Investigations have been done on Unstabilised, Stabilised and Fibre stabilised blocks of size 305x143x100mm. The results are very much akin to that of the cylindrical samples. As the characteristic curves are identical to that of the cylindrical samples, with a modification factor, they are not presented here to avoid duplication and repetition. The
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Compressive strength of the blocks was found to vary from 1.74 to 5.5MPa for different Cement content, Moulding pressure, type, length and volume of Fibres. Compared to the Compressive strength of cylindrical specimens, all blocks are having higher Compressive strength. The ratio of block strength to cylinder strength ranges from 1.068 to 1.247. This increase in strength (6.8 to 24.8 %) may be due to the platen effect, that is due to friction along the interface between the platen and test specimen, lateral expansion of the specimen is confined. This confinement of specimens by platen restraint increases apparent strength of the material (Walker, 2004; Morel et al. 2007; Piattoni et al. 2011). Also, with the decrement of the aspect ratio, there is an increment of the contact surface between the specimens and the platens (for cylindrical specimens, the contact area is circular with 101.5 mm diameter and for blocks, it is a rectangular area of 305 x 143 mm) and therefore there are big values of the tangential force caused by friction (Piattoni et al. 2011). As the distance between the platens, relative to the specimen thickness (aspect ratio) increases, the platen restraint effect reduces (Morel et al. 2007). Aspect ratio of the cylinders and blocks are 1.153 and 0.70 respectively. Jagadish (2007) reports that about 20% increase in strength may be expected for a 25% decrease in thickness. A sample comparison of Cylinder strength to Block strength, for an optimum Cement content of
7.5%, at different Moulding pressures, without any Fibre, is shown in Fig4.10(a).

![Fig 4.10(a) Comparison of Cylinder Strength to Block Strength (Cement 7.5%, No fibre)](image)

To highlight the performance of Kit fibres compared to that of the Bottle fibres, a sample comparison of the Compressive strength of the cylinder and that of the block obtained by using these fibres is shown in Fig 4.10(b) and Fig 4.10(c). From Fig 4.10(b), it is observed that the Bottle fibres, if used in large quantity and at a longer length, affect the strength. As these fibres are stiff, they may exercise a rebound, during the compaction, which would have resulted in a reduction in the Compressive strength. Lack of sufficient bond with Soil Cement matrix may also be another reason. Fig.4.10(c) gives a clear indication of the pronounced influence of Kit fibres, on increasing the Compressive strength. As these
fibres are flexible and longer, they bend and curl facilitating better bond with Soil Cement matrix. There will not be a rebound effect during the compaction, since the fibres are not stiff.

**Fig 4.10(b) Comparison of Cylinder Strength to Block Strength (Cement 7.5%, 2cm long Bottle fibre, 0.2%)**

**Fig 4.10(c) Comparison of Cylinder Strength to Block Strength (Cement 7.5%, 2cm long Kit fibre, 0.1%)**
Fig. 4.11 compares the effect of Fibre properties on the block Compressive strength. As the Kit fibres show better performance compared to that of the Bottle fibres, the extreme values of the two have been taken for the comparison. The performance of Blocks with no addition of fibres is also shown in the figure, to have the reference or base value.

4.5 Split Tensile Strength

The effect on the Split tensile strength, by varying Moulding pressure, varying Cement content and varying the type, quantity and the length of Fibres, has been studied. Fig 4.12 depicts the effect of Cement content on the Tensile strength for various Moulding pressures. There
results a continuous increase in the Tensile strength corresponding to an increase in the Cement content. When Cement content increases, the Tensile strength increases (Fig 4.13 and Fig 4.14), for given Moulding pressure. There is significant rise in the Tensile strength when the Cement content is increased, and the increase is supported by higher moulding pressures. The rate of increase is higher at higher values of Cement content, unlike in the case of compression, where the rate of increment is less beyond a Cement content of 10%. The rate of gain in Tensile strength is almost constant, in the case of Moulding pressure variation, from lower to higher.

Fig 4.12 Effect of Cement content on Split tensile strength
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Fig 4.13 Effect of Cement and Fibre content on Tensile strength
(1cm long Bottle fibre, 0.1%)

Fig 4.14 Effect of Cement and Fibre content on Tensile strength
(1cm long Kit fibre, 0.1%)
For low Moulding pressure, even though the fibres fail to increase the Tensile strength of the raw soil specimens, at higher pressures they enhance the Tensile strength even in the absence of Cement, unlike in the case of Compressive strength, where fibres are inert at low Moulding pressures and passive at higher pressures. However, they are partially active in the case of Tension. Fig 4.13 depicts the behaviour of Bottle fibres for smaller quantity and length, for different Cement content and Moulding pressures. Fig 4.14 details the features of Kit fibre for the same condition. Both of them help in improving the tensile properties of the specimens. The rate of increase in the Tensile strength is more for Bottle fibres than that for the Kit fibres.

Fig 4.15 Effect of Cement and Fibre content on Tensile strength (1cm long Bottle Fibre, 0.2%)
Fig 4.15 shows, how higher percentage of shorter Bottle fibres improves the Tensile strength. There exists an increase in Tensile strength for given length with higher fibre content. This effect is less pronounced in the case of Kit fibres (Fig 4.16). However at lower pressures also, they help the raw specimens to have higher values, once reinforced. Fig 4.17 highlights the role of fewer amount of long Bottle fibres, in enabling the specimens to have high tensile strength values. Raw soil specimens embedded with Bottle fibres take more tension both in low and high Moulding pressures. Longer the fibres, more the effectiveness will be. From Fig 4.18, long Kit fibres perform similar to the Bottle fibres at high Cement content and at higher Moulding pressures. However strength gain in the case of long Bottle fibres is consistent irrespective of magnitude of Cement content and Moulding pressure. Lesser quantity of long fibres picks up strength early, where gain and rate of gain in the strength is considerable. The fibres prove that, they can even replace a certain quantity of Cement, for given value of the Tensile strength. Bottle fibres are versatile in tension and they perform better even at low Moulding pressure and at low Cement content.
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**Fig 4.16 Effect of Cement and Fibre content on Tensile strength**

(1cm long Kit Fibre, 0.2%)

- 7.5% Cement
- 10% Cement
- 15% Cement

**Fig 4.17 Effect of Cement and Fibre content on Tensile strength**

(2cm long Bottle fibre, 0.1%)

- 7.5% Cement
- 10% Cement
- 15% Cement

**Moulding pressure (MPa)**

- Raw soil
- Soil & Fibre

**Split tensile strength (MPa)**

- Kit fibre: Length = 1 cm, Quantity = 0.2%
- Bottle fibre: Length = 2 cm, Quantity = 0.1%
Kit fibres enable the raw soil specimen to enhance its Tensile strength, even at low Moulding pressures. When the Moulding pressure is high, there exists a significant rise in the strength value, even in the absence of Cement. Hence the effect of Fibres, on the Tensile property of the specimen, is pronounced. The rate of increase in these values is higher in the presence of Cement. Higher Moulding pressure helps the fibres, to enable the specimens to take more Tension, in the presence of Cement.

**Fig 4.18 Effect of Cement and Fibre content on Tensile strength**

(2 cm long Kit fibre, 0.1%)
Fig 4.19 Effect of Cement and Fibre content on Tensile strength
(2cm long Bottle fibre, 0.2%)

Fig 4.20 Effect of Cement and Fibre content on Tensile strength
(2 cm long Kit fibre, 0.2%)
Fig 4.19 represents the behaviour of high quantity of long Bottle fibres. The performance of these fibres in Tension is high, unlike that in Compression. Interestingly, the Kit fibres of larger quantity and length behave similarly (Fig 4.20).

The role of Bottle fibres on influencing the Tensile strength is shown in Fig 4.21. The effect of Kit fibre on the Tensile strength is shown in Fig 4.22 and Fig 4.23. From these figures the following observations can be made: As Moulding pressure increases, Split tensile strength increases. Addition of Fibre increases the Split tensile strength. This increase in strength depends upon the Moulding pressure. As Moulding pressure increases, the effectiveness of fibres, in bringing up the Split tensile strength, increases. Similarly as Cement content increases, the effectiveness of fibres in improving the Split tensile strength, is increased. For given fibre length, increase in the percentage of fibre content, improves the Tensile strength. Similarly for given content of fibre, as the length of the fibre increases, tensile strength is increased.
As far as the tensile behaviour of Plastic Reinforced Soil samples is concerned, it is observed that, both the type of fibres (Kit and Bottle) performed in a similar way, by way of improving the Tensile strength of specimens. Improved bond between the Fibres and Soil Cement matrix due to the increased Cement content, higher Moulding pressure and increased length of fibres are responsible for better performance of Plastic Fibre Reinforced Soil in Tension.
Fig 4.22 Effect of Fibre content on Tensile strength
(1cm long Kit fibre 0.1%)

Fig 4.23 Effect of Fibre content on Tensile strength
(2cm long Kit fibre 0.2%)
Fig 4.24 (a) Correlation between Compressive strength and Tensile strength (Specimens without Fibre)

No fibre
\[ t = 0.174 c - 0.225 \]
\[ R^2 = 0.862 \]

Fig 4.24 (b) Correlation between Compressive strength and Tensile strength (Specimens with Bottle fibre)

Bottle Fibre
\[ t = 0.189 c - 0.131 \]
\[ R^2 = 0.701 \]
In the case of samples without fibre, a good relationship exists between the Compressive strength (c) and the Tensile strength (t) of the samples [Fig 24(a)]. This fact is evident from the regression equation, given as \( t = 0.174c - 0.225 \); \( R^2 = 0.862 \). Though scattered, there exists a good correlation between the Compressive strength and the Tensile strength \( t = 0.189c - 0.131 \); \( R^2 = 0.701 \) in the case of Bottle fibres[Fig 24(b)] and \( t = 0.185c - 0.196 \); \( R^2 = 0.739 \) for the Kit fibres [Fig 24(c)]. But from the regression equations it can be seen that, for given Compressive strength, samples with fibres gave more tensile strength than that without fibre. A comparison of Tensile strength, achieved by using the fibres is shown in Fig.4.25. Bottle fibres seem to be showing better performance than Kit fibres. This may be due to their higher stiffness and tensile strength than that of the Kit fibres.
The Kit fibres having a length of 2cm and weight 0.1% of the dry soil perform well in both Tension and Compression. Bottle fibres of the same length and the quantity are not contributing to the Compressive strength, where as they impart greater Tensile strength to the specimens. The Compacted Reinforced Cement Stabilised specimens show an increase of 4.5 times the tensile strength of the raw Soil specimen. This is one of the major advantages of adding fibres to the Stablised soil specimens

**4.6 compressive Strength of Masonry**

Results of the Compressive strength of masonry, made out of the blocks of different combination of Cement, Moulding pressure and Fibres are given in Table 4.4 and Table 4.5. The variation in Compressive strength of the masonry as a function of the block strength is shown in Fig 4.26.
### Table 4.4 Relation between masonry and block strength
(Cement content 10%, Moulding pressure 1.25MPa)

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Details of Fibre in the block</th>
<th>Compressive strength (MPa)</th>
<th>Reduction factor (M / L)</th>
<th>Strain at Ultimate stress of masonry (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type of Fibre</td>
<td>Length (cm)</td>
<td>Fibre content (%)</td>
<td>Block (L)</td>
</tr>
<tr>
<td>1</td>
<td>No Fibre</td>
<td>-</td>
<td>0</td>
<td>2.94</td>
</tr>
<tr>
<td>2</td>
<td>Kit</td>
<td>1</td>
<td>0.1</td>
<td>3.3</td>
</tr>
<tr>
<td>3</td>
<td>Kit</td>
<td>1</td>
<td>0.2</td>
<td>3.33</td>
</tr>
<tr>
<td>4</td>
<td>Kit</td>
<td>2</td>
<td>0.1</td>
<td>3.59</td>
</tr>
<tr>
<td>5</td>
<td>Kit</td>
<td>2</td>
<td>0.2</td>
<td>2.66</td>
</tr>
<tr>
<td>6</td>
<td>Bottle</td>
<td>1</td>
<td>0.1</td>
<td>3.15</td>
</tr>
<tr>
<td>7</td>
<td>Bottle</td>
<td>1</td>
<td>0.2</td>
<td>3.18</td>
</tr>
<tr>
<td>8</td>
<td>Bottle</td>
<td>2</td>
<td>0.1</td>
<td>3.16</td>
</tr>
<tr>
<td>9</td>
<td>Bottle</td>
<td>2</td>
<td>0.2</td>
<td>2.5</td>
</tr>
</tbody>
</table>

### Table 4.5 Relation between masonry and block strength
(Cement content 10%, Moulding pressure 7.5MPa)

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Details of Fibre in the block</th>
<th>Compressive strength (MPa)</th>
<th>Reduction factor (M / L)</th>
<th>Strain at Ultimate stress of masonry (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type of Fibre</td>
<td>Length (cm)</td>
<td>Fibre content (%)</td>
<td>Block (L)</td>
</tr>
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<td>No Fibre</td>
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<td>4.44</td>
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<td>Kit</td>
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<td>5.09</td>
</tr>
<tr>
<td>3</td>
<td>Kit</td>
<td>1</td>
<td>0.2</td>
<td>5.26</td>
</tr>
<tr>
<td>4</td>
<td>Kit</td>
<td>2</td>
<td>0.1</td>
<td>5.34</td>
</tr>
<tr>
<td>5</td>
<td>Kit</td>
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<td>0.2</td>
<td>4.33</td>
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<td>4.85</td>
</tr>
<tr>
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</tr>
<tr>
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<td>Bottle</td>
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<td>4.86</td>
</tr>
<tr>
<td>9</td>
<td>Bottle</td>
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<td>0.2</td>
<td>3.66</td>
</tr>
</tbody>
</table>
Compressive strength of masonry increases with an increase in block strength. For given Cement content, the ratio of masonry strength to block strength was found to vary from 0.38 to 0.52 and 0.45 to 0.72 for specimens subjected to low and high Moulding pressure respectively. Similar observations were also made, by Walker (2004) that the masonry Compressive strength varied between 34% and 96% of unconfined block strength. The prisms failed by developing vertical splitting cracks parallel to the loading direction. Hendry (1990) reports that the Compressive strength of masonry is roughly the square root of the unit strength and very poorly related to mortar cube strength. The results of the study by Reddy and Gupta (2006), where the block strength ranges between 3 and 8MPa, show that for Stabilised Mud block (SMB) masonry, the
Compressive strength went up, by about 4 times as the block strength is increased by 2.3 times. That is, the increase in masonry strength is proportional to the increase in the block strength.

Typical stress-strain relationship for the mud block masonry using mud blocks with different fibre length, quantity and types at 10% Cement content and at high Moulding pressure (7.5MPa) is shown in Fig 4.27(a) and Fig 4.27(b). For given Cement content, the ultimate stress increases with the addition of fibre content. Also strains at ultimate stress for masonry are more for blocks containing fibres (Table 4.4 and Table 4.5).
Above observation shows that the Fibre mud block masonry behaves more ductile and can store more elastic energy compared to the mud blocks without fibre. This renders it more resistance to earthquake forces. Hence the fibre reinforced mud brick is more advantageous compared to the conventional brick. Similar observations were made by Binici et al. (2005).

4.7 Analysis of Failure Pattern

The failure of specimens made of raw Soil was very quick without warning both in compression and tension (Fig 4.28), in contrast to the compression test of blocks with fibres. The deformation of these
specimens still continued, even after the ultimate load, and fine cracks could be seen on the specimens. Unlike raw Soil specimens, those with fibres showed fine irregular but distinguishable cracks on its surface (Fig 4.29). Similar observations were made by Marandi et al. (2008) in a study on strength and ductility of randomly distributed palm fibre reinforced silty sand soil and by Gelan-Marin et al. (2010) in a study on clay based composites with natural polymer and fibre. After failure, the Soil fibre composite was not disintegrated completely in contrast to the specimens with raw Soil. This behaviour is seen in the split tensile tests, the two halves of raw blocks fall apart on breaking, where as the specimens with fibre reinforcement stay intact (Fig 4.29), similar to the observations made by Oliver and Gharbi (1995). This behaviour was found more evident in samples with Kit fibre as shown in Fig 4.30(a). In the case of samples with Bottle fibres, slipping of the fibres from the soil cement is likely to happen due to poor bond, as seen in Fig 4.30(b) and Fig 4.31. From the observations of failure pattern, it can be concluded that benefits of fibre reinforcement includes both improved ductility and inhibition of large crack propagation after initial formation.

All the prisms have failed by developing vertical splitting cracks parallel to the loading direction. This can be explained as follows. In compression greater lateral expansion of the mortar joint places the blocks in
a state of compression and biaxial lateral tension (Walker, 1995; Moral et al. 2007; Hendry, 1990), whereas restraint of the blocks places the mortar joint in a state of tri-axial compression. So in uni-axial compression, masonry typically fails by vertical splitting, as a result of lateral tension developed in the units (Walker, 1995). This vertical tensile cracking is between 50 and 95% of the ultimate load, preceded by more general crushing of the prism (Walker, 2004). It can be observed that the masonry without fibre addition failed with the sudden enlargement of the initially formed crack and failure was all of a sudden without giving any warning (Fig 4.32). But the masonry specimens with fibre, instead of enlargement of a single crack, fine cracks were developed on its surface and the failure is due to cracks spreading in the whole structure giving enough warning before collapse thus demonstrating the ductile behaviour of Masonry (Fig 4.33). Marandi et al. (2008), after studying the behaviour of fibre reinforced blocks, suggests that, adding fibers to a soil medium that exhibits brittle material properties results in greater fiber connection and replacement of a portion of soil by elastic material. They have found that the soil becomes softer, the elasticity of the medium increases and as a result, the specimens fail at higher axial strains. Similar behaviour can be expected in masonry system, which is made out of fibre reinforced blocks.
Fig 4.28 Failure pattern in Compression and Tension (No Fibre)

Fig 4.29 Failure pattern in Compression (samples with Kit fibre)
Strength Characteristics of Cylinder, Block, and Masonry

Fig 4.30 Failure pattern in Tension

(a) Kit fibre  (b) Bottle fibre

Fig 4.31 Slipping of Bottle fibre from Soil Cement matrix
Fig 4.32 Failure of masonry prism (blocks without Kit fibre)

Fig 4.33 Failure of masonry prism (blocks with Kit fibre)
4.8 Summary

The influence of composition (basic parameters) viz. Moulding pressure, Cement content, Fibre type, length and quantity, on the density and strength of mud blocks has been studied. Effect of fibre addition on the Compressive strength of block masonry was also evaluated by studying the stress strain characteristics. Stabilised samples and fibre reinforced stabilized samples at higher Moulding pressure showed a strength values of 3.5 to 4.41MPa in the case of cylinders and up to 3.7 to 5.5MPa in the case of blocks, a value which is highly satisfactory compared to that of minimum Compressive strength of 3.5MPa for a well burnt brick as per BIS 1077 - 1992 and a minimum Compressive strength of Soil block for general building construction as per BIS: 1725 1982. One of the major advantages of addition of fibre is the increase in tensile strength. Above observations and failure pattern show that the fibre reinforced mud block masonry behaves more ductile and masonry can store more elastic energy compared to mud blocks without fibre, which renders it more resistant to earthquakes. A practical Mix of 7.5 to 10% of Cement, Kit fibre (from carry bags) having 2cm length and 0.1% by weight of Soil, 5MPa Moulding pressure, may be treated as the outcome of the test results, for the type of soil mentioned in table 3.3, having a lesser clay content and the percentage of sand high.