CHAPTER 6: DEVELOPMENT OF MIX DESIGN METHODOLOGY AND REGRESSION MODELS FOR NRLMFRHPC

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6.15 Unified Mix Design Methodology for Proportioning of NRLMFRHPC Mixes

6.16 Closure
6.1 General:

In most of the structural applications concrete is employed to resist the compressive stresses. The concrete making with various ingredients like cement, sand metal with some admixtures have to be measured in terms of the compressive strength. The strength of concrete is its resistance to rupture and is measured by way of compression, tension and flexure. The compressive strength became a quantitative measure for other properties of hardened concrete. So far there is no exact quantitative relationship has been developed between compressive strength and split tensile strength, compressive strength and flexural strength. Similarly there is no exact relationship between 28 days and 90 days compressive strength, split tensile strength and flexural strengths also. However for few concretes, approximate statistical relationships have been developed which give much information to engineers.

The strength of concrete depends on the strength of cement paste which depends on the dilution. The strength of paste increases with cement content but decreases with water and air content. Abrams in 1918 developed a relation between strength of the ordinary concrete and water cement ratio which is known as Abrams water cement ratio law. According to Abrams law, the strength of concrete depends on the water cement ratio provided the mix is workable. In this chapter the relation between water cement ratio and compressive strength, water cement ratio and split tensile strength and also the relation between water cement ratio and flexural strength
will be developed and presented for natural rubber latex modified fibre reinforced high performance concrete.

The water binder ratio laws for compressive strength, split tensile strength and flexural strength are developed in this chapter.

6.2 Relationship between W/B Ratio and Compaction Factor:

The workability of natural rubber latex modified fibre reinforced high performance concrete (NRLMFRHPC) for satisfactory placing and compaction is an important parameter in the mix proportioning. The workability required for a particular field application has to be properly assessed by the field engineers and is generally supplied to the mix designer in terms of slump or compaction factor. In the proposed unified mix design methodology, compaction factor has been considered to represent the workability. In the present work, huge experimental data on compaction factor workability has been generated for NRLMFRHPC mixes produced with mineral admixture metakaolin, various percentages of rubber latex and steel fibre. The compaction factors of various NRLMFRHPC mixes obtained from the present investigation are already presented in Table 4.3 of Chapter 4. The relationships between the compaction factor and the water-binder ratio have been developed using second degree polynomial regression analysis and are presented as Equations 6.1 to 6.9 with figures 6.1 (a-c).
Fig 6.1 (a) Regression plot for W/B Ratio vs Compaction Factor (RL=0.25%)

Fig 6.1 (b) Regression plot for W/B Ratio vs Compaction Factor (RL=0.50%)
Fig 6.1(c) Regression plot for W/B Ratio vs Compaction Factor (RL=0.75%)

REGRESSION EQUATIONS

R.L= 0.25%:

\[
CF = 0.9806 + (-1.234) \times \frac{W}{B} + 2.286 \left( \frac{W}{B} \right)^2 \quad \text{(Steel fibre = 0.5%)} \quad \text{Eq. 6.1}
\]

\[
CF = 0.432 + 1.377 \times \frac{W}{B} + (-1.143) \left( \frac{W}{B} \right)^2 \quad \text{(Steel fibre = 0.75%)} \quad \text{Eq. 6.2}
\]

\[
CF = 0.9105 + (-1.234) \times \frac{W}{B} + 2.286 \left( \frac{W}{B} \right)^2 \quad \text{(Steel fibre = 1.0%)} \quad \text{Eq. 6.3}
\]
The standard deviation of the above regression Equations is in the range of 0.0019 to 0.0037 and the correlation coefficients are in the range of 0.987 to 0.998 indicating excellent correlation. Accordingly these equations will be used to estimate the compaction factor workability for a chosen water-binder ratio and percentage of rubber latex & steel fibre content in the proposed unified mix design methodology.
6.3 Development of water-binder ratio law for compressive strength of NRLMFRHPC:

The 28-day compressive strengths of different NRLMFRHPC mixes obtained from the present investigation are presented in Table 4.5 of Chapter 4.

One of the specific objectives of the present investigation is to develop suitable water-binder ratio laws for the compressive, tensile and flexural strengths of latex modified fibre reinforced high performance concrete. For any mix design, water-binder ratio law is of prime importance and constitutes the first step. Hence, it is proposed to develop water-binder ratio law for NRLMFRHPC. From the discussion of test results presented earlier, it is observed that the variation of compressive strength of NRLMFRHPC is similar to that of ordinary concrete qualitatively and satisfies the spirit of Abram’s law. Hence it is proposed to use a model similar to Abram’s law for NRLMFRHPC. Accordingly, the water-binder ratio law for NRLMFRHPC is proposed as given below for a given percentage of rubber latex and steel fibre.

\[
f_c = \frac{A}{B^x}
\]  

Eq.6.10

Where

\( f_c \) = Compressive Strength in MPa

\( x \) = Water-Binder Ratio

A and B are constants which describe the water-binder ratio law.

The constants A and B in Equation (6.10) are evaluated by conducting statistical regression analysis. For the purpose of regression, Equation (6.10) has been transformed as below.
\[ \log(f_c) = \log(A) - x\log(B) \]  
\text{Eq. 6.11}

Denoting \( \log(A) = A', - \log(B) = B', \log(f_c) = f'_c \)

The Equation (6.11) can be rewritten as

\[ f'_c = A' + B'x \]  
\text{Eq. 6.12}

The values of constants \( A' \) and \( B' \) in Equation (6.12) have been determined by conducting statistical regression of the experimental results of the present work. Once the values of \( A' \) and \( B' \) are obtained, the values of \( A \) and \( B \) are calculated as per Equation (6.13).

\[ A = e^{A'} ; \text{And} \quad B = e^{-B'} \]  
\text{Eq. 6.13}

Substituting the values of \( A \) and \( B \) in Equation (6.13), the water-binder ratio law for the compressive strength of Natural Rubber latex modified fibre reinforced high performance concrete for a given percentage of rubber latex and steel fibre is obtained. The water-binder ratio laws for compressive strength for three different ratios of rubber latex and for various percentages of steel fibre obtained from statistical regression analysis of the results of this work are presented in figures 6.2 (a) to 6.2 (c).
Fig 6.2 (a). Regression plot for Water binder ratio vs Log of compressive strength (RL = 0.25\%)

Fig 6.2 (b) Regression plot for Water binder ratio vs Log of compressive strength (RL = 0.50\%)
Fig 6.2 (c) Regression plot for Water binder ratio vs Log of compressive strength (RL = 0.75\%)

REGRESSION EQUATIONS:

**RL = 0.25 \%**

\[
f_c = \frac{132.44}{3.912^x} \quad \text{(For steel fibre = 0.5\%)} \quad \text{Eq. 6.14}
\]

\[
f_c = \frac{145.61}{4.17^x} \quad \text{(For steel fibre = 0.75\%)} \quad \text{Eq. 6.15}
\]

\[
f_c = \frac{138.23}{2.84^x} \quad \text{(For steel fibre = 1.0\%)} \quad \text{Eq. 6.16}
\]

**RL = 0.50 \%**

\[
f_c = \frac{149.46}{4.76^x} \quad \text{(For steel fibre = 0.5\%)} \quad \text{Eq. 6.17}
\]

\[
f_c = \frac{146.49}{3.88^x} \quad \text{(For steel fibre = 0.75\%)} \quad \text{Eq. 6.18}
\]
In the above regressions, the standard deviations are in the range of 0.00215 to 0.0145 and the correlation coefficients are in the range of 0.957 to 0.998 indicating very good correlation. These Equations are able to predict the compressive strength of NRLMFRHPC satisfactorily. The maximum error is found to be only 7.76%. The Equations (6.14 to 6.22) describe the water-binder ratio and compressive strength relationship for NRLMFRHPC for various percentages of rubber latex and steel fibres.

6.4 Development of water-binder ratio law for Split tensile strength of NRLMFRHPC:

The 28-day split tensile strengths of different NRLMFRHPC mixes obtained from the present investigation are presented in Table 4.7 of Chapter 4.

The water binder ratio law for split tensile strength of NRLMFRHPC mix can be developed for various percentages of rubber latex and steel fibre ratios from figures 6.3(a-c). The water-binder ratio laws for split tensile strength for three different ratios of rubber latex and for various percentages of steel fibre have been
obtained from statistical regression analysis explained in section 6.3. The results of this work are presented below.

Fig 6.3 (a) Regression plot for Water binder ratio vs Log of split tensile strength

( RL = 0.25% )
Fig 6.3 (b) Regression plot for Water binder ratio vs Log of split tensile strength

(RL = 0.50%)

Fig 6.3 (c) Regression plot for Water binder ratio vs Log of split tensile strength

(RL = 0.75%)
REGRESSION EQUATIONS:

**RL = 0.25 %**

\[ f_t = \frac{8.48}{2.344^x} \text{ (For steel fibre = 0.5%) } \quad \text{Eq. 6.23} \]

\[ f_t = \frac{8.88}{2.45^x} \text{ (For steel fibre = 0.75%) } \quad \text{Eq. 6.24} \]

\[ f_t = \frac{9.49}{2.18^x} \text{ (For steel fibre = 1.0%) } \quad \text{Eq. 6.25} \]

**RL = 0.50 %**

\[ f_t = \frac{8.67}{2.28^x} \text{ (For steel fibre = 0.5%) } \quad \text{Eq. 6.26} \]

\[ f_t = \frac{9.23}{2.63^x} \text{ (For steel fibre = 0.75%) } \quad \text{Eq. 6.27} \]

\[ f_t = \frac{9.61}{2.09^x} \text{ (For steel fibre = 1.0%) } \quad \text{Eq. 6.28} \]

**RL = 0.75 %**

\[ f_t = \frac{8.24}{2.24^x} \text{ (For steel fibre = 0.5%) } \quad \text{Eq. 6.29} \]

\[ f_t = \frac{8.99}{2.48^x} \text{ (For steel fibre = 0.75%) } \quad \text{Eq. 6.30} \]

\[ f_t = \frac{9.58}{2.16^x} \text{ (For steel fibre = 1.0%) } \quad \text{Eq. 6.31} \]

In the above regressions, the standard deviations are in the range of 0.00215 to 0.0066 and the correlation coefficients are in the range of 0.991 to 0.996 indicating excellent correlation. These equations are able to predict the tensile strength of
NRLMFRHPC satisfactorily. The maximum error is found to be less than 1% when verified with experimental data generated in this investigation.

6.5 Development of water-binder ratio law for flexural strength of NRLMFRHPC:

The 28-day flexural strengths of different NRLMFRHPC mixes obtained from the present investigation are presented in Table 4.9 of Chapter 4.

The water binder ratio law for flexural strength of NRLMFRHPC mix can be developed for various percentages of rubber latex and steel fibre ratios from the figures 6.4(a) to 6.4 (c). The water-binder ratio laws for flexural strength for three different percentages of rubber latex and for various percentages of steel fibre obtained have been obtained from statistical regression analysis using the procedure presented in section 6.3. The results of this work are presented below.

![Regression plot for Water binder ratio vs Log of Flexural strength](image)

**Fig 6.4 (a) Regression plot for Water binder ratio vs Log of Flexural strength**

(RL = 0.25%)
Fig 6.4 (b) Regression plot for Water binder ratio vs Log of Flexural strength

( $RL = 0.50\%$ )

Fig 6.4 (c) Regression plot for Water binder ratio vs Log of Flexural strength

( $RL = 0.75\%$ )
REGRESSION EQUATIONS:

**RL = 0.25 %**

\[ f_r = \frac{9.85}{2.69^x} \] (For steel fibre = 0.5%) \hspace{1cm} \text{Eq. 6.32}

\[ f_r = \frac{9.80}{2.489^x} \] (For steel fibre = 0.75%) \hspace{1cm} \text{Eq. 6.33}

\[ f_r = \frac{9.65}{2.04^x} \] (For steel fibre = 1.0%) \hspace{1cm} \text{Eq. 6.34}

**RL = 0.50 %**

\[ f_r = \frac{9.74}{2.34^x} \] (For steel fibre = 0.5%) \hspace{1cm} \text{Eq. 6.35}

\[ f_r = \frac{10.16}{2.479^x} \] (For steel fibre = 0.75%) \hspace{1cm} \text{Eq. 6.36}

\[ f_r = \frac{10.01}{2.04^x} \] (For steel fibre = 1.0%) \hspace{1cm} \text{Eq. 6.37}

**RL = 0.75 %**

\[ f_r = \frac{9.48}{2.36^x} \] (For steel fibre = 0.5%) \hspace{1cm} \text{Eq. 6.38}

\[ f_r = \frac{9.627}{2.279^x} \] (For steel fibre = 0.75%) \hspace{1cm} \text{Eq. 6.39}

\[ f_r = \frac{9.83}{2.21^x} \] (For steel fibre = 1.0%) \hspace{1cm} \text{Eq. 6.40}

In the above regressions, the standard deviations are in the range of 0.0036 to 0.0086 and the correlation coefficients are in the range of 0.875 to 0.989 indicating
very good correlation. These equations are able to predict the flexural strength of NRLMFRHPC satisfactorily. The maximum error is found to be less than 1% when verified with experimental data generated in this investigation.

### 6.6 Development of relationship between water-binder ratio and chloride ion permeability of NRLMFRHPC:

The Rapid chloride ion permeability values of different NRLMFRHPC mixes obtained from the present investigation are presented in Table 5.3 (a-d) to 5.6 (a-d) of Chapter 5.

The relationship between water binder ratio and chloride ion permeability of NRLMFRHPC can be developed for various percentages of rubber latex and steel fibre ratios from the graphs 6.5(a) to 6.5 (c) using statistical regressions. The results of this work are presented below.

---

**Fig 6.5 (a) Regression plot for Water binder ratio vs Log of RCPT**

(RL = 0.25%)

---
Fig 6.5 (b) Regression plot for Water binder ratio vs Log of RCPT

(RL = 0.50%) 

Fig 6.5 (c) Regression plot for Water binder ratio vs Log of RCPT 

(RL = 0.75%)
REGRESSION EQUATIONS:

**RL = 0.25 %**

\[ CIP = \frac{412.44}{0.017^x} \]  
(For steel fibre = 0.5%)  \hspace{1cm} \text{Eq. 6.41}

\[ CIP = \frac{285.06}{0.0089^x} \]  
(For steel fibre = 0.75%)  \hspace{1cm} \text{Eq. 6.42}

\[ CIP = \frac{221.36}{0.0068^x} \]  
(For steel fibre = 1.0%)  \hspace{1cm} \text{Eq. 6.43}

**RL = 0.50 %**

\[ CIP = \frac{374.166}{0.0167^x} \]  
(For steel fibre = 0.5%)  \hspace{1cm} \text{Eq. 6.44}

\[ CIP = \frac{287.81}{0.0119^x} \]  
(For steel fibre = 0.75%)  \hspace{1cm} \text{Eq. 6.45}

\[ CIP = \frac{170.136}{0.0043^x} \]  
(For steel fibre = 1.0%)  \hspace{1cm} \text{Eq. 6.46}

**RL = 0.75 %**

\[ CIP = \frac{635.49}{0.0388^x} \]  
(For steel fibre = 0.5%)  \hspace{1cm} \text{Eq. 6.47}

\[ CIP = \frac{288.62}{0.012^x} \]  
(For steel fibre = 0.75%)  \hspace{1cm} \text{Eq. 6.48}

\[ CIP = \frac{153.32}{0.0017^x} \]  
(For steel fibre = 1.0%)  \hspace{1cm} \text{Eq. 6.49}

In the above regressions, the standard deviations are in the range of 0.0036 to 0.0086 and the correlation coefficients are in the range of 0.875 to 0.989 indicating very good correlation. These equations are able to predict the flexural strength of metakaolin based high performance concrete satisfactorily. The maximum error is
found to be less than 1% when verified with experimental data generated in this investigation.

6.7 Relationship between compressive and tensile strengths:

Though the tensile strength of concrete is less compared to its compressive strength, knowledge of its value is essential for the design of structural elements subject to transverse shear, torsion, shrinkage and temperature effects. To determine the direct tensile strength of concrete is difficult and hence, the splitting cylinder test for assessing the tensile strength in laboratory is widely accepted. Normally the tensile strength is expressed as a function of compressive strength of concrete. Keeping this in view, various researchers tried and succeeded to find out a relationship between cube compressive strength, splitting tensile strength and flexural strength of plain concrete. Every designer basically needs the compressive strength of the mix, and hence they conduct cube compressive strength test and determine the exact value of the compressive strength of the mix. Then, from the known value of compressive strength, an estimate of tensile strength of the mix is obtained from the relations proposed. The various relations proposed in different countries for plain concrete are in equations 6.50 (a) to 6.50 (c).

\begin{align*}
  \text{i) } & f_{ct} = b\sqrt{\sigma_c} & \text{Eqn 6.50 (a)} \\
  \text{ii) } & f_{ct} = a + b\sqrt{\sigma_c} & \text{Eqn 6.50 (b)} \\
  \text{iii) } & f_{ct} = a(\sigma_c)^b & \text{Eqn 6.50 (c)}
\end{align*}

Where, \( f_{ct} \) = split tensile strength

\( \sigma_c \) = cube compressive strength
The values of the constants \( a \) and \( b \) are obtained from the statistical analysis of the groups available. Of all the above relationships the square root function is mostly adopted for ordinary concrete. The Indian standard code IS 456 – 2000 proposed a square root function to estimate the tensile strength of plain concrete as

\[
F_{ct} = 0.7 \sqrt{f_{ck}} \text{ N/mm}^2, \text{ where, } f_{ck} = \text{cube compressive strength of concrete.}
\]

From the review of the literature available, it is observed that no systematic study is available to suggest a similar relationship between split tensile strength and cube compressive strength for NRLMFRHPC. In view of the above an attempt is made to establish a relationship between cube compressive strength and split tensile strength, cube compressive strength and Flexural strength of NRLMFRHPC from the experimental results of this investigation. The relationship between cube compressive strength and split tensile strength of NRLMFRHPC mixes is presented in Figure 6.6 (a-b).
A simple regression model has been developed from the results of the present investigation for predicting the split tensile strength of NRLMFRHPC mixes using the square root function and is presented in equation 6.51.

\[ f_{ct28} = 0.697 \sqrt{f_{ck28}} \]  
Eq.6.51

Where

\( f_{ct28} \) = 28-day split tensile strength, MPa

\( f_{ck28} \) = 28-day compressive strength, MPa

The standard deviation in the above regression equation is 0.237 and the coefficient of correlation is 0.955. This equation is quite helpful for estimating the tensile strength of NRLMFR4HPC mixes.
The similar regression model has been developed for predicting the 90 days split tensile strength of NRLMFRHPC mixes using the square root function and is presented in fig 6.6 (b).

From the linear regression of the data presented in the figure 6.6 (b), the following relationship is obtained between the compressive and split tensile strengths of NRLMFRHPC mixes for 90 days in equation 6.52.

\[ f_{ct90} = 0.712\sqrt{f_{ck90}} \]  

Eq.6.52

Where

\( f_{ct90} = 90\)-day split tensile strength, MPa

\( f_{ck90} = 90\)-day compressive strength, MPa
The standard deviation in the above regression equation is 0.35 and the coefficient of correlation is 0.886 indicating good correlation. This relationship can be effectively used for predicting the split tensile strength of NRLMFRHPC mixes.

6.8 Relationship between compressive and flexural strengths:

The relationship between the 28 days and 90 days compressive and flexural strengths of NRLMFRHPC mixes is presented in Figure 6.7(a) and 6.7 (b) from the results of the present experimental study.

![Regression plot for Square root of Compressive strength Vs Flexural strength of NRLMFRHPC (28 days)](image)

**Fig 6.7 (a) Regression plot for Square root of Compressive strength Vs Flexural strength of NRLMFRHPC (28 days)**

From the linear regression of the data presented in the figure 6.7 (a). The relationship is obtained between the compressive and flexural strengths of NRLMFRHPC mixes for 28 days in equationn 6.53.

\[ F_{cr} = 0.752 \sqrt{f_{ck}} \]

Eq. 6.53

Where
299

\( F_{cr28} = \) 28-day flexural strength, MPa

\( f_{ck28} = \) 28-day compressive strength, MPa

The standard deviation in the above regression equation is 0.193 and the coefficient of correlation is 0.942 indicating good correlation. This relationship can be effectively used for predicting the flexural strength of NRLMFRHPC mixes.

The similar regression model has been developed for predicting the 90 days flexural strength of NRLMFRHPC mixes using the square root function and is presented in figure 6.7 (b).

![Fig 6.7 (b) Regression plot for Square root of Compressive strength Vs Flexural strength of NRLMFRHPC (90 days)](image-url)

From the linear regression of the data presented in the figure 6.7 (b). The relationship is obtained between the compressive and flexural strengths of NRLMFRHPC mixes for 90 days in equation 6.54.

\[ f_r = 0.765 \sqrt{f_{ck}} \]  

Eq. 6.54
Where

\[ F_{cr28} = 90\text{-day flexural strength, MPa} \]

\[ f_{ck28} = 90\text{-day compressive strength, MPa} \]

The standard deviation in the above regression equation is 0.202 and the coefficient of correlation is 0.939 indicating good correlation. This relationship can be effectively used for predicting the flexural strength of NRLMFRHPC mixes.

**6.9 Relationship between 28 days and 90 days compressive strength of NRLMFRP:**

![Fig 6.8 Regression plot for 28 days Compressive strength Vs 90 days compressive strength of NRLMFRP](image)

From the linear regression of the data presented in the figure 6.8, the relationship is obtained between 90 days compressive and 28 days compressive strengths of NRLMFRP mixes in equation 6.55

\[ f_{ck90} = 1.08 \ f_{ck28} \quad \text{Eq. 6.55} \]
Where

\[ f_{ck \text{28}} = 28 \text{ day compressive strength in MPa} \]
\[ f_{ck \text{90}} = 90 \text{ day compressive strength in MPa} \]

The standard deviation in the above regression equation is 0.194 and the coefficient of correlation is 0.979 indicating good correlation. This relationship can be effectively used for predicting the 90 days compressive strength of NRLMFRHPC mixes.

### 6.10 Relationship between 28 days and 90 days Split Tensile strength of NRLMFRHPC:

**Fig 6.9** Regression plot for 28 days Split tensile strength Vs 90 days Split tensile strength of NRLMFRHPC
From the linear regression of the data presented in the figure 6.9, the relationship is obtained between the 90 days split tensile strength and 28 days split tensile strength of NRLMFRHPC mixes in eqn 6.56.

\[ F_{ct90} = 1.0634 \times F_{ct28} \]  

Eq.6.56

Where

\[ F_{ct28} = \text{28 day split tensile strength in MPa} \]

\[ F_{ct90} = \text{28 day split tensile strength in MPa} \]

The standard deviation in the above regression equation is 0.197 and the coefficient of correlation is 0.940 indicating good correlation. This relationship can be effectively used for predicting the 90 day split tensile strength of NRLMFRHPC mixes.

6.11 Relationship between 28 days and 90 days Flexural strength of NRLMFRHPC:

Fig 6.10 Regression plot for 28 days Flexural strength Vs 90 days Flexural strength of NRLMFRHPC
From the linear regression of the data presented in the figure 6.10, the relationship is obtained between the 90 days flexural strength and 28 days flexural strength of NRLMFRHPC mixes in equation.57.

\[ F_{c_{r90}} = 1.063 \, f_{c_{r28}} \]  \hspace{1cm} \text{Eq. 6.57}

Where \( f_{c_{r28}} \) = 28 day Flexural strength in MPa

\( F_{c_{r90}} \) = 28 day Flexural strength in MPa

The standard deviation in the above regression equation is 0.194 and the coefficient of correlation is 0.917 indicating good correlation. This relationship can be effectively used for predicting the 90 days flexural strength of NRLMFRHPC mixes.

6.12 Regression models for Rapid chloride ion permeability:

From the results of the experimentation, regression models for estimating the chloride ion permeability of different NRLMFRHPC mixes have been developed using simple linear regression analysis and are presented in equations 6.59 to 6.67.

\[ f_x = A + Bx \]  \hspace{1cm} \text{Eq. 6.58}

The values of constants A and B in Equation (6.61) have been determined by conducting statistical regression of the experimental results of the present work.
Fig 6.11 (a) Regression plot for Water binder ratio vs RCPT (RL = 0.25%)

Fig 6.11 (b) Regression plot for Water binder ratio vs RCPT (RL = 0.50%)
Fig 6.11 (c) Regression plot for Water binder ratio vs RCPT (RL = 0.75%)

REGRESSION EQUATIONS:

**RL = 0.25 %**

\[ CIP = -986.10 + 7756 \times \frac{W}{B} \] (For steel fibre = 0.5 %) \hspace{1cm} \text{Eq. 6.59}

\[ CIP = -1266.8 + 7912 \times \frac{W}{B} \] (For steel fibre = 0.75 %) \hspace{1cm} \text{Eq. 6.60}

\[ CIP = -1230.2 + 7168 \times \frac{W}{B} \] (For steel fibre = 1.0 %) \hspace{1cm} \text{Eq. 6.61}

**RL = 0.50 %**

\[ CIP = -914.3 + 7116 \times \frac{W}{B} \] (For steel fibre = 0.5%) \hspace{1cm} \text{Eq. 6.62}
\[ CIP = -995.8 + 6744 \times \frac{W}{B} \quad \text{(For steel fibre = 0.75 %)} \quad \text{Eq. 6.63} \]

\[ CIP = -1325.6 + 7088 \times \frac{W}{B} \quad \text{(For steel fibre = 1.0 %)} \quad \text{Eq. 6.64} \]

\[ RL = 0.75 \% \]

\[ CIP = -1188 + 8796 \times \frac{W}{B} \quad \text{(For steel fibre = 0.5 %)} \quad \text{Eq. 6.65} \]

\[ CIP = -1709 + 9676 \times \frac{W}{B} \quad \text{(For steel fibre = 0.75 %)} \quad \text{Eq. 6.66} \]

\[ CIP = -2211 + 10528 \times \frac{W}{B} \quad \text{(For steel fibre = 1.0 %)} \quad \text{Eq. 6.67} \]

The correlation coefficients of above linear regressions are in the range of 0.982 to 0.998 indicating very good correlations. Hence, the above equations can safely be used for estimating the chloride ion permeability of various NRLMFRHPC mixes in the ranges tested.

**6.13 Unified Mix design Charts for NRLMFRHPC:**

The steel fibre reinforced high performance concrete with latex modification has to be designed to give optimum strength, workability, service life, and durability. It gives more serviceability to structures within the allowable cost. Natural rubber latex modified fibre reinforced high performance concrete (NRLMFRHPC) being used in aggressive environments and to obtain special combinations. The mix design method available for conventional concrete cannot be used for NRLMFRHPC because they are compressive strength oriented concretes. So far there are no specific
guide lines are available for mix proportioning of NRLMFRHPC by combining both strength and durability aspects. The method generally used to obtain the mix proportions is “Trail and Error method”. Such methods for mix proportioning require large number of trial mixes. A good mix proportioning has to minimize the number of trial mixes and achieve economical and required strength and durability properties.

In the present investigation, a systematic research has been made to evaluate the effects of important parameters such as percentage of rubber latex and percentage of steel fibre on the strength, workability and durability properties of natural rubber latex modified fibre reinforced high-performance-concrete. It is essential that any mix design approach for NRLMFRHPC should consider both strength and durability aspects. In the present investigation, an attempt is made to develop a unified mix design methodology by combining strength and durability properties obtained from the experimentation. Compressive, tensile and flexural strengths of NRLMFRHPC are considered. Workability and durability have been considered in terms of compaction factor and chloride ion permeability respectively for developing the mix design methodology. Unified mix design charts relating water-binder ratio to strength and permeability have been developed from the results of the present work. Using these relationships and unified mix design charts, a new unified mix design methodology has been proposed for NRLMFRHPC. It is expected that this unified mix design methodology can minimize the proportioning of NRLMFRHPC mixes. The details of the mix design procedure are explained in this chapter.

In Chapter-5, the permeability values of different NRLMFRHPC mixes have been obtained from the experimentation and their variation with water-binder ratio has been modeled using linear regression (Equations 6.59 to 6.67). Similarly regression models for compressive, tensile and flexural strengths of NRLMFRHPC
were developed and presented in this chapter in Equations 6.14 to 6.22, 6.23 to 6.31 and 6.32 to 6.40 respectively. Unified charts for compressive strength and durability have been obtained by plotting Equations 6.10 to 6.22, 6.23 to 6.31 & 6.32 to 6.40 along with Equations 6.59 to 6.67 on double Y-Axis graph. These charts are presented below in Figures 6.12 (a - c) to 6.14 (a-c).

Fig 6.12 (a) Unified mix design chart for compressive strength (RL = 0.25%)
Fig 6.12 (b) Unified mix design chart for compressive strength (RL = 0.50%)

![Compressive Strength Chart](image)

**Fig 6.12(C) Unified mix design chart for compressive strength (RL = 0.75%)**

![Compressive Strength Chart](image)

Fig 6.13 (a) Unified mix design chart for tensile strength (RL = 0.25%)

![Tensile Strength Chart](image)
Fig 6.13 (b) Unified mix design chart for tensile strength (RL = 0.50%)

Fig 6.13 (c) Unified mix design chart for tensile strength (RL = 0.75%)
Fig 6.14 (a) Unified mix design chart for flexural strength (RL = 0.25%)

Fig 6.14 (b) Unified mix design chart for flexural strength (RL = 0.50%)
From Figures 6.12 (a-c) to 6.14 (a-c) the mix designer can choose a suitable water-binder ratio and percentage of rubber latex for a given target compressive strength or tensile strength or flexural strength. From the same chart one can easily estimate the permeability for the chosen mix. If the proportion so arrived is not satisfactory these charts present alternative options as well. The methodology for using this unified mix design chart is explained with an example.

6. 14 Procedure for using the unified charts:

The procedure for using the unified charts have been explained with fig 6.12(b1) and 6.12 (b2)
Fig 6.12 (b1) Unified mix design chart for compressive strength (RL = 0.50%)

Fig 6.12 (b2) Unified mix design chart for compressive strength (RL = 0.50%)
If the mix designer opts to proportion an NRLMFRHPC mix with a target compressive strength of 85 MPa, the following steps can be carried out.

1. Select the optimum dosage of Rubber Latex required for application (0.25, 0.50, 0.75)

2. Choose appropriate chart for percentage of rubber latex. Accordingly Figure 6.12(b) is to be considered. In this example say R.L=0.5% is selected.

3. Draw a line parallel to the x-axis from 85 MPa to cut the strength curve at point A as shown in Figure 6.12(b1). It can be observed from this figure that the line cuts the 0.5% steel fibre curve for strength at point A.

4. From this point A, drop a line parallel to y-axis to read the water-binder ratio as 0.363. (See Figure 6.12(b1))

5. Erect the line parallel to y-axis from W/B = 0.363 to cut the permeability curve of 0.5% steel fibre at point P.

6. From this point P, draw a line parallel to x-axis to read the permeability value as 1650 coulombs. (See Figure 6.12(b1))

On the other hand, as per the field requirements if the mix designer opts to design an NRLMFRHPC mix with a W/B ratio of 0.375, the following steps can be carried out.

1. Choose appropriate chart for percentage of rubber latex. For example let us choose the percentage of steel fibre is 0.5. Accordingly Figure 6.12(b) is to be considered.

2. Erect the line parallel to y-axis from W/B = 0.375 to cut the compressive strength curves of different percentages of steel fibre at points A, B and C and permeability curves at P, Q and R as shown in Figure 6.12(b2).
3. Draw a line parallel to x-axis from the point A to note the compressive strength as 83.5 MPa. Draw a line parallel to x-axis from point R on 0.5% steel fibre line to read the permeability of this mix as 1775 coulombs.

4. Alternatively if 0.75% steel fibre line is chosen, draw a line parallel to x-axis from point B to read the compressive strength as 88 MPa. Also draw a line parallel to x-axis from point Q to read the permeability as 1525 coulombs.

5. If the mix designer opts to use 1.0% Steel fibre line, draw a line parallel to x-axis from point C to read the compressive strength as 93.5 MPa. Also draw a line parallel to x-axis from point R to read the permeability as 1325 coulombs.

Thus it can be observed that the proposed unified charts provide different options for the mix designer to proportion the NRLMFRHPC mix of required strength and durability. Similar procedure can be used for proportioning NRLMFRHPC mixes for tensile strength and flexural strengths using appropriate unified charts.

6.15 Unified Mix Design Methodology for Proportioning of NRLMFRHPC Mixes:

Till today no specific mix proportioning guide lines are available for the mix proportioning of natural rubber latex modified fibre reinforced high performance concrete combining both strength and durability aspects. Based on the experimental data generated in the present work a unified mix design methodology which combines workability, strength and durability is proposed. In proposing this new methodology, the spirit of I.S. code method of mix design for ordinary concrete has been maintained. The proposed methodology consists of a series of steps which when completed provides a mix proportion meeting the strength, workability and durability
requirements based on the combined properties of the individually selected and proportioned ingredients. The various steps are listed below.

**Step 1:**

Compute the target mean strength from the characteristic strength by using the following relationship as given in I.S.Code method for the mix design of normal concrete.

\[
f_t = f_{ck} + 1.65S \quad \text{Eq. 6.68}
\]

where,

\[
f_t = \text{Target mean strength in MPa.}
\]

\[
f_{ck} = \text{Characteristic strength in MPa.}
\]

\[
S = \text{standard deviation.}
\]

The value of the standard deviation shall be calculated based on at least 30 test strength samples. Where sufficient test results are not available, the value of standard deviation may be assumed as 5.0 MPa for compressive strength and 0.3 MPa for tensile and flexural strengths expecting excellent quality control in the field. It is felt that works involving NRLMFRHPC will be of very important nature and hence only excellent quality control condition has been considered. The assumed values of standard deviation may be used in the mix design at first instance. As soon as results are available the mix should be redesigned using the actual calculated standard deviation.
Step 2:

Select any one suitable percentages of rubber latex. Based on the results of the present investigation, suggestive ranges of target strengths for choosing the dosage of rubber latex are presented in Table 6.1.

Table 6.1 Suggested ranges of target strengths for percentages of Rubber latex

<table>
<thead>
<tr>
<th>S.No</th>
<th>Range of target strength (MPa)</th>
<th>Percentage of Rubber latex</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>28-day Compressive strength</td>
<td>28-day Tensile strength</td>
</tr>
<tr>
<td>1.</td>
<td>74-98</td>
<td>5.5-7.5</td>
</tr>
<tr>
<td>2.</td>
<td>77-104</td>
<td>6.0-8.0</td>
</tr>
<tr>
<td>3.</td>
<td>75-100</td>
<td>5.5-7.5</td>
</tr>
</tbody>
</table>

The ranges presented in Table 6.1 are of suggestive nature only.

Step 3:

For the chosen percentage of rubber latex, select any one suitable steel fibre ratio among the three depending up on the target strength to be achieved. Based on the results of the present investigation, suggestive ranges of target strengths for choosing steel fibre ratio are presented in Table 6.2.
Table 6.2 Suggested ranges of target strengths for choosing Steel fibre ratio

<table>
<thead>
<tr>
<th>S. No</th>
<th>Percentage of Rubber latex</th>
<th>Range of target strength (MPa) (28 day)</th>
<th>Suggested Steel fibre ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Compressive</td>
<td>Tensile</td>
</tr>
<tr>
<td>1</td>
<td>0.25</td>
<td>74.0-85.2</td>
<td>5.5-6.4</td>
</tr>
<tr>
<td>2</td>
<td>71.0-91.5</td>
<td>6.0-6.7</td>
<td>6.5-7.30</td>
</tr>
<tr>
<td>3</td>
<td>88.0-98</td>
<td>6.8-7.5</td>
<td>7.1-8.0</td>
</tr>
<tr>
<td>1</td>
<td>0.50</td>
<td>77.0-91.0</td>
<td>6.0-6.7</td>
</tr>
<tr>
<td>2</td>
<td>82.0-94.7</td>
<td>6.1-6.9</td>
<td>6.8-7.5</td>
</tr>
<tr>
<td>3</td>
<td>96.0-104</td>
<td>7.0-8.0</td>
<td>7.4-8.0</td>
</tr>
<tr>
<td>1</td>
<td>0.75</td>
<td>75.0-85.7</td>
<td>5.5-6.4</td>
</tr>
<tr>
<td>2</td>
<td>80.0-92.50</td>
<td>6.1-6.8</td>
<td>6.7-7.4</td>
</tr>
<tr>
<td>3</td>
<td>91.0-100.0</td>
<td>6.9-7.5</td>
<td>7.0-8.0</td>
</tr>
</tbody>
</table>

**Step 4:**
For the chosen percentage of rubber latex and steel fibre ratio select the appropriate unified mix design chart from Figures 6.12 (a - c)-6.14 (a - c).

**Step 5:**
Determine the water-binder ratio (W/B) from the unified mix design chart chosen in Step 4.

**Step 6:**
Compute the compaction factor workability for the W/B ratio obtained in Step 5 by substituting W/B value in the appropriate equation among Equations 6.1 to 6.9 and check with the required workability.

**Step 7:**
Read the chloride ion permeability for the chosen W/B ratio from the unified mix design chart selected in Step 4.

**Step 8:**

If the workability and permeability requirements are satisfactory, proceed to compute the quantities of ingredients by absolute volume method, else revise W/B ratio, dosage of rubber latex and volume percent of steel fibre.

**Note:**

Though the suggested methodology is general, the tables and charts presented are bound by the range of parameters chosen in this investigation. Accordingly, the method suggested has following limitations.

1. Ordinary Portland cement of 53 grade alone is to be used.

2. Sand conforming to Zone-II of I.S: 383-1970 is only to be used. The weight of sand should be 40% of the total aggregate.

3. Crushed granite coarse aggregate with 50% passing through 12.5mm and retained on 10mm sieve and 50% passing through 20mm and retained on 12.5mm sieve is to be used. The weight of coarse aggregate has to be 60% of the total aggregate.

4. The super plasticizer conforming to IS: 9103–1999 is alone to be used. A constant dosage of super plasticizer @ 2.5% by weight of binder has to be used.

The methodology of mix designing a NRLMFRHPC mix of M80 grade as per the above steps is illustrated by an example below:
Example:

Design an NRLMFRHPC mix of M80 grade to have a split tensile strength of 6.00 MPa and flexural strength of 6.5 MPa. The required workability is 0.8 compaction factor. The mix should have a chloride ion permeability of not more than 1500 Coulombs. The specific gravity of cement is 3.10. Specific gravities of coarse and fine aggregate are 2.76 and 2.69 respectively. The specific gravity of Metakaolin = 2.60.

Procedure:

Step 1:

Calculation of target means strengths:

\[ f_t = f_{ck} + 1.65S \]

Target mean compressive strength

\[ f_{ct} = 80 + 1.65 \times 5 \]

\[ = 88.25 \text{ MPa.} \]

Target mean split tensile strength

\[ f_{st} = 6 + 1.65 \times 0.3 \]

\[ = 6.5 \]

Target mean flexural strength

\[ f_{rt} = 6.5 + 1.65 \times 0.3 \]

\[ = 7.0 \text{ MPa} \]
Step 2:

**Selection of suitable percentage of rubber latex based on the calculated mean strengths:**

From Table 6.1, it can be observed that we have the option to use 0.25, 0.50 & 0.75 percentages of rubber latex for the target compressive, tensile and flexural strengths computed in Step 1. In the present example, 0.5% of rubber latex is chosen.

Step 3:

**Selection of suitable volume percentage of steel fibre based on the percentage of rubber latex and the target mean strengths:**

From Table 6.2, it can be observed that we have an option to select percentage of steel fibre as 0.5 or 0.75 or 1.0%. Accordingly, steel fibre percent of 0.5% is chosen for this example problem.

Step 4:

**Selection of suitable unified mix design chart based on the percentage of rubber latex and steel fibre chosen:**

For the chosen percentage of rubber latex and steel fibre ratio, the appropriate unified mix design charts are selected as Figure 6.12 (b), 6.13 (b) and 6.14 (b) for compressive strength, split tensile strength and flexural strength respectively.

Step 5:

**Selection of W/B ratio based on the unified chart so selected:**

For the target mean compressive strength of 88.25 MPa, the water-binder ratios (W/B ratio) are read from Figure 6.12 (b) as 0.34.
Step 6:

**Computations of compaction factor workability from Equation 6.1 to 6.9 based on the W/B ratio obtained and check for the required workability:**

From Equation 6.4, the compaction factor has been computed as follows:

\[
CF = 0.9706 + (-1.234) \times \frac{W}{B} + 2.285 \left(\frac{W}{B}\right)^2 \quad \text{(Steel fibre = 0.5%)}
\]

\[
= 0.9706 - 1.234 \times 0.34 + 2.285(0.34)^2
\]

\[
= 0.815 > 0.8 \quad \text{Therefore, satisfactory.}
\]

From Figure 6.13(b), for W/B ratio of 0.34 and 0.5% steel fibre, the split tensile strength is obtained as 6.55 > 6.5 MPa Therefore, chosen W/B ratio is satisfactory.

From Figure 6.14(b), for W/B ratio of 0.34 and 0.5% steel fibre, the flexural strength is obtained as 7.25 > 7.0 MPa Therefore, chosen W/B ratio is satisfactory.

Step 7:

**Determination of chloride ion permeability for the chosen W/B ratio from the unified mix design chart Figure 6.12 (b):**

From the unified mix design chart (Figure 6.12 (b)), the chloride ion permeability (CIP) for W/B ratio of 0.34, RL of 0.5% and 0.5% steel fibre is obtained as:

\[
CIP = 1475 \text{ Coulombs} < 1500 \text{ Coulombs. Therefore, chosen parameters are satisfactory.}
\]
Step 8:

**Computation of quantities by Absolute volume method:**

From the Steps 1-8, following parameters have been chosen.

Dosage of Rubber latex = 0.5%; W/B = 0.34; steel fibre = 0.5%.

For the above chosen parameters, quantities of ingredients required are calculated by using Absolute volume method presented in the tabular form below:

**Table 6.3 Calculation of Quantity for ingredients**

<table>
<thead>
<tr>
<th>S.No</th>
<th>Material</th>
<th>Absolute volume of 50 Kg cement bag $m^3$</th>
<th>Material for cubic meter of concrete (Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Cement</td>
<td>50 x 0.9/(3.10 x1000) = 0.0145</td>
<td>50x0.9/0.070=642.85</td>
</tr>
<tr>
<td>2.</td>
<td>Metakaolin</td>
<td>50 x 0.1/(2.6 x1000) = 0.0019</td>
<td>50x0.1/0.070=71.43</td>
</tr>
<tr>
<td>3.</td>
<td>Water</td>
<td>50 x 0.34/(1.00 x1000) = 0.017</td>
<td>50x0.34/0.070=242.85</td>
</tr>
<tr>
<td>4.</td>
<td>Coarse Aggregate</td>
<td>50 x 0.6 x2/(2.76 x1000) = 0.0217</td>
<td>50x0.6x2.0/0.070=857.14</td>
</tr>
<tr>
<td>5.</td>
<td>Fine Aggregate</td>
<td>50 x 0.4 x2/(2.69 x1000) = 0.0149</td>
<td>50x0.4x2.0/0.070=571.43</td>
</tr>
</tbody>
</table>

**Quantities required for cubic meter of concrete:**

Cement = 643 Kg.

Metakaolin = 71.40 Kg.

Coarse aggregate = 857 Kg

Fine aggregate = 571 Kg
Water = 242.9 Lts

Rubber Latex = 3.215 Kg

Volume required for one trail mix:

For 6 cubes = 6 x 0.15x0.15x0.15 = 0.0203 m$^3$

For 6 cylinders = 6 x $\pi$ x 0.15$^2$ x 0.30 / 4 = 0.0318 m$^3$

For 6 beams = 6 x 0.15 x 0.15 x 0.60 = 0.0810 m$^3$

0.1331 m$^3$

Add 10% extra = 0.01331

Total = 0.1464 m$^3$

Qty of steel fibre

0.5 % steel fibre = 0.1464 x (0.50/100) x 7840 = 5.739 kg

Dosage of rubber latex

0.50 % rubber latex = 0.1464 x (0.50/100) x 940 = 0.688 Kg

With the above proportions, a trial mix has been prepared in the laboratory. Six cubes of 150x150x150 mm, six cylinders of 150 mm diameter and 300 mm height and six beams of 150X150X600mm were cast for conducting compressive, split tensile and flexural strength tests. Compaction factor of fresh concrete was also determined. Three specimens of 100 mm diameter and 50 mm thick were also cast and cured for 28 days for the determination of chloride ion permeability. The results obtained from the tests conducted on the trial mix are presented below.
<table>
<thead>
<tr>
<th>S.No</th>
<th>Compaction factor</th>
<th>Average compressive Strength(MPa)</th>
<th>Average split Tensile strength(MPa)</th>
<th>Average flexural strength(MPa)</th>
<th>Chloride ion Permeability (coulombs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>0.82</td>
<td>89.5</td>
<td>6.70</td>
<td>7.15</td>
<td>1450</td>
</tr>
</tbody>
</table>

The results obtained from testing the trial mix indicate that the chosen mix proportion satisfies the requirements of workability, compressive, split tensile, flexure strengths and permeability.

6.16 Closure:

In the mix design of ordinary concrete or high strength concrete, compressive strength alone is considered. However, it is felt that for NRLMFRHPC, all the three strengths i.e. compression, tensile and flexural strengths are to be considered depending on the chosen performance criteria. Accordingly, a systematic study has been conducted on NRLMFRHPC to evaluate its behavior in compression, tension and flexure. Different NRLMFRHPC mixes were produced in laboratory with W/B ratios ranging from 0.325 to 0.425, Rubber latex dosage of 0.25 to 0.75% and steel fibre volume of 0.0% to 1.0% were considered to obtain different ranges of strengths. Cement has been replaced by 10% with a mineral admixture Metakaolin. The Workability tests were conducted on fresh NRLMFRHPC mixes. Strengths and durability tests were conducted on hardened NRLMFRHPC after 28 days and 90 days of curing. The experimental results were used to analyze the influence of various parameters. W/B ratio laws have been developed for compression, tensile and flexure strengths using regression analysis of experimental data. Unified Mix design charts combining compression, tensile and flexure strengths with chloride permeability are presented. Inter relationships for various properties of NRLMFRHPC have been derived and presented in this Chapter. A step by step procedure for mix proportioning
has been developed and explained with an example problem. The proposed mix
design is quite effective and is expected that this will reduce the number of trails
required in proportioning NRLMFRHPC mixes.