

Influence of Metakaolin and Steel Fibre on Recycled Aggregate Concrete

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ABSTRACT: The utilisation of waste and recycled products in construction industry is sustainable and environmentally positive approach. The concrete being manufactured by such processes have lower properties than traditional concrete. Nowadays various recycled products are being investigated along with different supplementary materials in various ratio to achieve both sustainable and structural application. This study utilises coarse recycled aggregates at 15%, 30% and 45% replacement of natural aggregate in concrete and later phases focus on the improvement of strength properties of recycled aggregate concrete by utilising 10% metakaolin as cement replacement and addition of 1% steel fibre at the curing age of 28 days.

KEYWORDS: Recycled Aggregates, Metakaolin, Steel fibre, Compressive strength

I. INTRODUCTION

Concrete is the most used synthetic material worldwide. The high surge in urban population growth and better infrastructural facilities have increased the demand of concrete for the construction industry. Concrete traditionally is made up of various natural resources such as sand and coarse aggregates in particular ratios to achieve the required application. The dwindling natural resources and stricter environmental and government policies have shifted the focus of construction industry towards utilising recycled and waste resources. The main concern in utilising the recycled resources is the decrease in the quality of end product. Coarse recycled aggregates were first used in world war two by various nations as the supply of natural aggregates was badly affected. Till now various studies have been done to understand the behaviour of recycled aggregate concrete. The optimum percentage of recycled aggregate to be utilised in concrete is determined to be 15-30% depending upon the quality of source. Nowadays investigations are being done to improve the properties of recycled aggregate concrete. This study also focuses on the properties of recycled aggregate concrete and the influence of supplementary materials such as metakaolin and steel fibre.

II. LITERATURE REVIEW

Kou et al. (2011) compared the recycled aggregate concrete prepared with different mineral admixtures including silica fume (10%), metakaolin (15%), fly ash (35%), ground granulated blast slag (55%) used as cement replacement. The recycled aggregates were replaced at 50% and 100%. The recycled aggregate concrete with addition of silica fume and metakaolin exhibited positive effects on compressive strength at both replacement levels. Fly ash and ground granulated blast slag had a detrimental effect on the compressive strength.

Kanellopoulos et al. (2014) used recycled lime powder to study the mechanical property of recycled aggregate concrete. The recycled aggregates were substituted at 10%, 30%, 50% and 100% of natural aggregates. Cement was gradually replaced by 5%, 8%, 10% and 20% by volume. The flexural strength of beams containing recycled aggregates reduces due to weak interfacial transition zone between adhered mortar and new cement paste. The highest

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drop occurs when total replacement of natural aggregates is done by recycled aggregates. The average strength drop recorded was 10%. No serious decrease was found in compressive strength of mixes.

Carneiro et al. (2014) used steel fibres to reinforce recycled concrete, both recycled fine and coarse aggregates were used in mixes. The replacement being 25% by volume for RFA and RCA and 50% of both. The steel fibres substituted in volume fraction of 0.75% were both end hooked having 35 mm and 0.55 mm of length and diameter respectively. The flexural strength values indicate that type of recycled aggregate have very less influence. The values of mixtures containing coarse recycled aggregates are better than conventional mix. The addition of steel fibre, shows significant influence on the flexural strength of the mixtures. The compressive strength of mixtures increased 10-19% with the addition of steel fibres. In plain concrete low replacement levels showed positive results. The steel fibre increased the flexural strength by 8-36%.

Radonjanin et al. (2013) replaced 50% cement with different mineral admixtures such as milled limestone, fly ash, whereas 10% silica fume, metakaolin was used. The concrete mixtures consisted of 50% recycled aggregates. Seven concrete mixes were prepared. Chemical admixtures were added in some mixtures to achieve desired consistency. Different unconventional combinations such as 40% fly ash or milled limestone + 10% silica fume or metakaolin were also prepared. Concrete with Fly ash in combination with metakaolin or silica fume significantly improved the performance. Milled limestone in combination with metakaolin can also be used for low level structural work.

III. EXPERIMENTAL STUDY

Materials Used

- **Cement:** Ordinary Portland cement, 43 Grade conforming to IS 12269 – 1987
- **Fine aggregate:** Locally available river sand, conforming to Grading zone III of IS 383 –1970.
- **Coarse aggregate:** Locally available crushed blue granite stones conforming to graded aggregate of nominal size 20 mm as per IS 383 – 1970.
- **Recycled Coarse aggregate (RA):** Tested lab samples from concrete lab were manually broken down into required sizes.
- **Metakaolin (MK):** Metakaolin was provided from Delhi. Use of metakaolin significantly improves the strength properties of concrete. Chemical properties of metakaolin are given in Table 1
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Table 1. Chemical Properties of Metakaolin

Characteristics	Test Result
Specific Gravity	2.49
SiO ₂	52%
Al ₂ O ₃	41%
Fe ₂ O ₃	2%
TiO ₂	1.5%
CaO	0.2%
MgO	0.15%
Loss of Ignition (%)	0.35

- **Steel Fibre (ST):** Steel Fibre were obtained from Fibrezone, Ahmedabad. Both end hooked steel fibre with dia of 0.6mm and length of 30mm were used in this study. Figure 1 shows the steel fibres.

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Figure 1. Steel Fibres

- **Water:** Water used for mixing and curing was tap water.
- **Mix Proportion:** The mix design has been adopted as per IS 10262-2009. The concrete used in this study was proportioned to attain Characteristic strength of 30 MPa. Recycled Aggregates were partially replaced in the ratio of 0%, 15%, 30% and 45% by weight of coarse aggregate in concrete. Metakaolin was used to partially replace cement by 10%. The steel fibre were 1% of the concrete volume. Table 2 shows the mix nomenclatures.

Table 2. Mix Types

Mix	Recycled Aggregate (%)	Metakaolin (%)	Steel Fibre (%)
CC	0	-	-
A1	15	-	-
A2	30	-	-
A3	45	-	-
B1	0	10	-
B2	15	10	-
B3	30	10	-
B4	45	10	-
C1	0	-	1
C2	15	-	1
C3	30	-	1
C4	45	-	1
D1	0	10	1
D2	15	10	1
D3	30	10	1
D4	45	10	1

IV. RESULTS AND DISCUSSION

The compressive strength results were analysed and the mixes having both metakaolin and steel fibre exhibited the highest strength. The compressive strength results at 28 days of concrete containing recycled aggregates are presented in Table 3 and Figure 2.

Table3- CompressiveStrengthResultsforRecycled Aggregate concrete

Mix type	28 days (N/mm ²)
CC	38.45
A1	39.13
A2	37.84
A3	34.61

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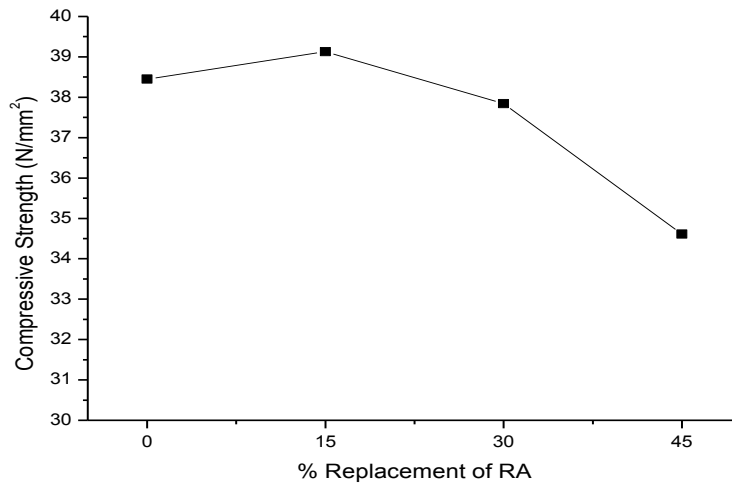


Figure 2. Compressive strength at 28 days for recycled aggregate concrete

Table 4 and Figure 3 shows the compressive strength of recycled aggregate containing metakaolin as 10% replacement of cement. The strength properties were improved with the addition of metakaolin, though the pattern of strength gain remained similar to the normal recycled aggregate concrete.

Table 4 - Compressive Strength Results for Recycled Aggregate concrete with 10% Metakaolin

Mix type	28 days (N/mm ²)
CC	38.45
B1	41.50
B2	43.40
B3	40.35
B4	38.05

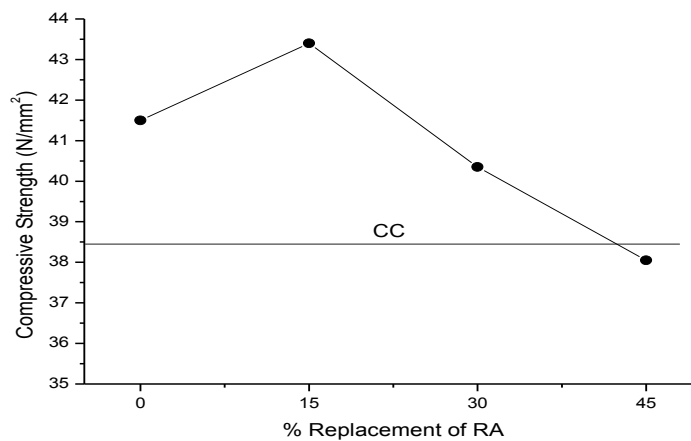


Figure 3. Compressive strength at 28 days for recycled aggregate concrete with 10% Metakaolin

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Table 5 and Figure 4 shows the compressive strength of recycled aggregate containing 1% steel fibre. The strength properties were significantly improved with the addition of steel fibre.

Table 5- Compressive Strength Results for Recycled Aggregate concrete with 1% Steel Fibre

Mix type	28 days (N/mm ²)
CC	38.45
C1	43.44
C2	46.25
C3	44.72
C4	41.50

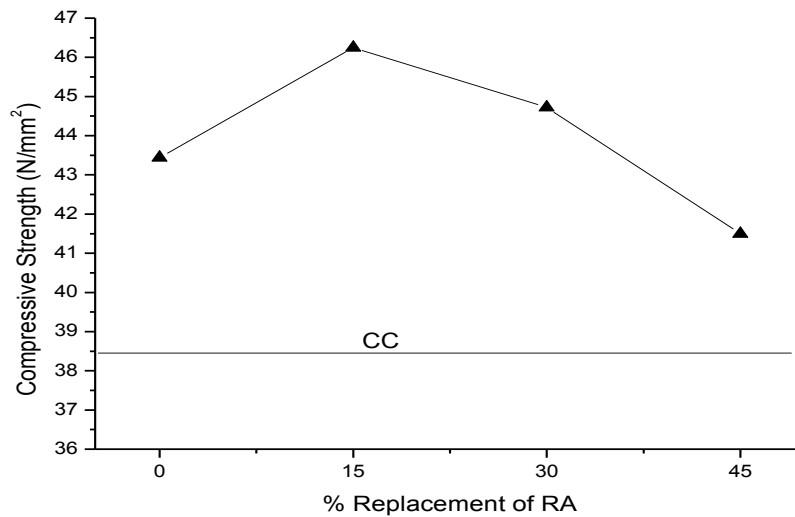


Figure 4. Compressive strength at 28 days for recycled aggregate concrete with 1% Steel Fibre

Table 6 and Figure 5 shows the compressive strength of recycled aggregate containing both 10% metakaolin and 1% steel fibre. The strength properties achieved were highest with the addition of metakaolin and steel fibre. Figure 6 shows the cumulative values of all the concrete mixes.

Table 6- Compressive Strength Results for Recycled Aggregate concrete with 10% Metakaolin and 1% Steel Fibre

Mix type	28 days (N/mm ²)
CC	38.45
D1	49.94
D2	52.07
D3	50.56
D4	46.81

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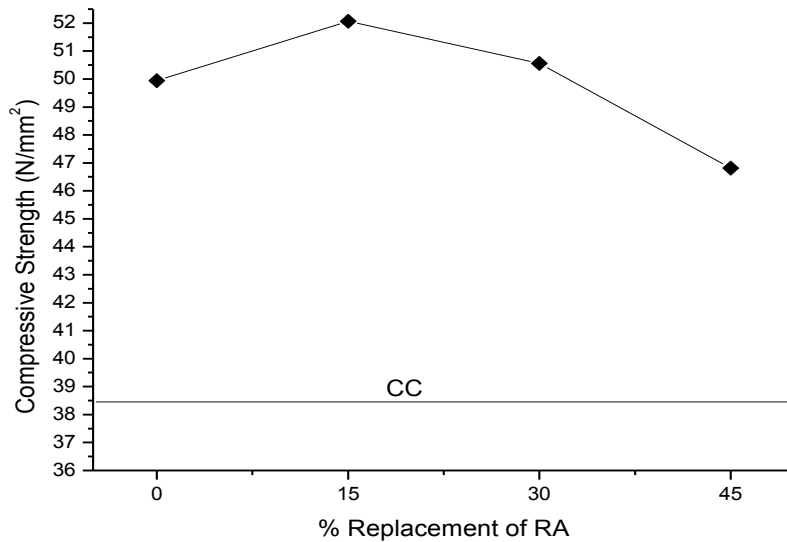


Figure 5. Compressive strength at 28 days for recycled aggregate concrete with 10% Metakaolin and 1% Steel Fibre

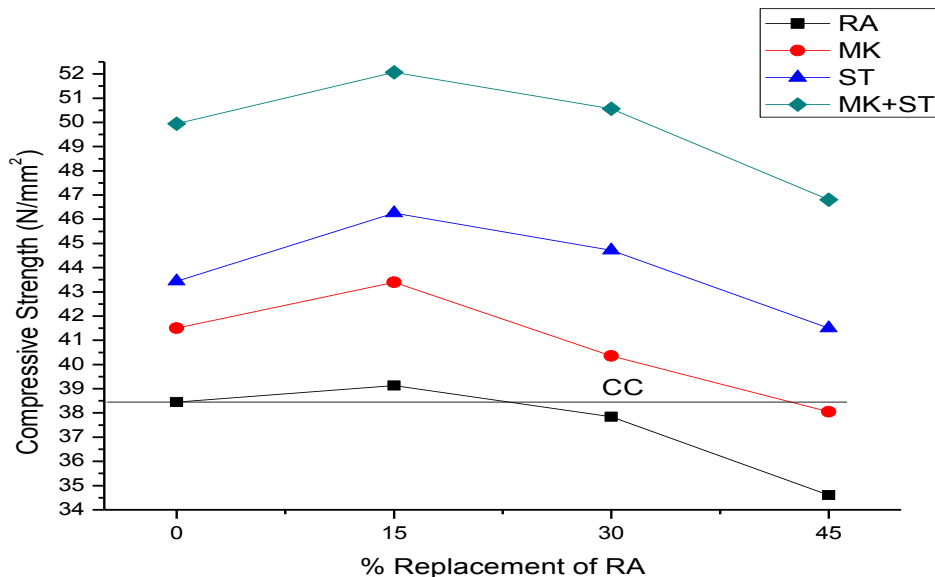


Figure 6. Compressive strength at 28 days for recycled aggregate concrete with Supplementary Materials

The flexural strength results were analysed and the mixes having both metakaolin and steel fibre exhibited the highest strength. In this case the strength development was poorer when compared to compressive strength values. The flexural strength results at 28 days of concrete containing recycled aggregates are presented in Table 7 and Figure 7.

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Table 7- Flexural Strength Results for Recycled Aggregate concrete

Mix type	28 days (N/mm ²)
CC	13.50
A1	12.30
A2	10.60
A3	9.23

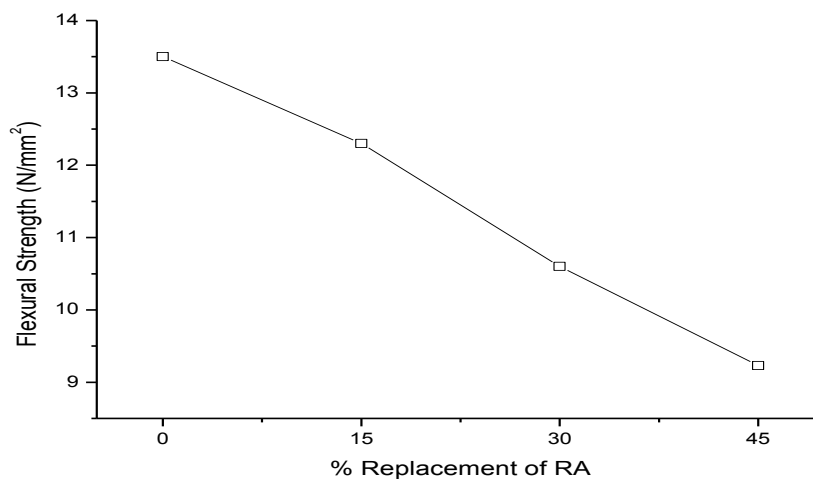


Figure 7. Flexural strength at 28 days for recycled aggregate concrete

Table 8 and Figure 8 shows the flexural strength of recycled aggregate containing metakaolin as 10% replacement of cement. The strength properties were improved with the addition of metakaolin, though the pattern of strength gain remained similar to the normal recycled aggregate concrete.

Table 8- Flexural Strength Results for Recycled Aggregate concrete with 10% Metakaolin

Mix type	28 days (N/mm ²)
CC	13.50
B1	14.01
B2	13.25
B3	12.55
B4	11.41

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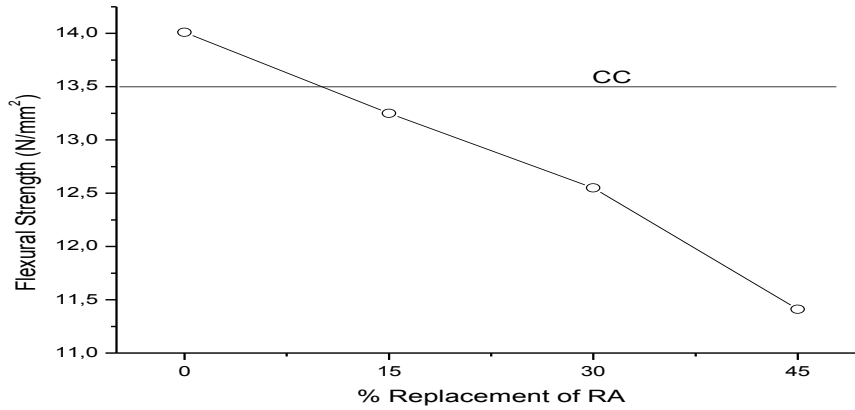


Figure 8. Flexural strength at 28 days for recycled aggregate concrete with 10% Metakaolin

Table 9 and Figure 9 shows the flexural strength of recycled aggregate containing 1% steel fibre. The strength properties were significantly improved with the addition of steel fibre.

Table 9- Flexural Strength Results for Recycled Aggregate concrete with 1% Steel Fibre

Mix type	28 days (N/mm ²)
CC	13.50
C1	15.00
C2	13.85
C3	13.01
C4	12.45

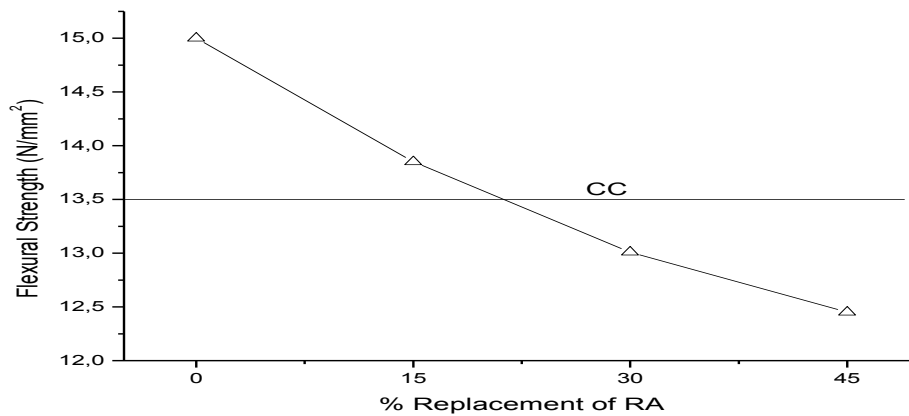


Figure 9. Flexural strength at 28 days for recycled aggregate concrete with 1% Steel Fibre

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Table 10 and Figure 10 shows the compressive strength of recycled aggregate containing both 10% metakaolin and 1% steel fibre. The strength properties achieved were highest with the addition of metakaolin and steel fibre. Figure 6 shows the cumulative values of all the concrete mixes.

Table 10- Flexural Strength Results for Recycled Aggregate concrete with 10% Metakaolin and 1% Steel Fibre

Mix type	28 days (N/mm ²)
CC	13.50
D1	16.90
D2	15.50
D3	13.65
D4	12.71

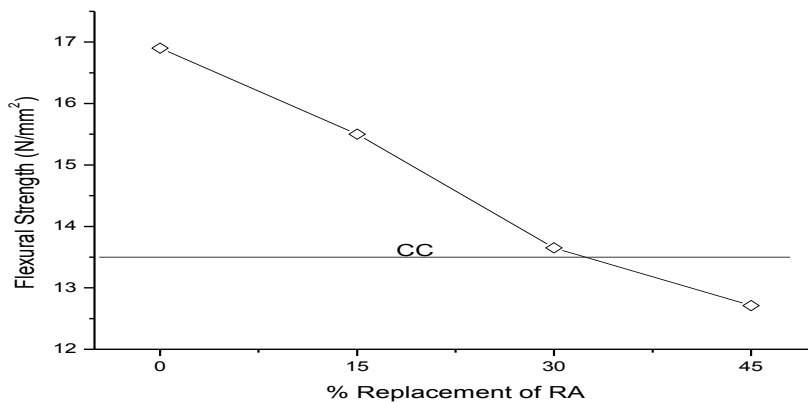


Figure 10. Flexural strength at 28 days for recycled aggregate concrete with 10% Metakaolin and 1% Steel Fibre

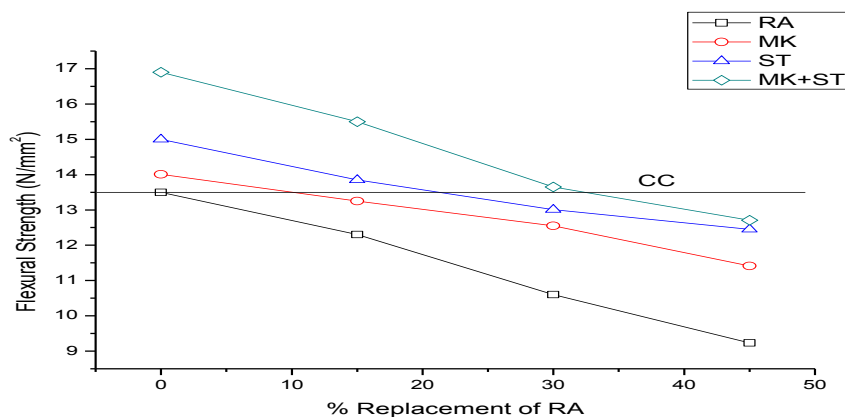


Figure 11. Flexural strength at 28 days for recycled aggregate concrete with Supplementary Materials

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V. CONCLUSION

- The use of Recycled aggregate helps in conserving the dwindling natural resources.
- The strength properties of recycled aggregate concrete can be improved by utilising the supplementary materials in proper ratios.
- The compressive strength values compared with control mix concrete increased by 1.76% when 15% recycled aggregates were used, at higher replacement of 30% and 45% the reduction observed was 1.58% and 9.98% at the age of 28 days.
- When 10% metakaolin was used as cement replacement the increase in observation was 12.87%, 4.94% when the coarse aggregate replacement was 15% and 30%. At higher proportion of 45% a decrease of 1.04% was observed at the age of 28 days.
- The addition of 1% steel fibre improved the compressive strength significantly by 20.28%, 16.30% and 7.93% when 15%, 30% and 45% recycled aggregate were used as coarse aggregate at the age of 28 days.
- Combination of both metakaolin and steel fibre yielded the highest compressive strength gain of 35.42%, 31.49% and 21.74% when 15%, 30% and 45% recycled aggregate were used as coarse aggregate at the age of 28 days.
- The flexural strength values compared with control mix concrete decreased by 8.88%, 21.48% and 31.62% when 15%, 30% and 45% recycled aggregates were used at the age of 28 days.
- When 10% metakaolin was used as cement replacement the decrease in flexural strength observation was 1.85%, 7.03% and 15.48% when the coarse aggregate replacement was 15%, 30% and 45% at the age of 28 days.
- The addition of 1% steel fibre improved the flexural strength by 2.59% when 15% recycled aggregate were used as coarse aggregate, at higher replacement of 30% and 45% a decrease of 3.62% and 7.77% was observed at the age of 28 days.
- Combination of both metakaolin and steel fibre yielded the flexural strength gain of 14.81% and 1.11% when 15% and 30% recycled aggregate were used as coarse aggregate, at higher replacement of 45% a decrease of 5.85% was observed at the age of 28 days.
- The use of metakaolin and steel fibre helped in the improvement of strength properties of recycled aggregate concrete.
- The presence of metakaolin act as filler to make the interfacial transition zone more compact.
- Steel fibres act as crack resistor and restrict slipping when stress is applied.

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