ASIAN JOURNAL OF CIVIL ENGINEERING (BHRC) VOL. 14, NO. 3 (2013)
PAGES 477-485

Technical Note

WORKABILITY AND STRENGTH PROPERTIES OF HYBRID FIBRE REINFORCED CONCRETE FROM INDUSTRIAL WASTE

A. Thirumurugan[a] and M. Sivaraja[b*]

[a]Department of Civil Engineering, SSM College of Engineering, Komarapalayam, India
[b]N.S.N College of Engineering and Technology, Karur, India

Received: 20 February 2012; **Accepted:** 14 July 2012

ABSTRACT

This paper investigates the workability and mechanical strength properties of the high strength concrete reinforced with two different industrial waste fibres. Locally available steel lathe waste and nylon waste were used at different volume fractions as fibre cocktails in concrete. Steel lathe wastes were used in as received lengths and nylon fibres were chopped in to 40 mm lengths. In total, 12 hybrid mixes were cast and tested at four different volume fractions i.e., 0.5%, 1.0%, 1.5% and 2.0%. The experimental programme used the slump test and the air content test on the fresh concrete. The hardened concrete was tested for its compressive strength, split tensile strength and modulus of rupture. All the mechanical properties of the different mixes were enhanced due to the hybrid nature of the fibre cocktails. Out of all the mixes, the hybrid mix at 2% volume fraction with a combination of steel ½ + nylon ½ gives the best performance.

Keywords: Fibre reinforcement; mechanical properties; industrial waste

1. INTRODUCTION

Investigations to overcome the brittle response and limiting post – yield energy absorption of concrete led to the development of fibre reinforced concrete (FRC) using discrete fibres within the concrete mass. The fibres were introduced to develop concrete with enhanced flexural and tensile strength. The fibres were included in the concrete is to delay and control the tensile cracking of the composite materials. The fibers, thus transform inherent unstable tensile crack propagation into a slow controlled crack growth. Thus the fibre reinforcement delays the initiation of flexural and shear crack. It strongly influences the post cracking

* E-mail address of the corresponding author: m.shivaraj2006@gmail.com (M. Sivarajab)

behaviour and significantly enhances the toughness of the composite. Fibres of different materials such as metallic, polymeric and cellulose are presently used in high strength concrete for various infrastructural applications. Among them, metallic steel fibres contribute considerably to the improvement in tensile and toughness and to the resistance to shrinkage by arresting the crack propagation of matrix [1]. Whereas low density polymeric fibres such as polypropylene, glass and nylon restrain the plastic cracks in the matrix [2]. High strength concrete with single fibres of either type does not offer a significant improvement in mechanical properties. Hence in recent years, there has been research on hybrid fibre reinforced concrete which incorporates the advantages of both types of fibres in a single matrix. One type of hybridization is to mix stiff and flexible fibres to enhance both the first crack strength and the post crack toughness. Another type of hybridization is simply based on the geometry of the fibres. In this type there are two possible combinations: different sizes (micro and macro fibre) and different shapes (straight and crimped/deformed). Brief information about the development of hybrid fibre reinforced concrete from the year 1975 to 2000 has been given by Banthia and Soleimani [3]. Table 1 lists of research works carried out in hybrid fibre reinforced concrete from 2001 - 2009.

Almost all the studies listed above were focused on commercially available fibres. But in developing countries, over half of the population is living in slums and villages. The earthquake damage in rural areas is worsened mainly due to the widely adopted non – engineered constructions. On the other hand, growth of various industries in developing countries leads to the production of waste materials. These industrial wastes include both metallic and non-metallic materials. Some research has been carried out on industrial waste fibres such as steel lath waste [4-5] and nylon waste [6-8]. Improvement in the mechanical and structural properties of concrete was obtained by the addition of industrial waste fibres. The present research aims to establish the optimal properties of hybrid fibre reinforced concrete using the locally available stiff metallic lathe waste and flexible non-metallic nylon fibres.

This paper studies the workability and mechanical strength properties of steel-nylon waste hybrid fibre reinforced concrete. Four volume fractions such as 0.5%, 1.0%, 1.5% and 2% were used in three combinations (1/3rd – 2/3rd, ½ - ½ and 2/3rd – 1/3rd) of steel and nylon fibres. A comparison of the hybrid fibre reinforced concrete, single fibre reinforced concrete and plain concrete was made based on the results of tests on fresh and hardened concrete such as slump, air content, compressive strength, split tensile strength, modulus of rupture, modulus of elasticity, shear strength, impact strength and flexural toughness.

2. MATERIALS AND EXPERIMENTAL METHODS

2.1 Materials

The materials used in this investigation are:

1. Cement: Ordinary Portland cement confirming to IS 12269
2. Fine aggregate: Locally available river sand having specific gravity of 2.62, fineness Modulus of 2.83 and density of 1654 kg/m^3
3. Coarse aggregate: Crushed granite stones of 20 mm maximum size having specific gravity of 2.70, fineness modulus of 2.73 and density of 1590 kg/m^3

4. Silicafume : Commercially available Grade 920-D Silicafume from Elkem India
5. Superplasticizer : Commercially available CONPLAST SP430 – Naphthalene Sulphonate based water reducing admixure
6. Fibre: (a) Lathe scrap fibres of as received length (10 to 15 mm) from local lathe industries (b) Nylon scrap collected from local industries chopped in to fibres of 40 mm length (aspect ratio of 90); specific gravity is 0.7; density is 567 kg/m^3

2.2 Mixing and Casting

Trial mixtures were prepared to obtain a target mean strength of 60 MPa at 28 days, along with a workability of 70-120 mm. In order to obtain the desired workability, only the superplasticizer dosage was varied. The detailed mix proportions used in this study are shown in Table 2. The specimens incorporated two different fibres namely lath waste and nylon waste in mix proportions of 1−0, 0−1, 1/3rd-2/3rd, ½-½ and 2/3rd–1/3rd at each volume fractions of 0.5%, 1.0%, 1.5% and 2.0%. For comparison purposes, specimens without any fibres were also cast. The details of specimens with different fibre combinations are listed in Table 1. A laboratory type concrete mixer machine was used to mix the ingredients of concrete. To avoid balling of the fibers, the following procedure was followed during casting. To begin with aggregates, cement and silica fume were allowed to mix for two minutes, after which water and superplasticizer were added within two minutes. The fibres were then added manually and allowed to disperse throughout the mass gradually. The materials were then allowed to mix thoroughly for three more minutes. After mixing, tests on the fresh concrete such as slump test, compaction factor test, Vee-Bee test and air content under pressure method were conducted. The fibrous concrete was manually placed in the respective moulds. All the specimens were well compacted using a table vibrator. The specimens were demoulded after 24 hours. Six specimens of each of the mixes of different dimensions were cast.

Table 1: Mix proportions of concrete

Cement (kg/m^3)	**Silicafume (kg/m^3)**	**Fine aggregate (kg/m^3)**	**Coarse aggregate (kg/m^3)**		**Water (kg/m^3)**	**Superplasticizer (kg/m^3)$^\#$**
			20 mm	**10 mm**		
410	60	780	620	510	164	10 (Base value)

\# varied to obtain the desired workability

2.3 Test Methods

Tests to obtain compressive strength, split tensile strength and modulus of rupture were conducted according to the Indian standards The modulus of elasticity is one of the most important mechanical properties of concrete since it impacts the serviceability and the structural performance of reinforced concrete structures. The closest approximation to the theoretical modulus of elasticity derived from a truly elastic response is its initial tangent modulus. But it is not always easy to determine it from a compression method. In such a case, the chord modulus of elasticity is used. The method currently used to determine the chord modulus of elasticity of concrete is the Compressometer method. For this, California test 522 procedure was followed to evaluate the chord modulus of elasticity.

3. RESULTS AND DISCUSSIONS

3.1 Workability

In total, 21 mixes which include plain and fibre reinforced concrete along with the workability of 70 to 120 mm slump were cast by adding appropriate dosage of superplasticizer. The other workability tests such as compaction factor and Vee-Bee consistometer tests were also conducted and the results are shown in Table 2. In all the workability tests, the addition of fibres significantly reduces the workability of the plain concrete. It is observed that concrete with nylon fibres alone has good workability when compared with other fibre combinations. The combination of Steel 2/3 + Nylon 1/3 fibres has the lowest workability than others. Similar pattern of results was obtained in all the workability tests. Another property of fresh concrete known as air content was measured by using the pressure method and results are tabulated in Table 2.

Table 2: Fibre Mix and workability details

Specimen ID	**Volume fraction of**		**Slump in mm**	**Compaction Factor**	**Vee-Bee time in sec**	**Air content in %**
	Lath waste	**Nylon waste**				
CC	-	-	110	0.98	2.0	2.8
L1 0.5	0.5	-	95	0.90	5.5	4.4
L11.0	1.0	-	91	0.84	6.4	4.5
L11.5	1.5	-	84	0.79	7.0	4.6
L12.0	2.0	-	78	0.73	8.5	4.8
N1 0.5	-	0.50	100	0.92	4.6	4.2
N11.0	-	1.00	94	0.86	5.8	4.5
N11.5	-	1.50	88	0.82	6.7	4.8
N12.0	-	2.00	80	0.78	7.9	4.8
L2/3N1/3 0.5	0.33	0.17	90	0.85	6.7	4.4
L2/3N1/3 1.0	0.67	0.33	84	0.78	7.9	4.8
L2/3N1/3 1.5	1.00	0.50	78	0.73	9.2	4.8
L2/3N1/3 2.0	1.33	0.67	70	0.70	10.5	4.9
L1/2N1/2 0.5	0.25	0.25	92	0.86	6.0	4.5
L1/2N1/2 1.0	0.50	0.50	84	0.81	6.9	4.7
L1/2N1/2 1.5	0.75	0.75	79	0.76	7.7	4.7
L1/2N1/2 2.0	1.00	1.00	73	0.72	8.1	4.9
L1/3N2/3 0.5	0.17	0.33	94	0.85	6.0	4.2
L1/3N2/3 1.0	0.33	0.67	88	0.82	6.8	4.4
L1/3N2/3 1.5	0.50	1.00	80	0.76	8.5	4.7
L1/3N2/3 2.0	0.67	1.33	74	0.72	9.4	4.7

The air content of plain concrete was only 2.8%, where as other fibre combinations had air contents up to 4.9%. Amongst the fibre reinforced concrete, nylon 0.5% yielded the least air content and fibre combinations of steel ½ + nylon ½ and steel 2/3 + nylon 1/3 had the maximum air content. Further, increase in volume fraction decreases the workability in all the fibre combinations.

3.2 Compressive strength

Results of tests for mechanical properties such as compressive strength, split tensile strength and modulus of rupture conducted on plain concrete and waste steel lath – nylon hybrid fibrous concrete with at four volume fractions of 0.5%, 1.0%, 1.5% and 2.0% with three combinations such as 2/3rd + 1/3rd, ½ + ½ and 1/3rd + 2/3rd are presented in Table 3.

Table 3: Mechanical strength properties

Specimen ID	**Hardened density in kg/m^3**	**Compressive strength in MPa**	**Split tensile strength in MPa**
CC	2427	60.5	4.4
L_1 0.5	2454	64.2	4.8
$L_1$1.0	2462	65.8	5.4
$L_1$1.5	2465	66.4	5.8
$L_1$2.0	2472	66.2	6.0
N_1 0.5	2440	60.8	4.6
N11.0	2448	61.2	4.9
N11.5	2452	62.4	5.3
N12.0	2454	62.4	5.5
L2/3N1/3 0.5	2458	62.5	5.4
L2/3N1/3 1.0	2455	63.4	5.8
L2/3N1/3 1.5	2451	66.5	6.5
L2/3N1/3 2.0	2458	67.0	6.8
L1/2N1/2 0.5	2450	63.7	5.4
L1/2N1/2 1.0	2457	64.8	5.9
L1/2N1/2 1.5	2460	65.0	6.4
L1/2N1/2 2.0	2465	64.8	6.8
L1/3N2/3 0.5	2452	62.5	5.2
L1/3N2/3 1.0	2456	63.1	5.8
L1/3N2/3 1.5	2458	63.5	6.0
L1/3N2/3 2.0	2456	63.2	6.3

The test results shown are the average values of six specimens. The co-efficient of variation obtained in the compressive strength results varied in the range 4.5 to 12. The hardened density of different concrete mixes varied from 2427 kg/m^3 for plain concrete to 2472 kg/m^3 for concrete with 2% steel lath waste. There are close relationships in between the density and compressive strength of concrete. The compressive strength values improved to some extents in response to the volume fraction of the fibres. Compressive strengths of different concrete mixes varied from 60.5 MPa for plain concrete to 69 MPa for steel 2/3 + nylon 1/3 hybrid fibrous concrete mixes. Figure 1 shows the relationships between compressive strength and fibre volume fraction for different fibre combinations. It is evident that mono steel lath fibres at four volume fractions such as 0.5%, 1.0%, 1.5% and 2.0% increased the compressive strength of plain concrete by 6.5%, 8.7%, 9.7% and 9.4% respectively.

But adding mono nylon waste fibres did not show any improvement in compressive strength over plain concrete. The improved percentage of compressive strength obtained by the hybrid fibrous concrete with steel lath 2/3rd + nylon 1/3rd combination of 0.5%, 1.0%, 1.5% and 2.0% volume fraction are 3%, 5%, 10% and 10.7% respectively. It can also be observed that there is an increase in compressive strength of 5.2%, 7.1%, 7.4% and 7.1% for hybrid concretes with steel lath ½ + nylon ½ fibre combination having 0.5%, 1.0%, 1.5% and 2.0% volume fractions respectively. Adding steel lath waste 1/3rd + nylon waste 2/3rd hybrid fibre combination to all the four volume fractions increased the compressive strength of plain concrete by 4%. A similar pattern of improvement is shown in the modulus of elasticity test results. There are some corresponding increases in the values of chord modulus obtained with different volume fractions of hybrid combinations. Hence it is evident that no significant improvement was attained in the compressive strength parameter by the hybrid fibrous concrete with industrial wastes.

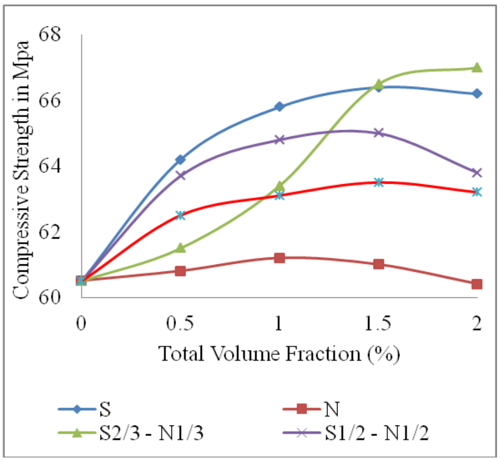

Figure 1. Shear strength vs total volume fraction

3.3 Split tensile strength

The average split tensile strength of six companion cylindrical specimens with and without hybrid fibres of different combinations at four volume fractions are shown in Table 3. The co-efficient of variation obtained for the split tensile strength results varied from 5.5 to 9.5. It is clear that significant improvements were achieved in split tensile strengths of all fibrous concrete mixes. The maximum split tensile strength of 6.8 MPa was achieved from fibrous concrete mixes having 'steel 2/3rd + nylon 1/3rd' and 'steel ½ + nylon ½' with 2% volume fractions. Figure 2 shows the relationship between split tensile strength and four volume fractions of different hybrid fibrous concrete mixes. It is observed that in fibrous concrete with volume fractions such as 0.5%, 1.0%, 1.5% and 2.0%, there is an increase in split tensile strength of 9%, 22%, 31%, 36% and 4.5%, 11%, 20%, 25% for fibrous concrete having mono steel lath waste and nylon waste respectively. Adding 'steel 2/3rd + nylon 1/3rd' and 'steel ½ + nylon ½' hybrid fibre combinations at the four volume fractions such as 0.5%, 1.0%, 1.5% and 2.0% increased the split tensile strength of plain concrete by 22%, 32%, 46% and 54% respectively. It can also be observed that increase in split tensile strength of 18%, 31%, 36% and 43% were achieved by the hybrid combination of 'steel 1/3rd + nylon 2/3rd'.

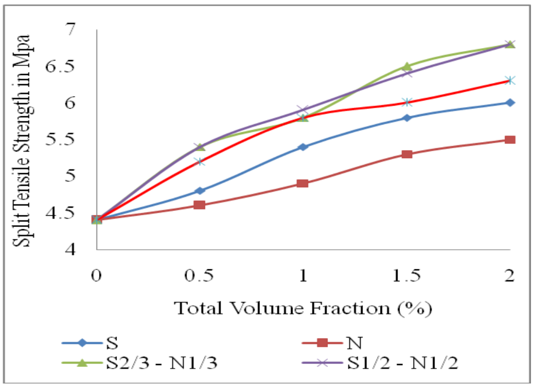

Figure 2. Split tensile strength vs total volume fraction

Hybrid combination of strong steel lath waste and increased fibre availability of nylon waste may be the reason for the significant enhancement in split tensile strength. When the specimens were subjected to cracking, ductile nylon fibres would improve the bridging between the cracks until the stress was transferred to the strong steel fibres.

3.3 Modulus of rupture

Table 3 also shows the test results of modulus of rupture of hybrid fibre reinforced concrete specimens. The co-efficient of variation obtained from the test results of six specimens for each mix varied from 4 to 8. The modulus of rupture of plain concrete is 5.4. The maximum value of 8.1 was obtained in the hybrid fibrous concrete mix ‘steel ½ + nylon ½’. Comparing with conventional plain concrete, the increases in percentage of modulus of rupture of mono steel fibrous concrete at 0.5%, 1.0%, 1.5% and 2.0% volume fractions are 15%, 22%, 27% and 31% respectively. Similarly in mono nylon fibre reinforced concrete specimens, the augmented percentages obtained are 7%, 16%, 22% and 27%.

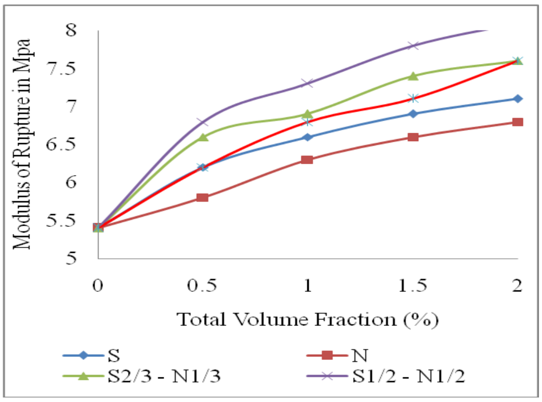

Figure 3. Modulus of rupture vs total volume fraction

From Figure 3, it is evident that the hybrid combination ‘steel 2/3rd + nylon 1/3rd’ exhibited increases of 22%, 27%, 37% and 40% in the modulus of rupture over the value for plain concrete. It is also observed that the percentage increase in modulus of rupture obtained from the fibre combinations such as ‘steel½ + nylon½’and ‘steel1/3rd + nylon2/3rd’

are 26%, 35%, 44%, 50% and 14%, 26%, 31%, 40% respectively. The reasons for the superior performance of hybrid fibre reinforced concrete specimens might be due to the availability of strong fibres in tensile zone which take care of tensile stresses and increased availability of low modulus nylon fibres which increases the bridging action of micro cracks.

4. CONCLUSION

A detailed experimental investigation was carried out on the workability and mechanical properties of hybrid fibre reinforced high strength concrete with locally available industrial fibres such as steel lath waste and nylon waste in different combinations. In total, five fibre combinations such as steel alone, nylon alone, steel 2/3rd + nylon 1/3rd, steel ½ + nylon ½ and steel 1/3rd + nylon 2/3rd were used in this investigation. Fibrous concrete specimens were cast with four different volume fractions such as 0.5%. 1.0%, 1.5% and 2.0%. The following conclusions are made from the above investigation:

- As expected, the addition of fibres significantly reduces the workability. Steel lath waste fibres contribute more in workability reduction than nylon waste fibres. There is no significant improvement in the compressive strength of concrete due to the addition of industrial waste fibres. A maximum increase in compressive strength of the order of 15% over plain concrete was achieved using steel 2/3rd + nylon 1/3rd. There are close relationships obtained in between the density and compressive strength of concrete. Similar pattern of improvement has been obtained between the compressive strength and the modulus of elasticity.
- A 54% increase in split tensile strength with respect to plain concrete was achieved in two fibre mixes 'steel 2/3 + nylon 1/3' and 'steel ½ + nylon ½' at volume fraction of 2%. Adding hybrid fibre combination of 'steel ½ + nylon ½'at 2% volume fraction to concrete influences the maximum modulus of rupture by 50%.

REFERENCES

1. Song PS, Hwang S. Mechanical properties of high-strength steel fiber-reinforced concrete, *Cement and Concrete Research*, **18**(2004)669-73.
2. Hsie M, Tu Ch, Song PS. Mechanical properties of polypropylene hybrid fiber reinforced concrete, Mater of Science and Engineering – A, **494**(2007)153-7.
3. Banthia N, Soleimani SM. Flexural response of hybrid fiber Reinforced cementitious composites, *ACI Materials Journal*, **102**(2005)382-9.
4. Sekar T. Fibre reinforced concrete from industrial waste, *Institution of Engineers Journa (India)l*, **84**(2004)287-90.
5. Samson M, Niranjana G, Jaypalan P. Scrap steel fibre reinforcement for strength enhancement of rigid pavement, National conference, workshop and exposition on trends in road making materials, methods and machines for quality, economy and speed, LNCT, Bhopal, India, 2007, pp. 61-75.
6. Sivaraja M and Kandasamy S. Reinforced concrete beams with rural composites under cyclic loading, *Journal of Engineering and Applied Sciences*, No. 11, **2**(2007) 1620-6.

7. Sivaraja M, Kandasamy S. Characterization of concrete composites for energy absorption, *Journal of Reinforced Plastics and Composites*, No. 2, **27**(2008)135-44.
8. Sivaraja M, Kandasamy S. Seismic behaviour of exterior beam-column joint with fibre Composites, *National Building Materials and Construction World*, No. 5, **14** (2008) 295-300.