Modification of Concrete Railway Sleeper Mix Design, Using a Hybrid Application of Steel Fibers

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Abstract: Concrete railway sleepers have been used for years without an update in production and design, to be compatible with demands for increasing train axle loads and speed. In the current research, concrete railway admixture is modified with consuming (0.5% straight-1.5% hooked), (1.5% straight-0.5% hooked) and (1% straight-1% hooked) steel fibers combinations. Three main mechanical experiments as compressive, flexural and splitting tensile strengths and fresh mortar "flowability" were performed. Results showed that the hybrid of 1% straight and 1% hooked steel fibers shows the optimal performance among other hybrid combinations. This hybrid admixture efficiently improves the compressive, flexural and splitting tensile strengths of the concrete railway sleeper mix design.

Keywords: Concrete railway sleeper; Steel fibers; Optimal hybrid reinforced concrete

1   Introduction

Railway sleeper are one the critical components of railway tracks, which have a role to distribute and decrease train loads from the rail foot to the underlying ballast bed and consequently to subgrade [1-3]. The traditional sleepers are manufactured using timber, concrete and steel [4]. Wooden sleepers are contained in the majority part of railway tracks, but concerning their environmental disadvantages, were gradually replaced by the other types of sleepers [5]. In order to replace wooden sleepers, steel

sleepers, as an alternative, were used [6]. Considering the performance of steel sleepers, they face problems in high speed of train and corrosion issues [7].

Concrete sleepers are extensively used in railway engineering [8]. Their performance in railway tracks leads to less maintenance cost, track stability and longer life cycles [9-, 10, 11, 12]. Pre-stressed concrete has different kinds that mono-block concrete sleeper is one of the most popular kinds implemented in railway tracks [13]. Recently, by increasing axle load, speed and traffic, finding a better quality of concrete sleepers is an approach. The common behaviors of sleepers under overloading or fatigue are tensile fracture, longitudinal and cross cracks under rail seat of railway tracks [20] [21]. Occasionally, it has been seen that the tensile strength of sleepers is not enough and leads to some physical damage. An effective solution is use of fiber reinforced concrete. Consuming short, discrete or long fibers lead to a new construction material challenges [14]. Fiber-reinforced concrete (FRC) is produced in different types mixed during fresh concrete production [15], and leads to an increase in mechanical performance of concrete [16]. Almost four popular kinds of fibers fabricated from steel, plastic, glass, and natural materials are consuming in a variety of shapes, sizes, and thicknesses. Three kinds of steel fibers in shapes of straight, hooked and crimped are commonly preferred to use [17]. It is concluded that using hybrid shape of steel fibers has the best influence on concrete performance [18].

Recently, by proving the performance of steel fibers in concrete admixtures, some researchers have tried to assess its behavior combined with concrete sleeper admixtures. Sadeghi et al. [19] followed two approaches, firstly, the effects of straight steel fibers on the mechanical behavior of pre-stressed concrete sleepers with the different percentages in contents of (0, 0.3, 0.5, 0.7 and 1% by volume) and, secondly, decreased the number of pre-stressed rebars. The results indicate that consuming steel fibers in concrete sleeper admixtures leads to an improvement in the sleeper bending strength, energy absorption capacity, and cracking resistance increase. Zhu et al. [20] investigated the effects of straight steel fibers on production cost and cracks opening in a concrete beam with polymer rebars. The results showed that all parameters of crack width, ductility and cost decreased due to presence of steel fibers. Shin et al. [21] assessed the effects of straight steel fibers mixed with different kinds of fine aggregates in pre-stressed concrete railway sleeper admixtures. The results showed that the fraction of 0.75% of steel fibers mixed with slag concrete leads to enhance its static and impact flexural capacity. Parvez and Foster [22] inspected the performance of straight steel fibers in carrying capacity and fatigue of railway sleepers. Pre-stressed concrete sleepers were researched with fiber contents of 0, 0.25% and 0.5% by volume, under cyclic and static loading. The sleepers with 0.5% fibers have higher static capacity and extended fatigue life, lower deflections and finer crack widths compared to those sleepers without fibers. Moreover, Hwang et al. [23] tried to design pre-stressed sleepers with 0.75% steel fibers by volume and features of 30 mm length and aspect ratio of 55 [24]. Results showed that toughness and durability of sleepers were improved.

None of the aforementioned papers have assessed hybrid behavior of steel fibers in railway concrete sleeper mix design. In order to decrease fiber content and increase mechanical performance of concrete, hybrid use of steel fibers with low aspect ratio is proposed that consequently, reduce the disadvantages of the presence of steel fiber in concrete admixtures. Therefore, in the current research, respect to different admixture and low aspect ratio of steel fibers, performance of single and hybrid steel fibers are investigated, to improve concrete railway sleeper mix design.

2 Experimental Program

2.1 Concrete Sleeper Test

The sleeper under test is a commercially available mono-block type used for high speed railways. The pre-stressed concrete sleeper consists of almost 320 mm × 260 mm × 2600 mm dimensions with 10 numbers of Ø7 mm strands. The lowest width and height of the sleeper structure are by 280 mm and 185 mm, respectively. European standard EN 13230-2 [25] provides guidelines for calculating reference test loads for different concrete sleeper types. As shown in Figure 1, sleeper is tested in middle negative bending moment test with flexural strength of 70 kN, (the load that the first crack is identified by operator using portable microscopes). Figure 2 shows load against deflection of sleeper under flexural load. Load is applied until 140 kN to capture bending behavior of sleeper. Until 20 kN, sleeper shows more flexibility and less stiffness, however, it has a sharp increase in sleeper stiffness after 20 kN flexural load. The first crack has been seen in almost 70 kN, when the sleeper stiffness has been reduced again due to the crack initiation.

Figure 1
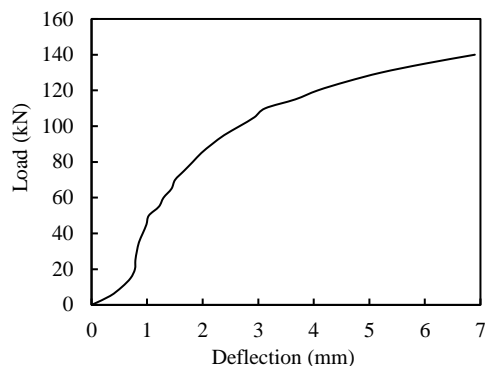The middle negative bending moment test

Figure 2
The flexural strength of concrete sleeper

2.2   Steel Fiber Reinforced Concrete

2.2.1   Materials and Mix Proportion

Ordinary Portland Cement (II) and silica fume was consumed in this research. A polycarboxylate superplasticizer including air entraining agent, 40% solid and 60% water with specific gravity of 1.09 and solid contents of 32% was used in all the concrete mixtures. Furthermore, steel fibers with properties according to the Table 2 have been used. 4 mixtures are presented in Table 1, Ref. mixture is without any steel fiber and is concrete sleeper mix design. The workability and mechanical properties of the concrete mixtures were considered to select the optimal admixture with hybrid use of steel fibers. To combine powder materials with concrete admixture, they are mixed before the water and superplastisizer addition, in this way particle agglomeration can be avoided. Firstly, the fine aggregates are mixed in the mixer contains quartz sand. Afterwards, the powder materials are added to mixer's contents and mixed for around 4 minutes. Then almost half of the 2% (by cement weight) high-range superplastisizer is diluted in the admixture water and is gradually added within 2 minutes. The remaining superplastisizer are gradually added during a next 4 minutes of mixing. Steel fibers are added in three parts, in first, middle and almost at the end of mixing time. The fresh concrete is placed in two kinds of molds as 100 * 100 * 400 mm prismatic and 100 mm cubical. Vibration table is used for 2 minutes. The specimens without movement are covered with plastic sheets and are kept at 240 ℃ for a day before demolding. After demolding, the samples are cured in an autoclave system with heat and vapor. By using this system, concrete sleeper cure system is simulated as Figure 3. Firstly, specimens are cured at 20 ℃ for 73 hours of cure time, then the heat is smoothly raised to 90 ℃. This much heat is stable for 50 hours, afterwards, it is slowly reduced to

20 ℃ again (Fig. 2). It should be mentioned that for validity of test results for each mix, 3 specimens are constructed and tested.

Table 1

Concrete admixtures

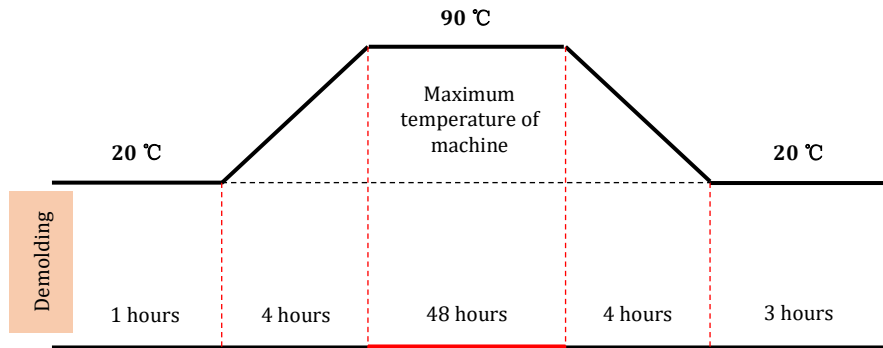| No.	Cement	Quartz sand	Silica fume	Water	Admixture	Volume content (%)		Notation
						Straight fiber	Hooked fiber	
1	706	1255	160	124	68	-	-	Ref.
2	706	1255	160	124	68	0.5	1.5	S05H15
3	706	1255	160	124	68	1	1	S10H10
4	706	1255	160	124	68	1.5	0.5	S15H05

Figure 3

Steam curing process of concrete specimens in curing machine

Table 2

Steel fibers properties

Type of fiber	Diameter	Length	Aspect ratio	Density	Tensile strength	Elastic modulus	Picture
	(mm)		(l_f/d_f)	(g/cm^3)	(MPa)	(GPa)	
Straight fiber	0.2	13	65	7.8	2850	200	
Hooked fiber	0.3	22	73	7.8	2850	200	

2.2.2   Compressive Strength Test

The compressive strength results of different admixtures are shown in Figure 5. The results indicate that the presence of steel fiber increases compressive strength. Hybrid fiber content (S10H10) has more compressive strength as 171 Mpa that shows better performance. Flowability of concrete mixtures is measured using slump test. S10H10 hybrid concrete has 108 mm flowability. It should be noted that in case of concrete sleeper production, the low value of flowability cannot make a significant problem, because in production procedure of concrete sleepers a special vibration system has been used that can overcome this much of low value of flowability. The references compressive strength is about 93 Mpa, which increased by adding hybrid fibers. S05H15 has a compressive strength value by 40% greater than Ref., these percentages for S10H10 and S15H05 are almost 45% and 44% higher, respectively. Therefore, the comparison of results shows that S10H10 admixture has the maximum value of compressive strength but with minimum flowability as 108 mm.

Figure 4
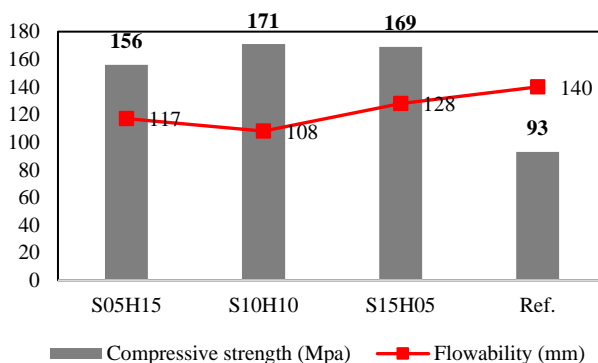
An overview of compressive strength test machine

Figure 5

Compressive strength and flowability of concrete specimens

2.2.3   Flexural Strength Test

Figure 6 shows flexural test instrument machine. The diagram of flexural strength for concrete admixtures is shown in Figure 7. The results indicate that addition of steel fiber results in a significant increase in the flexural strength value. The flexural strength of S05H15, S10H10 and S15H05 increase by 52%, 55% and 50%, respectively, compared to Ref. It should be paid attention that the summation of total hybrid fiber percentage usage in every admixture is 2%. For instance, 0.5% straight plus 1.5% hooked fibers equal to 2%. Therefore, three kinds of hybrid admixtures do not show a significant difference but among those S10H10 has better performance. It should be noted that performance of 2% hybrid fiber is 55% more than Ref. Concrete sleepers according to their loading pattern with trains, may face high bending moments, therefore, flexural strength is critical in their performance.

Figure 6
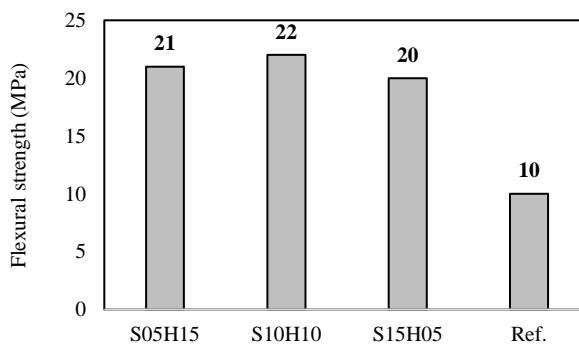An overview of flexural test layout

Figure 7
Flexural strength test results of concrete specimens

2.2.4   Splitting Tensile Strength

The splitting tensile strength of the different admixtures were prepared in this study that are shown in Figure 10. Concrete has weakness in tension. Thus, splitting tensile strength test is necessary to determine the load at which the concrete members may crack (Figures 8 and 9). The results indicate that the presence of fibers in admixture significantly improves the concrete splitting tensile strength. Among different admixtures considered, the highest strength value is achieved by the admixture containing S10H10. The splitting tensile strength of S05H15, S10H10 and S15H05 admixtures increase by 77%, 80% and 77% compared to Ref., respectively. In case of hybrid consumption of steel fibers, the summation of each percent of hooked or straight is 2%, therefore, a great deviation between tensile strength of admixtures cannot be seen. Maximum value of tensile strength belongs to S10H10 admixture with value of 24 Mpa. Tensile strength is part of those features that is critical in pre-stressed concrete sleepers, therefore, improving tensile strength of concrete mix design makes sleepers better in dynamic performance.
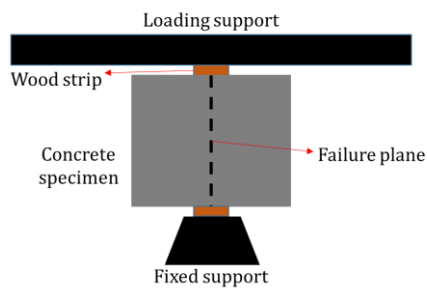

Figure 8
A schematic of Splitting tensile test

Figure 9
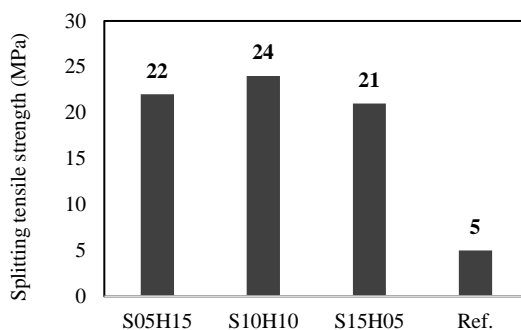Splitting tensile test layout of concrete specimens

Figure 10
Splitting tensile strength of concrete specimens

3   Results and Discussion

This study shows the improvement of the physical and mechanical properties of railway concrete mixtures, by the application hybrid steel fibers. Because, content of more than 2% steel fiber in concrete mixture, generally, reduces workability and fiber dispersion, it is therefore required to apply a special mix design or special concrete casting techniques. Thus, the concrete mixture has been hybridized by adding fibers with S05H1.5, S10H10 and S15H05. The mechanical properties for all mixtures were measured and compared with compressive, tensile and flexural strengths, to determine the performance of railway concrete mix design (Table 3).

Table 3
Steel fibers properties

Notation	Compressive strength	Splitting tensile strength	Flexural strength
	MPa		
Ref.	93	5	10
S05H15	156	22	21
S10H10	171	24	22
S15H05	169	21	20

The test results show that the mechanical performance of admixture S10H10, has the best performance among all the admixtures. It can be due to the same load of single and hooked shape fibers, which provide better mechanical performance for concrete. It can be concluded that to obtain compressive strengths of more than 170 Mpa, hybrid fibers can be an effective solution. Concrete quality plays a critical role in load bearing of concrete sleepers, as well as, its pre-stressing system. Therefore, it is expected as the quality of concrete is increased and the pre-stressing systems

of conventional pre-stressed concrete sleeper and steel fiber pre-stressed concrete sleeper are identical, steel fiber pre-stressed concrete sleeper shows better performance due to the better mechanical performance of its steel fiber concrete.

Conclusions

In this study, 4 admixtures are prepared in order to investigate the performance of hybrid fibers and their influence, on concrete railway sleeper mix design. To study hybrid use of steel fibers and compare their behavior, different fiber contents as, (0.5%straght-1.5%hooked), (1%straght-1%hooked) and (1.5%straight-0.5%hooked) are considered to research. The main focus of the current study is on the mechanical behavior of concrete railway sleeper mix design, by performing compressive strength, flexural strength and splitting tensile strength experiments. The following points can be concluded from this study:

1) S05H15 has a compressive value 40% greater than Ref., these percentages for S10H10 and S15H05 are 45% and 44% higher, respectively.

2) The flexural strength of S05H15, S10H10 and S15H05 increased by 52%, 55% and 50%, respectively, compared to Ref.

3) The splitting tensile strength of S05H15, S10H10 and S15H05 admixtures increase by 77%, 80% and 77% compared to Ref., respectively.

4) **S10H10 hybrid steel fiber mix design shows the best performance in case of mechanical properties and is a good choice to fiberize concrete railway sleeper mix design.**

Acknowledgement

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