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RESEARCH ARTICLE

Performance of Steel Fiber Reinforced Concrete under Different Cooling Methods at High Temperature

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ABSTRACT - To explore the tensile properties of steel fiber reinforced concrete under different cooling methods after high temperatures, this paper considers steel fiber reinforced concrete after five different temperatures, under natural cooling and rapid water cooling, conducting split-tension mechanical property studies. The failure form and splitting peak stress of steel fiber reinforced concrete under different working conditions are obtained by experiments, comparative analysis of cooling methods, influence of high temperature and steel fiber content on tensile properties of concrete splitting, the main conclusions are as follows: as the temperature rises, the failure pattern of steel fiber reinforced concrete developed from one main penetrating crack to several cracks on the specimen surface; the addition of steel fiber can effectively improve the plastic characteristics of concrete, the apparent cracks in the concrete also increase. As the temperature rises, the peak tensile stress of steel fiber reinforced concrete decreases gradually, the increase in temperature leads to some extent to a greater influence of steel fiber on the mechanical properties of concrete splitting; as the steel fiber dosage increases, significant increase in concrete splitting mechanical properties, concrete splitting peak stress after high temperature is relatively high. The peak stress of concrete splitting under natural cooling is lower than that under rapid water cooling. At the same time, mathematical modeling of the effect of steel fiber admixture and high temperature on the peak splitting tensile stress of concrete under two cooling methods is derived, and the force mechanism is discussed and analyzed. The results of the study provide a theoretical basis for the analysis and calculation of steel fiber concrete structures after fire.

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1.0 INTRODUCTION

Steel fiber concrete is a multi-phase composite concrete material formed by mixing an appropriate amount of steel fiber into ordinary concrete, the presence of steel fiber can effectively inhibit the evolution and expansion of internal cracks in concrete, and at the same time, it can effectively improve the tensile, impact and fatigue properties of concrete, it is applied to the key stress area of the structure [1-4]. There are fire safety problems in the concrete structure during normal use, after the fire, the concrete structure generally adopts the water-cooling method to control the fire development in time, it is valuable to study the mechanical properties of steel fiber concrete after high temperatures in conjunction with the effect of cooling method, the importance for the computational assessment of the safety of steel fiber concrete structures after fire [5].

The study of mechanical properties of concrete after high temperatures generally focuses on temperature, temperature rise, and influencing factors such as cooling method and resting time. For temperature influencing factors, the results of the study show that an increase in temperature will lead to a sharp deterioration in the mechanical properties of concrete, and increased plastic deformation capacity, where after exceeding 400°C, rapid deterioration of their mechanical properties [6-7]. Some researchers have found that concrete strength increases and then decreases with increasing temperature, at temperatures up to 800°C, concrete loses its durability, basic loss of load bearing capacity at 900°C [8-10]; Loss of load bearing capacity of specimens after 1000°C of natural rubble concrete [11-12]; Steel fiber concrete heated at 800°C has a compressive strength of 8.5% of room temperature [13]. For factors affecting the rate of temperature increase, the results show that the higher the rate of warming, the faster the deterioration of the mechanical properties of concrete, at the same time, an increase in the rate of warming will increase the likelihood of concrete bursting at high temperatures [14]. For cooling method and resting time influencing factors, when the resting time is less than 3 days, rapid water-cooling results in a relatively significant deterioration of the mechanical properties of concrete compared to natural cooling, as the resting time increases, secondary hydration of concrete in rapid water-cooling mode, restore the stress to a certain extent [15-16].

Analysis of the literature shows, that the mechanical properties of steel fiber concrete after high temperatures are mostly focused on the study of mechanical properties in compression, less literature on split-tension force analysis. It has been shown in the literature that the incorporation of steel fibers can not only effectively improve the mechanical

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properties of concrete, it also improves the residual mechanical properties of concrete after high temperatures and reduce the risk of bursting during high temperatures [17-18]. However, regarding the split tensile mechanical properties of steel fiber concrete after high temperatures although some research literature exists, there is no research on the splitting and tensile damage mechanism and calculation model of steel fiber concrete with different cooling methods. The research in this paper is characterized by the clarification of the mechanism of the effect of steel fiber admixture and high temperature on the splitting and tensile damage of concrete, proposes a computational model, and has some research value.

In this paper, the hydraulic servo machine is used to carry out experimental research on the splitting and tensile mechanical properties of concrete after different steel fiber admixtures and different high temperatures, considering the natural cooling method after high temperature and fast water cooling method, obtaining splitting damage patterns and peak splitting stresses of steel fiber concrete under different loading conditions, this analyses the effect of steel fiber dosage and high-temperature influences on the splitting tensile mechanical properties of concrete under the two cooling methods.

2.0 EXPERIMENTAL PROGRAM

2.1 Test Materials

In this paper, the design strength class is 40MPa ordinary concrete, the main raw materials used in the preparation of concrete are cement, water, fine aggregates, and coarse aggregates. In which the cement is ordinary silicate cement P.O 42.5 grade; fine aggregate is natural river sand, river sand with fineness modulus of 2.3~3.0, average particle size is 0.35mm~0.5mm; coarse aggregate is natural aggregate crushed stone, grain size range 4~16mm. According to the "Design Regulations for Proportioning of Ordinary Concrete (JGJ55-2011)", determine the concrete strength class C40 for this paper, mix proportion as shown in Table 1. The steel fiber used is end-hooked, with parameters as in Table 2, shape as shown in Figure 1.

Table 1. Concrete mixing ratios with different steel fiber admixtures

Steel fiber content (quality ratio)	Water (Kg/m^3)	Cement (Kg/m^3)	Sand (Kg/m^3)	Coarse aggregate (Kg/m^3)	Steel fiber (Kg/m^3)
0%	202	450	670	1095	0
1%	202	450	670	1095	24.17
2%	202	450	670	1095	48.34
3%	202	450	670	1095	72.51

Table 2. Characteristic parameters of steel fiber

Types of steel fiber	Average length L_f (mm)	Equivalent diameter D_f (mm)	Modulus of elasticity	Ultimate tensile strength
End hook type	35	0.5	210MPa	1000MPa

Figure 1. End-hooked steel fiber

Pouring of concrete specimens according to the mixing ratios in Table 1, pour the cement, fine aggregate, and, steel fiber into the mixer and mix well, the coarse aggregate is then poured into the mixer and mixed well again, slowly pour the weighed water into the mixture, mix well and pour into the mold, fully compact the concrete mix with a vibrating rod. Demoulding after 24 hours, placed in a standard maintenance room for curing, curing room temperature 20±3°C, humidity 95%, samples were taken immediately after 28 days of maintenance for experimental testing in this paper.

2.2 Test Equipment and Programmes

In this paper, the process of high-temperature treatment of concrete consists of three main stages. The first stage is pre-processing, placing the concrete in a hot oven and baking for 2 hours, setting the temperature to 100°C, the main consideration is to dry the water in the concrete, and control of bursting concrete during warming; The second stage is the warming process, determined by the "building components fire test method (GB / T 9978-2008)" specimen heating mode, place the pre-treated specimens in a high-temperature furnace, set the temperature rise rate to 5°C/min, constant temperature for 90min after reaching the set temperature. The compressive strength of concrete decreases rapidly under the influence of high temperatures of 1000°C, about 10% of the compressive strength of concrete at room temperature. When under the influence of high temperature at 800°C, the compressive strength of concrete is 20-30% of that at room temperature [19-20]. Therefore, in this paper we consider five different temperature effects, normal temperature, 200°C, 400°C, 600°C and 800°C respectively; The third phase is the cooling down phase, there are two types of cooling, natural cooling, and fast water cooling respectively, the rapid water-cooling method is to place the specimen after high-temperature treatment in water for rapid cooling treatment, dry and leave for 30 days after treatment. After three stages of treatment, experimentation to follow.

For the uniaxial split tensile mechanical property test of concrete after high-temperature treatment, test loading by hydraulic servo, setting up a load cell and displacement sensor at the loading end, testing the use of axial load terminals to complete loading, maximum load range of 100 tonnes for axial devices, accuracy ± 0.1% of maximum load range, maximum displacement of axial device 100mm, accuracy ±0.0005mm. Experimental study on the mechanical properties of concrete splitting and tensioning using Brazilian disc specimens, the specimen loading schematic and specific dimensions are shown in Figure 2, the concrete specimen diameter is 74mm, the thickness is 37.5mm, the loading angle of 20^0, the specimen loading rate was 0.08m/s. From this Equation 1 is applied to calculate the tensile stress in the concrete specimen.

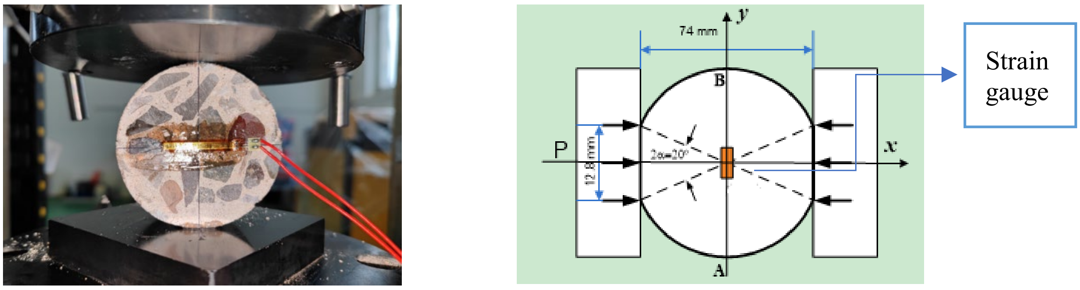


Figure 2. Schematic diagram of concrete split-tension loading method

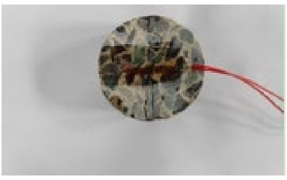
$$\sigma_t = \frac{P}{\pi BR} \Upsilon(\theta) \tag{1}$$

Formula: Y is a parameter related to the loading angle, when2α=0, then Y =1, consistent with the formula used for conventional Brazilian discs, this paper 2α=20º, Y=0.964; P is the value of the applied split tensile load, unit KN. Analysis of the effect of different loading angles on the resulting tensile stresses using finite element theory [21-22].

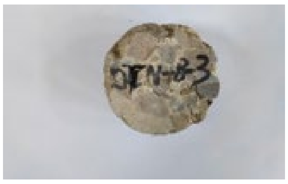
3.0 ANALYSIS OF TEST RESULTS

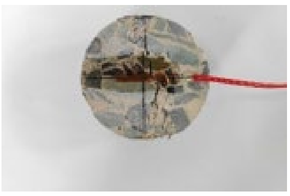
3.1 Destructive Form

According to the test plan, obtaining splitting and tensile damage patterns of steel fiber concrete under different loading conditions. The steel fiber dosage was selected as 0%, analysis of the effect of high temperature on concrete damage patterns, Select high temperature 200℃, analysis of the effect of steel fiber admixture on the damage pattern of concrete. The damage patterns of naturally cooled and rapidly water-cooled concrete are shown in Figures 3-4 respectively.


(a) 0%-200℃


(b) 0%-400℃


(c) 0%-600℃


(d) 1%-200℃


(e) 2%-200℃


(f) 3%-200℃

Figure 3. Split-tension damage pattern of steel fiber concrete under natural cooling mode

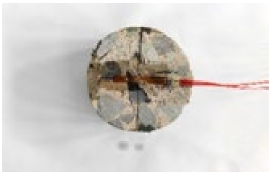
Analysis by Figure 3, under natural cooling after high temperature, the failure modes of concrete with different steel fiber content under splitting tensile load are different. When the content of steel fiber is 0%, concrete shows brittle failure characteristics under splitting tensile load, the surface of the specimen is damaged by penetrating cracks. When the content of steel fiber is not 0%, the specimen shows certain toughness characteristics under splitting tensile load, and the failure mode of sudden fracture will not occur, affected by steel fiber, after the specimen is destroyed there will be no complete fracture, there are a few steel fiber connections. As steel fiber dosage increases, the gradual reduction of apparent crack size in concrete specimens, and the gradual increase in number, the longer it takes for the specimen to reach destruction under split-tension loading. Subject to the effects of temperature, as the temperature increases, the concrete surface develops from a greenish color to a pale yellow, and then it turns grey, at the same time, the increase in temperature leads to fine cracks all over the concrete surface, fracture between mortar and coarse aggregate, when temperatures above 400°C, the apparent form is particularly obvious. Thus at lower temperatures, concrete subjected to split tensile loading tends to produce a penetrating type of main crack in the center of the specimen, when the temperature is increased to 400°C, the temperature increases, the specimen under load, the apparent morphology of the specimen is easy to produce uniformly distributed multi-crack failure morphology, at the same time the concrete splitting tensile load under the action of the damage pattern presents the less obvious brittle characteristics. Different steel fiber admixture concrete in the high temperature after the natural cooling effect of splitting tensile damage morphology are showing the rule of change of the law.

(a) 0%-200°C

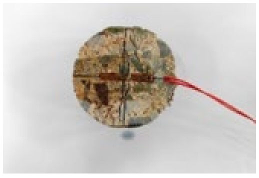
(b) 0%-400°C

(c) 0%-600°C

(d) 1%-200°C



(e) 2%-200°C



(f) 3%-200°C

Figure 4. Split-tension damage pattern of steel fiber concrete under rapid water-cooling mode

Analysis according to Figure 4, fast water cooling after high temperature, concrete affected by steel fiber mixing split tensile load under the action of the destruction of the pattern of change law and the natural cooling mode is the same, at the same time the concrete is affected by high temperature and its destruction pattern is similar to the natural cooling method. The difference is that the concrete in the rapid water-cooling mode is subjected to splitting tensile loads with a relatively high number of cracks in the apparent form, and relatively large crack sizes.

3.2 Peak Stress

Calculations based on the test loading program and equation 1, obtaining peak stresses in steel fiber concrete splitting for different loading conditions, analysis of the effect of steel fiber dosage, high temperature, and cooling method on the peak splitting stress of concrete, as shown in Table 3. From Table 3 peak stress of steel fiber concrete splitting for different working conditions, the effects of steel fiber dosage, high temperature, and cooling mode on the peak stress of concrete splitting were investigated separately. The splitting strength of steel fiber concrete decreases progressively with increasing temperature. For high temperatures with natural cooling, when the steel fiber dosage is 0%, steel fiber concrete is affected by temperature by reducing the peak split tensile stress from 2.42MPa at room temperature to 0.18MPa at 800°C, the year-on-year split peak stress reduction was 92.65%.

Table 3. Peak stress in splitting of steel fiber concrete for different working conditions (MPa)

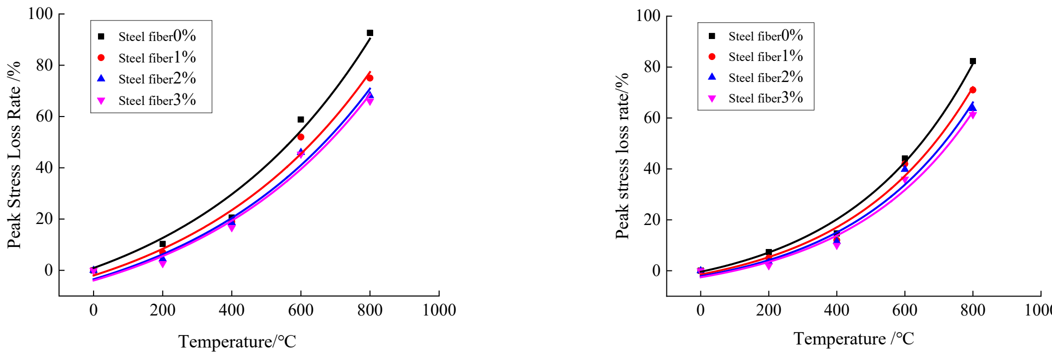
Temperature / Dosage	NT	200℃		400℃		600℃		800℃	
Cooling method	N/W	N	W	N	W	N	W	N	W
0	2.42	2.17	2.24	1.92	2.06	1.00	1.35	0.18	0.96
1%	3.56	3.31	3.38	2.88	3.13	1.71	2.06	0.89	1.78
2%	4.02	3.84	3.88	3.27	3.56	2.17	2.42	1.28	2.17
3%	5.33	5.19	5.23	4.44	4.80	2.92	3.41	1.81	2.95

Note: (Normal Temperature: NT; Natural cooling: N; Fast water cooling: W)

When steel fiber dosage is 1%, 2%, and 3%, the peak splitting stress of steel fiber concrete as affected by the action of high temperature, from normal temperature to 800°C, their peak splitting tensile stresses were reduced by 75.00%, 68.14%, and 66.00% respectively. For high temperature and then fast water cooling, at 0%, 1%, 2%, and 3% steel fiber dosage, the maximum reductions in peak split tensile stress of concrete subjected to high temperatures were 82.35%, 71.00 %, 63.72 %, and 61.33%. From the overall trend analysis, with two different cooling methods, the incorporation of steel fiber results in a gradual increase in the residual mechanical properties of concrete subjected to high temperatures, with a gradual decrease in the peak stress loss.

As the steel fiber dosage increases, the peak concrete split tensile stress shows a gradual increasing trend. When the temperature is at normal temperature, the peak split tensile stress of concrete increased from 2.42MPa at 0% steel fiber dosage to 5.33MPa at 3% steel fiber dosage, an increase of 2.20 times. In natural cooling mode, at temperatures of 200°C, 400°C, 600°C and 800°C, the peak concrete split tensile stresses were increased by 2.39, 2.31, 2.92, and 3.94 times respectively by the effect of steel fiber. When the temperature is 800°C, concrete without steel fiber is almost impossible to withstand split tensile loads, incorporation of a certain amount of steel fiber can effectively increase the peak splitting tensile stress of steel fiber concrete after high temperatures. With fast water cooling, at temperatures of 200°C, 400°C, 600°C and 800°C, the peak concrete split tensile stresses were increased by 2.33, 2.33, 2.53, and 2.15 times respectively by the effect of steel fiber. Analysis of the overall trend, the incorporation of steel fiber was effective in increasing the peak splitting tensile stress of concrete, the increase in the peak stress of concrete splitting by steel fiber in the natural cooling method after high temperature is higher than in the rapid water-cooling method.

Analysis of the effect of different cooling methods on the peak stress of steel fiber concrete splitting, affected by two types of cooling, the peak stresses in the splitting of steel fiber concrete were lower in the natural cooling method than in the rapid cooling method. At a temperature of 200°C, the peak split tensile stresses of the four different steel fiber dosage concrete rapid water-cooling methods were in the range of 1% ~ 3% higher than those of the natural cooling method. Temperature 400 °C, 600 °C, and 800 °C, fast water-cooled mode splitting tensile peak stress compared with the natural cooling mode range of 1% ~ 3%, 7% ~ 9%, and 13% ~ 16% respectively. From the general trend analysis, as the temperature increases, there is a gradual increase in the interval of change of the peak stress of steel fiber concrete splitting under the influence of cooling mode. Analysis of the temperature dependence of the peak stress loss rate of steel fiber concrete split tensile by the natural cooling method and the fast water-cooling method by Figure 5, based on image-only science, the expression shown in Equation 2 is proposed. Formula, γ is the rate of loss of peak stress in concrete splitting tension, namely γ= fT /f0, among fT is the peak stress in split tensile of steel fiber concrete at different temperatures, f0 is the peak splitting stress of steel fiber concrete at room temperature, unit: %; T is a temperature parameter, unit: °C ; γ0, a and b indicate the parameter value to be determined.



(a) Natural cooling (b) Fast water cooling

Figure 5. Effect of temperature on the rate of loss of peak stress in split tensile steel fiber concrete

$$\gamma = \gamma_o + a \times e^{-\frac{T}{b}} \tag{2}$$

Consideration of temperature on different steel fiber dosage of concrete splitting tensile peak stress loss rate change rule is the same, and simplifying parameter considerations, mathematical regression analysis of the rate of peak stress loss in steel fiber concrete splitting by applying Equation 2 to the two different cooling methods of steel fiber concrete in this paper, obtaining the resultant parameters γ0 and b are minimally affected by the steel fiber dosage, from this, the mean values of parameters γ0 and b were extracted for the four steel fiber dosages, thus determining that the parameters γ0 and b are the same values for different steel fiber dosages, Analysis of parameter an at different steel fiber dosages. As a result, the temperature dependence of the peak stress loss rate of steel fiber concrete splitting under natural cooling and rapid cooling are shown in Equations 3-4 respectively.

$$\gamma = -24.94 + a \times e^{\frac{T}{535.26}} \tag{3}$$

$$\gamma = -10.88 + a \times e^{\frac{T}{367.83}} \tag{4}$$

Mathematical regression analysis applying the temperature parameters of the two cooling methods in this paper and the rate of loss of peak stress in the splitting of steel fiber concrete, the relationship between parameter a and steel fiber dosage was obtained, as shown in Figure 6.

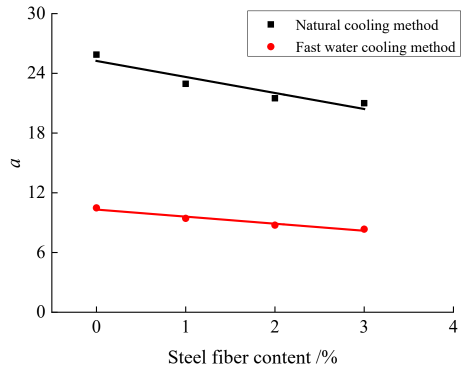


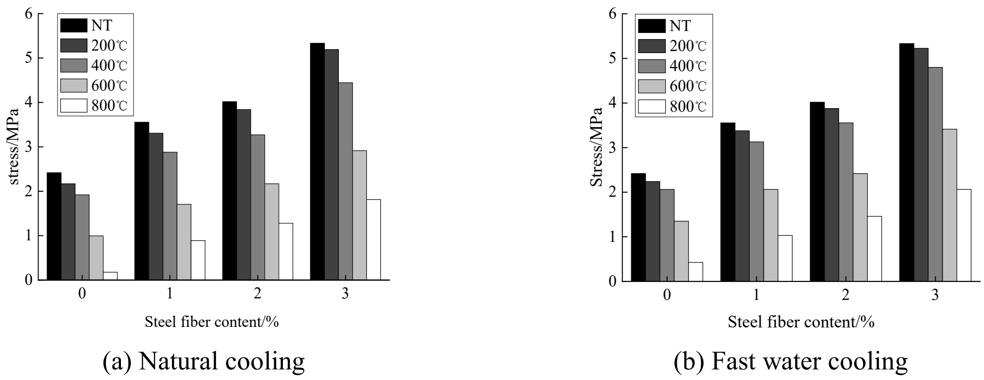
Figure 6. Relationship between steel fiber dosage and parameter *a*

According to Figure 6 analysis of the relationship between steel fiber dosage and parameter a for different cooling methods, the relationship between the two is linear, therefore the steel fiber quantity ξ and parameter a are analyzed by mathematical regression, to obtain the mathematical model relationship between the two and substitute them into Equations3-4respectively, mathematical modeling of the relationship between temperature and steel fiber dosage on the rate of loss of peak stress in concrete splitting under natural and fast water-cooling methods, as shown in Figure6 and Equations5-6.

$$\gamma = -24.94 + (25.25 - 1.61 \times \xi) \times e^{\frac{T}{535.26}} \tag{5}$$

$$\gamma = -10.88 + (10.32 - 0.71 \times \xi) \times e^{\frac{T}{367.83}} \tag{6}$$

Analysis of the test data, as shown in Figure 7, the steel fiber dosage increases, concrete splitting peak stress shows a gradual increasing trend, increase in temperature leads to a tendency for the peak concrete splitting stress to increase as a result of the steel fiber admixture. Analysis of the mechanistic causes, that end-hooked steel fiber has a large adhesive force and clamping force with the cementitious material, under splitting load, steel fiber can produce a bridging effect, thus as the steel fiber dosage increases, concrete splitting peak stress shows a gradual increasing trend. After the action of high temperature, the cementitious materials and coarse aggregates in concrete are different due to the thermophysical parameters, which produce uneven deformation, and improved bonding between mortar and steel fiber, the resulting increase in temperature leads to a gradual increase in concrete splitting tensile stress as a result of the steel fiber dosage.



(a) Natural cooling (b) Fast water cooling

Figure 7. Effect of different temperatures on splitting strength of steel fiber concrete
NT-- Normal Temperature

4.0 DISCUSSION

Based on relevant references, combined with the research data in this paper, a comparative analysis of splitting and tensile mechanical properties of concrete after high temperature, as shown in Table 4. Temperature ranges from room temperature to 1000°C, as the temperature increases, gradual decrease in peak split tensile stress in plain and steel fiber concrete. When the temperature reaches 1000°C, the concrete surface is covered with cracks, loose serious, burst phenomenon, and split tensile force after showing powder, bearing capacity tends to zero. After the high temperature of ordinary concrete, the peak split tensile stress after natural cooling is higher than the peak cooling by water spraying. In steel fiber concrete at high temperatures, the split tensile stress peak after natural cooling is lower than the water jet cooling peak, with the addition of steel fiber, under the same temperature condition, the peak stress of split tensile tends to increase.

From the analysis, as the temperature increases, the peak concrete splitting stress decreases gradually, incorporation of steel fiber can effectively improve the mechanical properties of concrete splitting after high temperature, consistent with the findings of several scholars [5,24-25]. Relatively higher peak stresses in steel fiber concrete splitting under rapid water cooling after high temperature than under natural cooling, at the same time, the bridging effect provided by steel fibers in the fast water-cooling method is higher than in the natural cooling method. Increased temperatures lead to varying degrees of physicochemical reactions in the mortar and coarse aggregates of concrete and different thermophysical parameters of mortar and coarse aggregate, lead to deformation incongruity of mortar and coarse aggregate after high temperatures, which results in varying degrees of damage within the concrete, the higher the temperature the greater this type of damage, and ultimately the peak concrete splitting stress decreases progressively as the temperature increases, validated several research findings[26-27]. The chemical reaction of cementitious mortar materials after high-temperature action, the secondary reaction of cooling water after rapid water cooling with decomposed components of mortar and coarse aggregate after high temperatures, over time, the reaction will become progressively more pronounced and the mechanical properties of the concrete will be restored to some extent, the test was conducted for 30 days after high temperature, after the hydration reaction, the adhesion between the mortar and the steel fiber interface is improved to a certain extent, this ultimately leads to relatively higher peak stresses in steel fiber concrete splitting in the fast water-cooling method than in the natural cooling method, the bridging effect provided by steel fiber in the fast water cooling method is higher than in the natural cooling method.

Table 4. Mechanical properties of high temperature plain concrete under different working condition (MPa)

Dosage \ Temperature			Normal temperature	200℃	300℃	400℃	500℃	600℃	700℃	800℃	1000℃
Xu [7]		N	5.85	5.2		4.45		2.12	1.63	1.16	0.44
		W	5.85	4.4		4.13		1.70	0.93	0.81	
Qu [20]		N	4.5	4.2		4.0		2.2		0.8	
		W	4.5	4.0		3.6		2.1		1.1	
Niu [19]		N	1.68	1.65		1.43		0.56		0.38	
Chen [23] Steel fiber conten (kg/m³)	0		3.8		2.6		2.3			1.4	
	40		4.5		3.4		3.3			1.7	
	80	N	4.6		3.5		3.3			2.1	
	120		5.5		4.8		3.9			2.6	
	160		6.1		5.2		4.3			3.6	
Tian [11]	Ordinary concrete		2.17	2.30	1.91		1.45		0.59		0
	2% Steel fiber reinforced concrete		4.57	2.95	2.26		1.73		1.56		1.26
Research in this paper steel fiber content (kg/m³)	0	N	2.42	2.17		1.92		1.00		0.18	
		W	2.42	2.24		2.06		1.35		0.96	
	24.17	N	3.56	3.31		2.88		1.71		0.89	
		W	3.56	3.38		3.13		2.06		1.78	
	48.34	N	4.02	3.84		3.27		2.17		1.28	
		W	4.02	3.88		3.56		2.42		2.17	
	72.51	N	5.33	5.19		4.44		2.92		1.81	
		W	5.33	5.23		4.80		3.41		2.95	

5.0 CONCLUSION

Split tensile mechanical properties of steel fiber concrete were tested according to different steel fiber admixtures, and different post-temperature and cooling methods in this paper, to obtain the splitting damage pattern and peak splitting stress of steel fiber concrete under different loading conditions, the main conclusions from the comparative analysis are as the temperature increases, the damage pattern of steel fiber concrete under split tensile loading develops from a single penetrating main crack in the center of the specimen to multiple cracks on the surface of the specimen and relatively small crack sizes. Concrete splitting damage develops from brittle to plastic characteristics as the steel fiber dosage increases, also the number of apparent cracks in the concrete is relatively high and the size is relatively small at higher steel fiber dosage. In addition, as the temperature increases, the peak split tensile stress of steel fiber concrete decreases gradually, and the increase in temperature leads to a gradual increase in the peak split tensile stress of steel fiber concrete as affected by the steel fiber admixture. With the increase of steel fiber dosage, the peak splitting tensile stress of steel fiber concrete increases gradually, and the increase of steel fiber dosage can effectively improve the peak splitting tensile stress of concrete after high temperatures. The peak stress of steel fiber concrete splitting under rapid water cooling after high temperature is higher than that under natural cooling. Based on the experimental data in this paper, a model is proposed for the relationship between steel fiber dosage and high temperature influencing factors on the peak stress of concrete splitting under natural cooling mode and fast water-cooling mode. The mechanism of steel fiber, high temperature, and cooling on the mechanical properties of concrete splitting is also discussed.

6.0 ACKNOWLEDGEMENT

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8.0 AUTHOR CONTRIBUTIONS

Zhang Li: Writing- Original draft preparation, Software, Modify

Mohamed Nor Azhari Azman: Data curation, Reviewing and Editing, Supervision, Methodology

Zhu Bin: Software, Validation

9.0 DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included within the article.

10.0 CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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