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THE EFFECT OF SINGLE AND HYBRID FIBRES ON FIBRE REINFORCED SELF COMPACTING CONCRETE PRODUCED WITH HIGH LEVEL OF FLY ASH USAGE

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Abstract

The aim of this paper is to present results of investigation carried out on fresh and mechanical properties of Fibre Reinforced Self Compacting Concrete (FRSCC) produced with fly ash which is an industrial waste material. Concrete industry is an important one between the industry branches for sustainability. In this study, high level of fly ash was used to reduce Portland Cement (PC) consumption as well as CO_2 emission through the use of that waste material. For this purpose, a control Self Compacting Concrete (SCC) and 10 FRSCCs were designed applying slump flow, V-funnel and L-box tests to determine fresh concrete properties. In the design of FRSCC, both single and hybrid FRSCC mixes were produced using 3 macro and 1 micro steel fibres in different lengths and aspect ratios. Hybrid FRSCC mixes were prepared using each macro fibres together with micro fibre at two different percentages (50% and 75%) by weight. After design process, cubic and prismatic concrete specimens were produced to determine hardened properties. Flexural tensile and compressive strength tests were performed on the concrete specimens at the ages of 3, 7, 28 and 90-days. The test results showed concrete mixes including macro fibres gave the higher tensile strength properties, although they gave the lower fresh concrete properties.

Key words: Hybrid fibre, Fibre reinforcement, Self compacting concrete.

YÜKSEK ORANDA UÇUCU KÜL KULLANIMI İLE ÜRETİLEN LİF TAKVİYELİ KENDİLİĞİNDEN YERLEŞEN BETON ÜZERİNE TEKİL VE KARMA LİFLERİN ETKİSİ

Özet

Bu makalenin amacı bir endüstriyel atık olan uçucu kül ile üretilen lif takviyeli kendiliğinden yerleşen betonun (LTKYB) taze beton ve mekanik özellikleri üzerine yürütülen bir çalışmanın sonuçlarını sunmaktır. Beton endüstrisi sürdürülebilirlik açısından endüstri kolları arasında önemli bir yere sahiptir. Bu çalışmada, yüksek oranda uçucu kül kullanımı ile Portland çimentosu (PC) tüketimi ve de CO_2 salımı düşürülmüştür. Bu amaçla, taze beton özelliklerini belirlemek için çökeme-yayılma, V-kutusu ve L-kutusu deneyleri uygulanarak bir adet kontrol kendiliğinden yerleşen beton (KYB) ve 10 adet LTKYB tasarlanmıştır. LTKYB tasarımında farklı uzunluk ve boy/çap oranlarında 3 makro ile 1 mikro çelik lif kullanarak tekil ve karma LTKYB karışımları üretildi. Karma LTKYB karışımları her makro lifin mikro lif ile birlikte ağırlıkça 2 farklı oranda (%50 ve %75) kullanımı ile hazırlandı. Tasarım süreci sonrasında, sertleşmiş beton özelliklerini belirlemek için kübik ve prizmatik beton numuneleri hazırlandı. Beton numuneler üzerinde 3, 7, 28 ve 90. günlerde eğilmede çekme ve basınç dayanımı deneyleri gerçekleştirildi. Deney sonuçları makro fiber kullanımının daha düşük taze beton özellikleri vermesine rağmen daha yüksek eğilmede çekme dayanım özellikleri verdiğini göstermiştir.

Anahtar kelimeler: Karma fiber, Fiber takviyesi, Kendiliğinden yerleşen beton.

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1. Introduction

Concrete types having different properties for different usage aims have existed thanks to recent concrete addition materials. Fibre reinforced concrete (FRC) can be given as an example for that kind of concretes. FRC is the concrete including fibres spreading coincidentally at three dimensions in the concrete matrix. As for the Hybrid FRC, it is a new kind of composite material produced adding different type, shape and dimensions of fibres in a concrete mix (Doğru, 2006; Komlos, 1995). Because concrete is complex material, its structure has multiple-phase. The structure of concrete includes calcium-silicate-hydrate (c-s-h) gel in scale of micron and fine/coarse aggregate in scale of millimetre and centimetre. It is not possible to expect improvements in all phases using only one type fibre in concrete structure including complex phases (Yao, 2003; Avar, 2006). FRC produced using fibre types including different shape and dimensional properties instead of single fibre will give higher engineering advantages and more serviceable abilities (Qian and Stroeven, 2000). During last three decades, usage of FRC has continuously increased and remarkable improvements have been observed (Lim and Nawy, 2005; Köksal et al., 2008; Nataraja et al., 1999). In the development of the concrete technology, another one of the most important improvements is the SCC (Byfors, 1999). SCC first developed in Japan at the end of the 1980's can be described as a concrete type which fills the forms and consolidates with self weight (Okamura and Ouchi, 2003; Nunes, 2006). Although most of existing SCC studies in the literature is generally on new concrete design, studies about FRSCC are rather new and limited. Özkul et al. (2006) explained basic principle and properties of SCC afterwards investigated some SCC durability properties for instance water absorption and permeability, carbonation resistance and chloride penetration etc. Sahmaran et al. (2005) investigated the workability properties of hybrid FRSCC and declared that SCC in comparison with FRC was a relatively new kind of concrete technology due to its advantages as flowability. Moreover, they reported that fibre volume, length and aspect ratios had a quantifiable effect on workability properties of hybrid FRSCC while shape and surface roughness of fibres had importance but their effect could not be clarified based on their research parameters. Corinaldesi and Moriconi (2004) worked on durable FRSCC to produce thin precast elements. In the manufacturing process, they used steel fibre instead of ordinary steel-reinforcement mesh. They conducted out compressive and flexural strength tests besides durability tests such as freezing-thawing, carbonation etc.

The Buildings systems having generally big capacity and complexity have constructed by using concrete material in Turkey. That kind of construction design is a disadvantage for countries like Turkey in the aspect of earthquake and similar disaster menace. In considering market demand, earthquake and resembling disasters, combination of those two different special concrete, FRC and SCC, will constitute FRSCC giving wider technical advantages and more economical benefits. Another issue is that the development and acceptance of the appropriate methods for environment protection in all industry branches has been coerced by the gaining acceleration of the sustainable improvements containing also construction industry. Approximately 20-25% of whole world energy has been spent to produce construction materials such as cement, steel and plastics. Furthermore, concrete manufacturing plants have brought along the high rate power consumption which increases the CO_2 emission and the spending of the raw materials. Accordingly, every year, 1 billion ton of water, 1.5 billion tons of cement and 10 billion tons of aggregate have been consumed as raw materials in all over the world (Becchio, 2009). Therefore, the aim of this paper is to declare designed as a new special concrete type eliminating each other's negative features in both fresh and hardened situations, and having better engineering properties. In addition, the high rate of fly ash usage will provide an advantage in terms of sustainability.

2. Experimental Program

2.1. Materials and mix design

CEM I 42.5 Class N, which was provided by Elazig in Turkey was used in this study. Fly ash was obtained from Kangal Power Plant in Sivas in Turkey. The specific chemical composition and some physical properties of Portland cement and fly ash are given in Table 1. Total powder ratio of all designed mixtures was 17.3% in the mix proportion (see Table 5). Fly ash constituted approximately 35% of total powder by volume. The fine and coarse aggregates which are used were natural obtained from Palu/Elazığ in Turkey. The physical properties of natural fine and coarse aggregates are also given Table 2. In the study, high performance third generation hyper-plasticiser was used as a chemical addition. That chemical product has provided both high level of water decreasing and long time of workability (Sika Ürün Bilgi Föyü, 2009). Some technical details about hyper-plasticiser are given in Table 3. Steel fibres were used in the study. Differences between those fibres (S1, S2, S3 and S4) are shown Table 4. In the mix design, those fibres were used firstly as single and secondly as hybrid in two different percentages combination of macro and micro fibres. In the first combination, every single macro fibre was used together with micro fibre at the percentage of 50%-50% by weight. Through this way, first group of hybrid fibres mixes was obtained. In the second group of hybrid combinations, 75% of micro fibre was used together with 25% of macro fibres. Of course lastly, a control SCC (K) was also designed to compare with FRSCCs results. The details related to mix designs are given in Table 5.

Table 1. Specific chemical and some physical properties of cement and fly ash

Chemical Properties (%)							Physical Properties			
Oxide=>	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**SO_3**	**LOI**	**Blaine**	**Spec.gr.**	**f_{ce}**
CEM I 42.5 N	21.12	5.62	3.24	62.94	2.73	1.79	1.78	3382	3.10	51.7
FA	38.34	16.69	5.11	27.62	1.60	4.44	0.79	1343	2.50	18.1*

*Togetger with Portland cement.

Table 2. Physical Properties of Aggregates

Physical Properties	Natural Aggregates	
	Coarse	Fine
Specific gravity (kg/dm^3)	2.71	2.65
Los Angeles test (500 rev. %)	11.6	-
Water absorption (%)	1.15	1.18

Table 3. Technical detail of hyper-plasticiser

Color/Condition	Light brown/Liquid
Chemical structure	Polymer based Modified poly-carbocsilat
Density (kg/l, 20°C)	1.07-1.11
Ph	3-7
Freezing point (°C)	-9
Alkali portion (equal to %Na_2O)	Max. 4

Table 4. Fibres specifications

Fibre codes	Length and asp. ratio	Spec.gr. (kg/dm^3)	Strength (MPa)	Geometry
S1 (macro fibre)	60 mm, 80	7.85	Min 1050	Hooked end
S2 (macro fibre)	35 mm, 64	7.85	Min 1150	Hooked end
S3 (macro fibre)	30 mm, 55	7.85	Min 1100	Hooked end
S4 (micro fibre)	6 mm, 40	7.17	2000	Straight

Table 5. Mix proportions obtained from design process

Series No	Cement	Fly Ash	Water	Fine aggr.	Coarse aggr.	Fibre	HP**
1	11.3	6	20	32.65	29.41	0.64	1.25
2	11.3	6	20	32.63	29.43	0.64	1.25
3	11.3	6	20	32.62	29.44	0.64	1.25
4	11.3	6	20	32.60	29.40	0.70	1.25
5	11.3	6	20	32.60	29.44	0.66	1.25
6	11.3	6	20	32.60	29.44	0.66	1.25
7	11.3	6	20	32.60	29.44	0.66	1.25
8	11.3	6	20	32.60	29.41	0.68	1.25
9	11.3	6	20	32.60	29.41	0.68	1.25
10	11.3	6	20	32.60	29.41	0.68	1.25
K*	11.3	6	20	32.95	29.75	-	1

*Control SCC mix without fibre.
**Hyper- Plasticiser have been added to mixes based on cement percentage

2.2. Tests

In this study, Slump-flow (T_{500} and flowing diameter), V-funnel and L-box tests were applied to be able to design FRSCC and control SCC mixes. L-box test was separately performed to assess passing ability with 1, 2, 3 rebars and without any rebar for fibres having high length. In considering previous studies and suggestions from those studies, L-box tests were applied as mentioned above (Yardımcı, 2007; EFNARC, 2005; Grünewald, 2004; Groth, 2000).

Compressive strength test was performed after 3, 7, 28 and 90-days water curing. Each FRSCC and control SCC series were prepared number of three samples for compressive strength test in the dimensions of 100 mm width, 100 mm length and 100 mm height. Compressive strength test was applied on concrete samples based on TS EN 12390-3 (2003). Three point flexural tensile strength tests were also applied like compressive strength test. In the flexural tensile strength test, concrete samples had the dimensions of 75mm x 75 mm 300 mm.

3. Experimental Results

Fresh concrete properties of 10 FRSCC mixes and control mix K were given in Table 6. Roman numerals (I,II,III) used in the table mean that how many rebar was used for L-box test. The character "Ø" point out the experiment performed without any rebar in L-box test while letter "T" indicate becoming congestion because of fibres used in the concrete mix and rebar in the L-box test.

As a general result, usage of smaller fibres in the single FRSCC mix design and decreasing of the long fibres density in the hybrid FRSCC mix design caused an improvement on fresh properties of FRSCC. As can be seen from the Table 6, slump-flow diameters of all concrete series changed between 690-745 mm. These results are in class SF2 meaning to be good enough for flow-ability and filling-ability based on EFNARC (2005). Micro steel fibre whose length is 6 mm and aspect ratio is 40 (series 4) gave the best flowing diameter. In the Table 6, slump-flow time (T_{500}) and V-funnel time results indicate both viscosity and flow-ability properties of fresh concrete mixes about FRSCCs and K. According to EFNARC (2005), 4, 7-10 and K series are in the class VS1 while others are in the class VS2. V-funnel time result also confirmed the general result mentioned above. Namely, the longer flow times through the V-funnel were obtained from the series 1, 6 and 8 which had longer single fibre and had high density of long fibres in the hybrid mix. As for the L-box test results, these also verify previous fresh concrete test results. As can be seen from the Table 6, all results acquired from the FRSCCs and K series are satisfactory according to EFNARC classification (2005). Except series 1, segregation and blocking were not seen in the application of L-box test. But it can be understood to be an unavoidable result if rebar spaces in the L-box and fibre length used in series 1 are considered. According to blockage ratios in the Table 6, appropriate results could not be obtained from the concrete series 1 and 2 for L-box test with III and II rebars. On the other hand, series 2 gave better blockage ratio results than series 1. It is clearly seen from the Table 6 that 50% and 75% decreasing of the long fibres density in the total volume of the hybrid fibre mix caused big development on the fresh properties tests.

Table 6. Fresh concrete properties of designed concrete

Mix No	Slump-Flow Diameter (mm)	Slump-Flow Time/T_{500} (sn)	V-Funnel (sn)	L-Box Rebars	L-Box Blockage	FreshConc.Dens. (kg/dm^3)
1	690	3.2	17.8	III	T	2.34
				II	T	
				I	0.81	
				Ø	0.88	
2	720	2.7	13.4	III	0.55	2.44
				II	0.70	
				I	0.83	
				Ø	0.89	
3	720	2.5	11.1	III	0.77	2.36
				II	0.87	
4	745	1.9	10.5	III	0.91	2.41
5	725	2.3	10.5	III	0.40	2.42
				II	0.83	
6	730	2.1	13.3	III	0.63	2.31
				II	0.83	
7	730	2.0	11.6	III	0.60	2.38
				II	0.82	
8	730	1.9	7.7	III	0.88	2.42
9	735	1.8	7.4	III	0.90	2.36
10	735	1.6	7.6	III	0.92	2.38
K	740	1.7	9.0	III	0.95	2.38

Figure 1 present compressive strength results of the all concrete series. It can be seen that all concrete series gave similar compressive strength performances in the same ages. These results are quite normal because all experimental parameters are the same except fibre properties, its aspect ratio and different fibre mix in the design (see Table 5). Nevertheless, the lowest compressive strength results were obtained from the series 1 and 6 including fibre coded as S1and S2 while series 4 was giving the best results containing fibre coded as S4 in all curing ages. In general, FRSCCs including macro fibres gave lower compressive strengths than series K although FRSCCs including micro fibres gave higher compressive strengths than series K. Sahmaran and Yaman (2007), Nehdi and Ladanchuk (2004) pointed out that usage of micro fibre instead of macro one in the concrete mix gave higher compressive strength results. Qian and Stroeven (2000) declared that adding micro fibre in to the concrete mix increased highly compressive strength while macro fibres affected results on the contrary. In this paper, decreasing of the fibre length, aspect ratio and macro fibre density in the mix volume showed an increasing on the compressive strengths. This increasing got closer to series K when the decreasing of macro fibre sizes and density in the mix and surpassed specifically at 90 days.

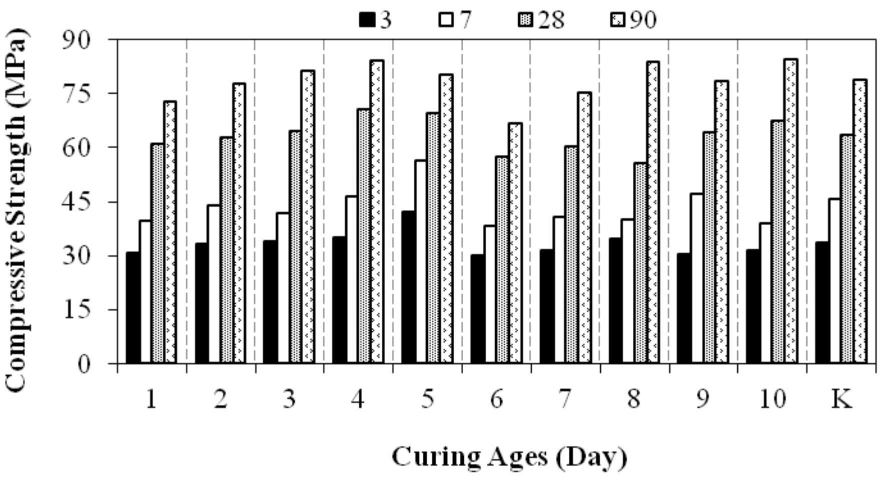

Figure 1. Compressive strength test results of concrete series

The results obtained from flexural tensile strength tests for FRSCCs and K for all concrete ages are given in Figures 2-5, respectively. While concrete series are showing normal strength gaining behaviour until 7 days age and between the 28-56 days ages, a jumping is seen at the results of 28 days and 90 days ages. These jumping can be attributed to be 28 days of standard strength age of concrete because concrete material has gain vast majority of its strength. Moreover, thanks to using of fly ash as a dust material in the all mixes, it showed the pozzolanic activations at further ages like 90 days (Erdoğan, 2003). In Figure 2, it is seen that fibre coded as S1 has the best effect on flexural tensile strength results of FRSCCs. Furthermore, no matter which FRSCC includes the S1 fibre (see Table 5), that concrete series gave the best flexural tensile strength values in the group. In all concrete groups, the lowest flexural tensile strength value was obtained from the series K. From the results, it was recognised that the decreasing of the fibre length and aspect ratio in the single mix design and decreasing of the long fibre density in the hybrid mix design leaded to dramatically fallen of the flexural tensile strength. Nonetheless, series 5 which was hybrid design used 50%S1-50%S4 fibres gave a very close result to series 1 on flexural tensile test. In the Figure 3, based on the result obtained from the series 1 used S1 fibre, it was observed that nearly 40% and 20% decreasing of the fibre length and aspect ratio, respectively, caused 9% drop of flexural tensile strength while 50% and 31% decreasing of them were resulting 12% dropping at 90 days. In addition, it was calculated 23% fallen from flexural tensile strength at 90 days when the fibre length and aspect ratio decreased to 90% and 50% respectively. Similarly, Yazıcı et al. (2007) and Miao et al. (2003) declared that increasing of the fibre dimensional sizes in the mix tended to rising of the splitting and flexural tensile strengths.

First hybrid FRSCC series is the group of 5, 6 and 7 including fibres 50%macro+50%micro in the mixes (see Fig. 2 and 4). After 90 days curing ages, the highest flexural tensile strength was obtained from the series 5 containing 50%S1+50%S4 fibres. The flexural tensile strength of series 5 was about 66% more than series K which was control SCC without any fibre. The usage of smaller long fibres than S1 in the hybrid mix gave the lower flexural tensile strength values. The rates of lower values compared to series 5 were 17% and 22% for series 6 and 7, respectively. Nevertheless, these series gave the higher strength result than series K. They were 37% and 29% for the series 6 and 7, respectively. In the last hybrid FRSCC series, the density of the macro fibres in the mix volume was largely decreased. It is said that high level reduction of macro fibres in the total fibre mix volume caused a dramatic decline of the flexural tensile strength (see Figure 2 and 5). Anyway, hybrid FRSCC series in this second group gave also higher strength properties than the series K at all curing ages. At 90 days, series 8, 9 and 10 gave 34%, 16% and 24% higher strength ratios than series K, respectively. In spite of these results, a strength decline was observed from the series 9 and 10 compared to series 8. The strength decline ratios were 13% and 8% for series 9 and 10 in sequence. The reason of this strength fall can be attributed to the smaller fibre using than the macro fibre of the series 8.

If have a close look at series 1, 5 and 8 on Figure 2, it can be said that using of macro fibres together with micro one gives higher flexural tensile properties, but high level of macro fibre reduction is going to show low flexural tensile properties as being at series 8.

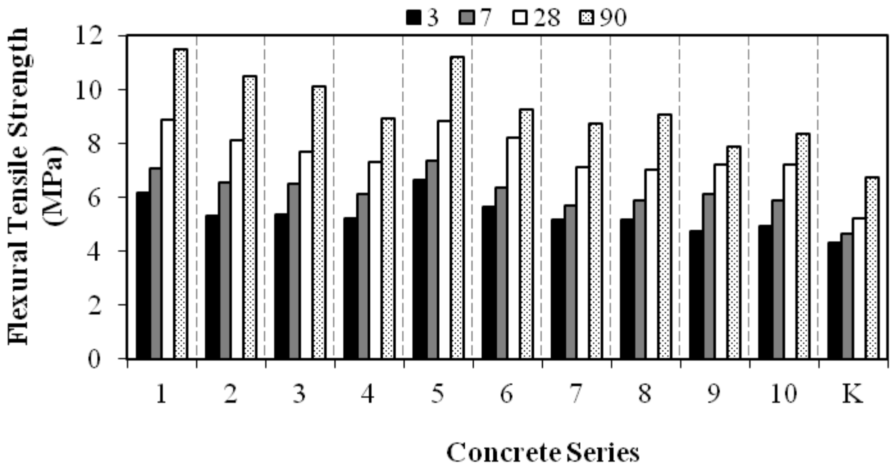

Figure 2. Flexural tensile strength test results of concrete series

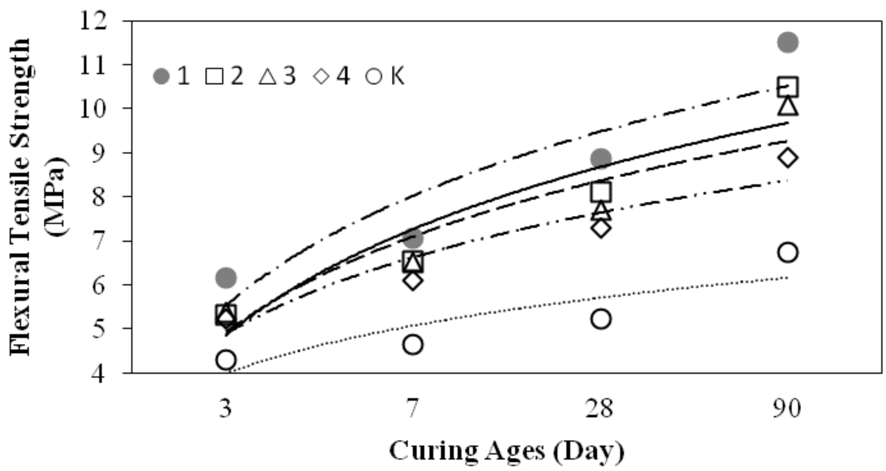

Figure 3. Flexural tensile strength test results of concrete series including single fibres

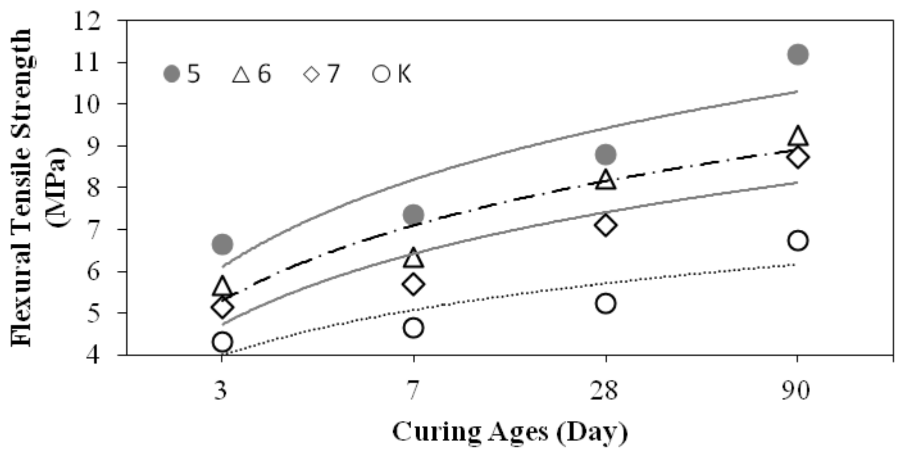

Figure 4. Flexural tensile strength test results of concrete series including 50% macro and 50% micro fibres

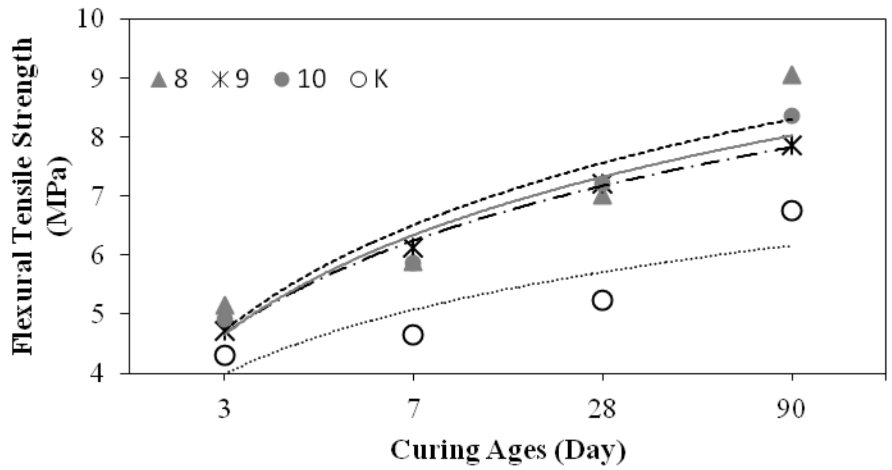

Figure 5. Flexural tensile strength test results of concrete series including 25% macro and 75% micro fibres

4. Concluding Remarks

Big variations occurred on fresh concrete properties of Concrete series used single fibres in the mix because of changes of fibre length and its aspect ratio. The best fresh concrete properties were obtained from the series 4 including S4 fibres, of course K series, produced as a control SCC, as well. In the FRSCC series containing hybrid fibres, decreasing of the fibre length and aspect ratios and increasing of the S4 fibres density in the mixes led to improvement on fresh concrete properties. Usage of fibres longer than 35 mm in the FRSCC caused the high level of performance loss on fresh concrete properties, specifically passing ability between the rebars. Although the decreasing of the macro fibres density in the hybrid FRSCCs resulted a development on the fresh concrete properties, it caused negative influence on flexural tensile strength.

All FRSCC series showed similar compressive strength behaviours at same curing ages in their groups. The decreasing of fibre sizes in the usage of single fibres and macro fibre density in the hybrid mix caused a minor increasing on compressive strength results.

Flexural tensile strengths of FRSCC series were quite higher compared to series K which was control SCC. On the contrary compressive strength, macro fibres gave the highest flexural tensile strength results. Besides, the decreasing of fibre sizes and macro fibre density in the

mix caused to obtain low flexural tensile strength values. Using macro fibres together with micro fibres in specific ratios may give better flexural tensile strength properties.
The usage of fly ash in production has been more economic and environment friendly. On the other hand, returning of that waste material to industry decreased cement consumption, of course CO_2 emission as well.

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