 Journal of Polytechnic, 2017; 20 (2) : 451-457

Analysis of Usability of Waste Erosion Wires as Fiber in Reactive Powder Concrete

Metin İPEK*
Sakarya University, Technology Faculty, Civil Engineering Department, 54187 Sakarya, TURKEY
(Received : 13.04.2016 ; Accepted : 25.07.2016)

ABSTRACT

In this study, waste erosion wires' usability, which are being used in metal processing industry, as fiber in Reactive Powder Concrete (RPC). Waste erosion wire resembles to micro steel fibers used in RPC. In the study, comparison was done by using waste erosion wires and micro steel fibers in the same amount in RPC. In this sense, 2% and 4% non-fibrous waste erosion wire and steel fiber included RPC samples were used. Mechanical features of samples were determined by doing compressive and flexural tests on these samples. Moreover, cost analysis of samples was done and unit cost strength was determined. Finally, compressive strength of samples including 4% waste erosion wire and steel fiber were 230 MPa and 260 MPa while they reached the values of 40.50 MPa and 22.06 MPa as a result of flexural test. It was seen that it would be beneficial to use waste erosion wires as fiber in RPC both in the sense of recycling and cost.

Keywords: Erosion Wires, Recycling, Mechanical Properties.

Atık Erozyon Tellerinin Reaktif Pudra Betonunda Lif Olarak Kullanılabilirliğinin Araştırılması

ÖZ

Bu çalışmada, metal işleme endüstrisinde kullanılan erosion teli atıklarının RPB'de lif olarak kullanılabilirliği araştırılmıştır. Atık erosion teli, Reaktif Pudra Betonunda (RPB) kullanılan mikro çelik liflere çok benzemektedir. Çalışmada, Atık erosion telleri ile mikro çelik lifler RPC'de aynı oranlarda kullanılarak karşılaştırma yapılmıştır. Bunun için lifsiz, %2 ve %4 oralarında atık erozyon teli ve çelik lif içerikli RPC numuneleri hazırlanmıştır. Bu numuneler üzerinde basınç ve eğilme deneyleri yapılarak numunelerin mekanik özellikler belirlenmiştir. Ayrıca maliyet analizleri yapılarak numunelerin birim dayanım maliyetleri belirlenmiştir. Sonuç olarak %4 atık erosion teli ve çelik lif içeren numunelerin basınç dayanımı sırasıyla 230 MPa ve 260 MPa ulaşırken eğilme deneyi sonucunda 40.50 MPa ve 22.06 MPa değerlerine ulaşılmıştır. Atık erozyon tellerinin, hem geri dönüşüm hem de maliyet açısından RPC'de lif olarak kullanılmasının yararlı olabileceği görülmüştür.

Anahtar Kelimeler: Erezyon Teli, Geri Dönüşüm, Mekenik Özellikler.

1. INTRODUCTION

Metal cutting operation with erosion wire in an electro-thermal method in which material is removed with sequent sparks which occurred between wire electrode and the workpiece in dielectric liquid media [1]. Different from conventional methods which involves physical contact and relative motion; unconventional custom manufacturing techniques are those which process, etch and shape material by using various energy types (chemical, electro-chemical, thermal energy etc ...) without applying mechanical force [2]. Wire erosion which is one of these techniques and does cutting with electro-thermal energy has been used commonly in metal working industry, aerospace industry, nuclear and automotive industry [3]. In these cutting processes, brass, molybdenum, tungsten and copper wires which usually have the diameter of 0.76 – 0.4 mm were used [4]. The wire which is electrode set is fed from a roller and moves along workpiece. Depending on application voltage during process, serial sparks are formed between workpiece and wire within insulating liquid (water, kerosene or other hydrocarbons), feed rate changes according to the amount of energy at each sparkle (Fig. 1) [5,6].

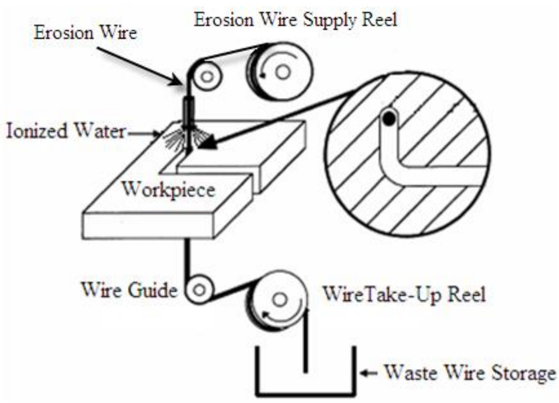

Figure 1. The Wire-Cut Electrical Discharge Machining (EDM) Process [6,7].

*Corresponding Author
e-mail: metini@sakarya.edu.tr
Digital Object Identifier (DOI) : 10.2339/2017.20.2 451-457

Wire used in metal processing industry, wires which are generally brass or copper and do the cutting in eroding machine are thrown off after cutting. These waste wires are cropped at will from the cutting machine for ease of storage and brought to re-cycle in this way. As a result of cutting erosion occurs on both workpiece and partly on the surface of wire and the diameter of wire gets thin and craters occur. Erosion waste wires erode very little since they do not physically contact with the material being cut during cutting process and erosion as a result of cutting makes the surface of wire rough. As a result of deformation on wire, the wire cannot be used for the second time and is collected in waste wire store. Erosion wires can be reutilized after long recycling processes and high costs.

RPC is a cement-based ultra high performance concrete which has superior mechanical and physical properties, exhibiting excellent ductility and durability characteristics. RPC has compressive strength of 150-800 MPa, while its, tensile strength changes between 25 and 150 MPa. Moreover, its fracture energy changes between 1200-40000 J/m^2. The durability properties of RPC are better than current high performance concrete in orders of magnitudes [8-12].

At the first glance, waste erosion wires resembles to micro brassy fibres used in RPC. Different from this the surface of wire is rough and this toughness will cause the adherence between fibre and paste. Moreover, study of waste wire being economic (4 times cheaper than steel wire) and its usability instead of steel wires which makes up nearly half of the cost of RPC was the main subject of this study. There has not been any study on literature about RPC usage of erosion wires yet. Therefore, in this study it was aimed to use erosion wires which resembles to micro fibre in RPC doing any recycling process.

In the studies in literature, brassy steel fibres which are generally in micro dimensions, 0.2 mm diameter and 13 mm long were used in RPC. Diameters of waste erosion wire are similar to steel fibre and generally vary between 0.05 – 0.4 mm [8,10-18]. Since the diameter of waste erosion wire used in the study is 0.25 mm it was used in the same amount with steel fibre. Waste erosion wire and steel fibre was substituted to RPC in the rate of 2% and 4% in volume. Mechanical features of samples were determined by doing pressure and flexural tests on these samples. Moreover, cost analysis of samples was done and unit cost strength was determined.

2. EXPERIMENTAL STUDY

2.1. Materials

High performance cement, PC 52.5 CEM I R type, was preferred for this study. RPC needs a puzzolanic material that will fill voids of micro particulates in binder paste and will contribute strength by producing secondary hydrates by puzzolanic reaction with the lime resulting from primary hydration [8-12]. In this study undensified silica fume (SF) provided from Elkem Company in Norway was used. Two different quartz sands and powder used as aggregate with maximum particle size of 0.6 mm, 0.3 mm and 0.100 mm, respectively. Figure 2 and 3 show the granule structure of the quartz powder and particle size analysis of granule materials, respectively. A polycarboxylate based superplasticizer was used to fluidify the mixture. Effect of this superplasticizer is to maintain fluidity within time of fresh concrete and to attain high strength in a short time.

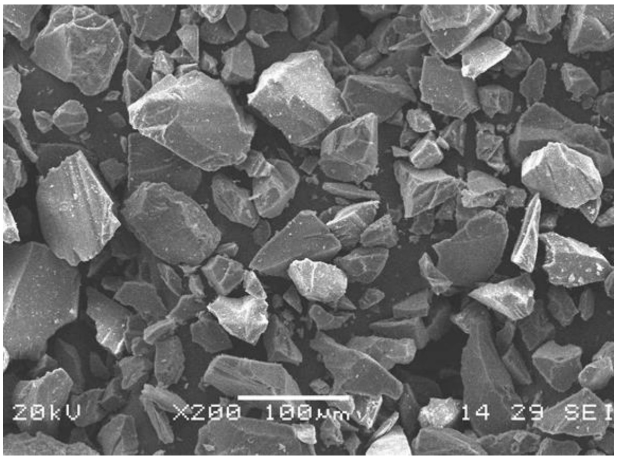

Figure 2. Granule structure of the quartz powder

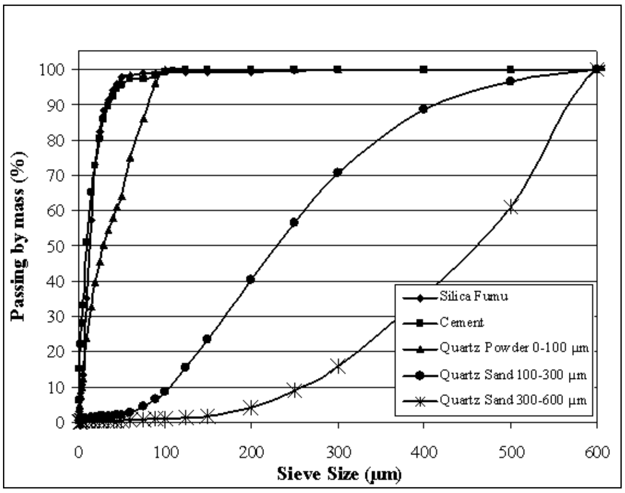

Figure 3. Particle size analysis of granule materials

In the study, brassy hookless micro fibre which has the diameter of 0.16 mm and 13 mm long was used. As waste erosion wire brass wire which has the diameter of 0.25 mm, 13 mm long, has 900 MPa tensile strength and named as CuZn37 Master Brass was used (Fig. 4). The physical and mechanical properties of steel fiber and erosion wire presented in Table 1. Erosion wires roughen forming shapes of crater on the upper surface after metal processing (Fig. 5) [19].

Figure 4. Erosion wire

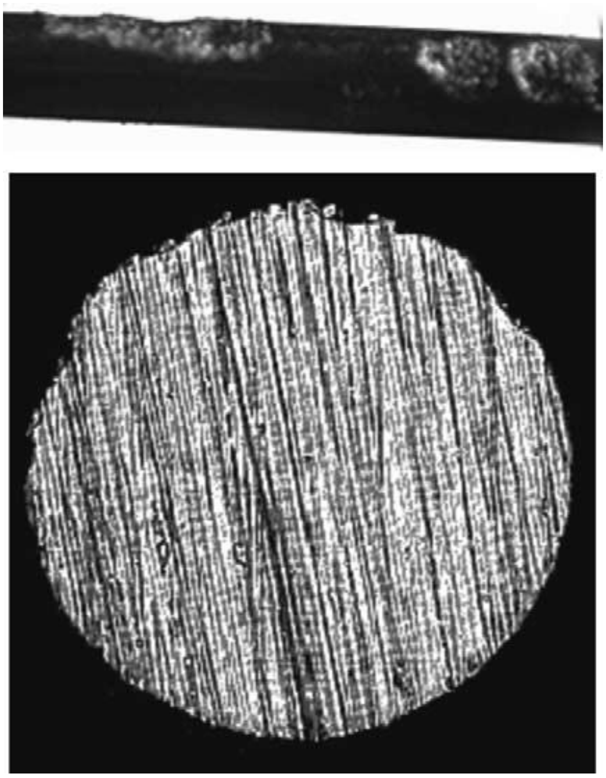

Figure 5. Craters formed after machining on the wire electrode [19]

2.2. Experimental Procedures

Mixture rates were taken from mixing process procedure Ref. 9 (Table 2). All samples were cured during three days at 90 ºC water steam and in remaining days it was hold in water at 20ºC after demoulding. Compressive strength and young's modulus and poisson ratio of RPC were determined using cylinder samples had a length of 200 mm and a diameter of 100 mm. Young's modulus and poisson ratio tests were made by computer-aided system was able to measure load, axial and lateral deformation at the same time as stated in Ref. 9.

The flexural strength and toughness of the concrete were determined using samples having dimensions of 50x50x300 mm. The testing of all specimens was conducted in the four points loading flexural test. The loading speed of the experimental device was adjusted such that it was 0.05-0.10 mm/min at the midpoint of the beam [12,21-25]. The samples were loaded until they were completely fractured and the load-deflection plots were obtained. Using these graphs, the crack strength, flexural strength, equivalent flexural strength and fracture toughness were calculated. Toughness equivalent to the area under the load-deflection curves up to 10 mm deflection. The area under the load-deflection curve was calculated by a Matlab 7.5.0 software program.

In the study, five samples were produced for each test. Samples which were substituted with 2% and 4% waste erosion wire were coded as RPC-EW2 and RPC-EW4 respectively, samples which were substituted with steel fibre were coded as RPC-SF2 and RPC-SF4 respectively.

Table 2. Components of mixture, compressive strength and elasticity modules

	Fiber Ratio (%)		
Material	**Ctrl**	**2**	**4**
Cement	900	882	864
Silica Fume	270	265	259
Q. Powder	360	353	346
Q. Sand (100-300)	258	253	248
Q. Sand (300-600)	258	253	248
Water	225	221	216
SP	27	27	26
Air %	2	1,8	1,8
Steel Fiber (Erosion wire)	0	144 (170)	287 (340)
7 days Comp. Strenght (MPa) (RPC-EW)	140	197 (173)	235 (202)
28 days Comp. Strenght (MPa) (RPC-EW)	170	220 (190)	260 (230)
Young's Modulus (GPa) (RPC-EW)	58, 88	62,34 (60,05	60,97 (59,74

Table 1. Physical and mechanical properties of steel fiber and erosion wire [9,12,20]

Fiber Type	Diameter (mm)	Lenght (mm)	Tensile strength (MPa)	Young's modulus (GPa)	Unit weight (g/cm^3)
Steel fiber	0,16	13	2250	2100	7.181
Erosion wire	0,25	13	900	117	8.50

3. RESULTS AND DISCUSSION

3.1. Mechanical Properties

The compressive strength of RPC which were substituted steel and erosion wire fiber increased with increasing of the fiber ratio (Fig. 6). Compared to non-fibrous RPC; compressive strength has increased in the rate of 29.4% in RPC-SF2, 11.8% in RPC-EW in 2% fibre content (Table 3 and Fig. 6). This rate of increase has reached up to 52.9% in RPC-SF, 35.3% in RPC-EW with 4% fibre content. The effect of steel fibre on compressive strength in RPC is distinctly more than erosion wire. The main reason of this can be that tensile strength of erosion wire is lower than that of steel fibre. Steel fibres serve as strong aggregate in concrete [9]. Likewise, erosion wires which serve as aggregate cannot resist internal tension of concrete as well as steel fibres. While samples were broken, it was seen that steel fibres peel through RPC paste whereas erosion wires rupture.

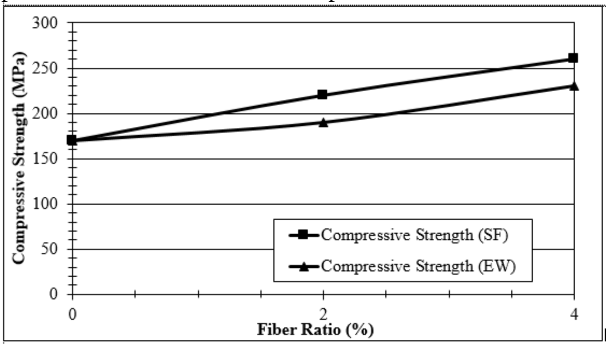

Figure 6. The effect of steel fibre and erosion wire on compressive strength

As the compressive strength increase so does the modulus of elasticity in RPC, such in normal concrete (Fig. 7). Increase of fibre amount in RPC causes increase of compressive strength as well as ductility. With the increase of fibre amount from 2% to 4%; ductility of fibre on concrete has increased and modulus of elasticity has decreased parallel to this. Modulus of elasticity of erosion wires is 117 GPa. Modulus of elasticity of steel fibre is 2100 GPa. That the modulus of elasticity of erosion wires is lower than steel fibre caused modulus of elasticity of RPC-EW samples to be low (Table 2). There has not been any significant change in poisson rates according to fibre content. Poisson rate varies between 0.20 – 0.22.

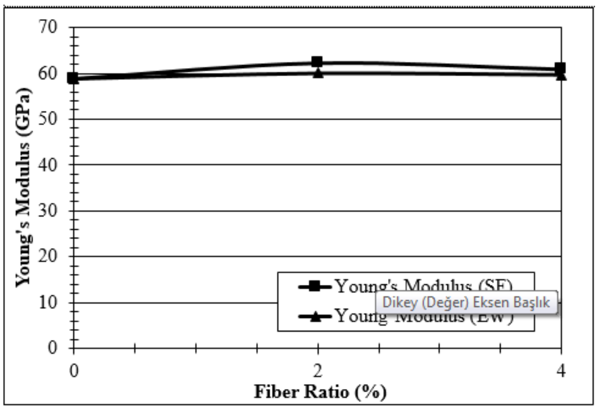

Figure 7. The effect of steel fibre and erosion wire on elasticity module

The specimens taken from the beam samples were examined also under the microscope. As can be seen in Fig. 8 and 9, during crack and crack mouth opening of test samples that waste erosion wires ruptured and steel fibres pulled-out through RPC paste. Rupture of erosion wires after the formation of crack caused sudden decrease of load-deflection curve after maximum load and rupture without doing too much deflection. Interface of waste erosion wire and steel fiber with RPC paste investigated (Fig. 10,11). Due to surface of waste erosion wire is rough that RPC paste with adherence is better than steel fiber.

Figure 8. Pulled-out steel fibers

Figure 9. Ruptured waste erosion wires

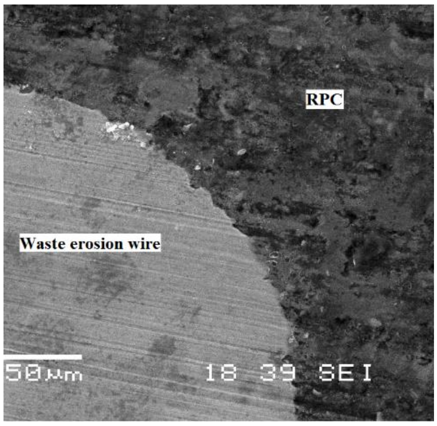

Figure 10. Interface of waste erosion wire with RPC paste

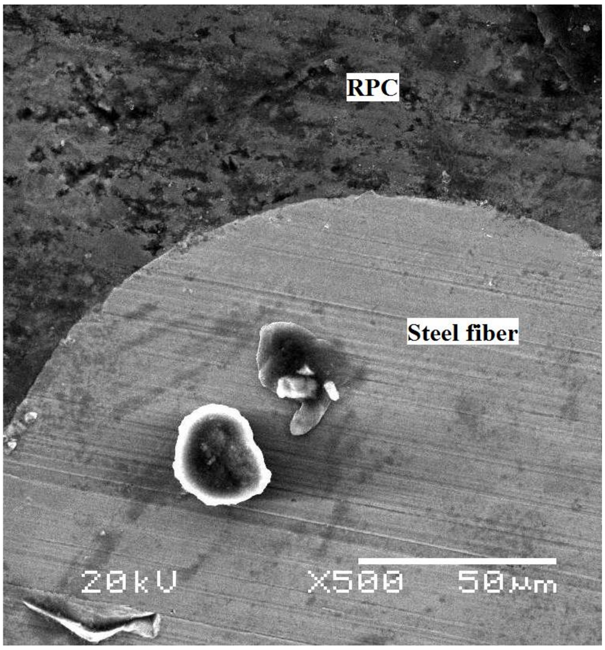

Figure 11. Interface of steel fiber with RPC paste.

Interface of waste erosion wire with RPC paste has a strong structure and very strong adhesive. Therefore waste erosion wires ruptured during the flexural test. On the other hand, strength of steel fibers is bigger than that of waste erosion wire. Thus, steel fibers pulled out in paste without rupture. Results of flexural test were given in Table 3 and Fig. 12.

When the results were observed; it was seen that crack, flexural strength and fracture toughness of waste erosion wires are distinctly lower than samples including steel fibre. That the tensile strength of erosion wires are lower than steel fibre and moreover its surface being rough after cutting process made it difficult to peel through RPC paste and caused rupture. As a result of such rupture, fracture toughness of erosion wire samples had quite low values. When control sample is compared with RPC-EW2 and RPC-EW4, flexural strength has increased 121% and 125%, fracture toughness has increased 368% and 586% respectively. In RPC-SF2 and RPC-SF4; flexural strength has increased 200% and 352%, fracture toughness has increase 574% and 788% respectively. When RPC-SF2 and RPC-EW2 samples are compared with RPC-SF4 and RPC-EW4 samples, flexural strength values are more in the rate of 40.7% and 83.6%; while this difference in fracture toughness is about 14 and 13 times more respectively due to low tensile strength of erosion wires.

3.2. Unit Cost

In Table 5, unit price of steel fibre and erosion wire content RPC were given in terms of TL (Turkish Liras). Unit cost is calculated considering market conditions. Micro steel fibre is the material which forms the greatest cost in RPC mixture. Unit price of RPC with 2% steel fibre content is 2 times more than non-fibrous RPC. Therefore, the cost of fibre comes up to the total cost of other materials in the mixture and this time, the usage of RPC makes a significant restrictive effect. Since waste

Table 3. Results of flexural strength and toughness

Sample Code	Crack Strength (MPa)	Flexural strength (MPa)	Total Deflection (mm)	Toughness (Nm)
Ctrl	8.96	8.96	1	1.27
RPC-SF2 (RPC-EW2)	21.95 (18.03)	26.81 (19.06)	10.97 (1.48)	85.64 (5.94)
RPC-SF4 (RPC-EW4)	35.84 (21.17)	40.50 (22.06)	10 (1.63)	112.75 (8.71)

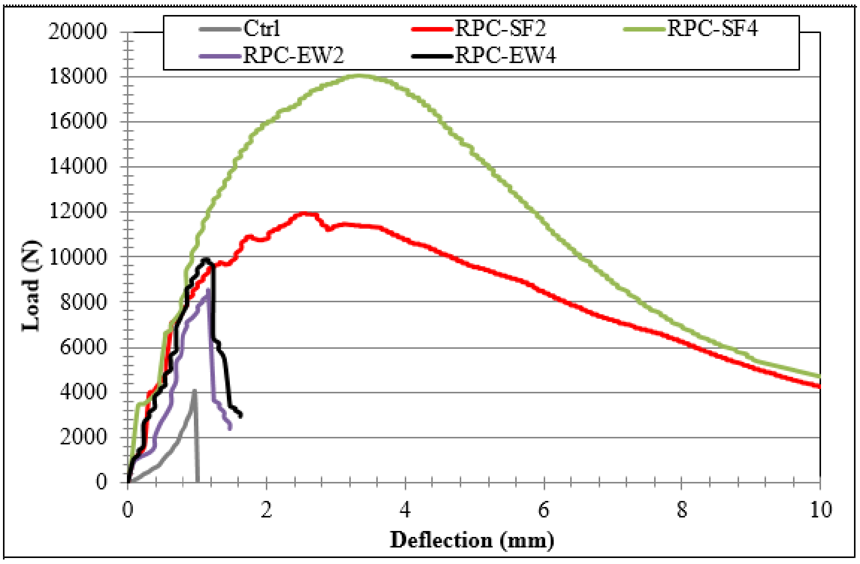

Figure 12. Load-deflection curve on the ratio of fiber

erosion wire is a waste material, it increases the cost of RPC with 2% wire content in the rate of 25%. In order to compare waste erosion wire with steel fibre economically unit strength costs were calculated and they were given in Table 4 and Figure 13-15. While unit strength costs of samples with steel fibre and erosion wire are close to each other, it was seen that waste erosion wire is more economic in unit costs of compressive strength (Fig. 13). It was seen that unit cost of fracture toughness of erosion wire is not highly economic compared to steel fibre (Fig. 15). As a result, although waste erosion wire is disadvantageous in terms of fracture toughness, it is economical in the sense of unit costs of flexural and compressive strengths (Fig. 13,14). Unit costs of flexural, compressive strengths and toughness were calculated using the ratio among strengths and unit cubic RPC cost.

Table 4. Unit cost of RPC with steel fibre and erosion wire content

Fiber Ratio (%)	**RPC-SF Cost (TL/m^3)**	**RPC-EW Cost (TL/m^3)**	**RPC-SF Unit Cost**			**RPC-EW Unit Cost**		
			Flexture Strength (TL/MPa)	**Comp. Strength (TL/MPa)**	**Fracture Toughness (TL/Nm)**	**Flexture Strength (TL/MPa)**	**Comp. Strength (TL/MPa)**	**Fracture Toughness (TL/Nm)**
Ctrl	559.06	559.06	62.39	3.29	440.20	62.39	3.29	440.20
2	1063.06	695.06	39.65	4.83	12.41	36.47	3.66	117.01
4	1563.56	831.06	38.61	6.01	13.87	37.67	3.61	95.41

4. CONCLUSIONS

Steel fibre has better values than erosion wire in terms of mechanical features. The biggest disadvantage of erosion wire against steel fibre is its low tensile strength. Rough surface of erosion wire causes false adherence with RPC paste. Due to inadequate adherence as a result of tensions during experiments. they cannot peel through and rupture. On the other hand. usage of waste wire enhances compressive and flexural mechanical features distinctively compared to non-fibrous RPC and is more economic than steel fibre in the sense of compressive strength cost. Although usage of waste erosion wire give lower values than steel fibre in the sense of flexural strength and fracture toughness. its unit cost of flexural strength is nearly the same as steel fibre. Waste erosion wire which is an industrial waste can be used as fibre in RPC without any additional processing. Usage of RPC which is obtained by erosion wire in construction elements for which compressive and flexural strengths are sufficient will be beneficial both for recycling and in the sense of cost.

ACKNOWLEDGEMENTS

This work was supported by Sakarya University Scientific Research Foundation (Project number: 2007-01-04-003. 2006-50-02-055. 2012-05-08-008). The authors would like to thank Sakarya University and Turkish Cement Manufacturers' Association (TCMB) due to its financial support for this study.

REFERENCES

[1] Takeuchi. L.. Jianxin. D.. "Mechanical surface treatments of the (EDMed) ceramic composite for ımproved strength and reliability". ***J. of the Eur. Ceram. Soc..*** 22: 545-550,(2002).

[2] idea.metu.edu.tr/program/aiy (24.08.2011).

[3] Shajan. K.. Kamal. M.. Shunmugam M.S.. "Data mining applied to wire – EDM process" ***J. of Mater. Process. Technol..*** 142: 182-189, (2003).

[4] Boyer. E.H. Gall. L.T.. "Nontraditional machining processes". Metals Handbook. Desk Edition. ***American Society for Metals Park.*** Ohio. (1992).

[5] Çaydaş. U.. Hasçalık. A.. "CNC tel erozyon tezgahlarında farklı malzemelerin işlenebilirliğinin araştırılması". ***DPÜ Fen Bilimleri Enstitüsü Dergisi.*** 6: 201-214, (2004).

[6] Aktaş. M.. Okumuş. H.I.. "Doğrudan moment kontrollü asenkron motorun stator direncinin yapay sinir ağı ile kestirimi". ***International XII. Turkish Symposium on Artificial Intelligence and Neural Networks.*** July 02-04, 189-191, (2003).

[7] Lok. Y.K. Lee. T.C.. "Processing of advanced ceramics using the wire-cut EDM process." ***J. of Mater. Process. Technol..*** 63: 839-43, (1997).

[8] Dugat. J.. Roux. N.. Bernier. G.. "Mechanical properties of reactive powder concretes". ***Mater. Struct..*** 29: 233-40, (1996).

[9] Ipek. M.. Yılmaz. K.. Sümer. M.. Sarıbıyık. M.. "Effect of pre-setting pressure applied to mechanical behaviours of reactive powder concrete during setting phase". ***Constr. Build. Mater..*** 25: 61-68, (2011).

[10] Richard. P.. Cheyrezy. M.H.. "Composition of reactive powder concrete". ***Cem. Concr. Res..*** 25: 1501-1511, (1995).

[11] Yazıcı. H.. "The effect of curing conditions on compressive strength of ultra high strength concrete with high volume mineral admixtures". ***Build. Environ..*** 42: 2083-2089, (2007).

[12] Ipek. M.. Yilmaz. K.. Uysal. M.. "The effect of pre-setting pressure applied flexural strength and fracture toughness of reactive powder concrete during the setting phase". ***Constr. Build. Mater..*** 26: 459–465. (2012).

[13] Özek. C.. Cebeli. C.. "Tel erozyon tezgahında Ç8620 dişli çeliğinin kesilme davranışlarının araştırılması". ***DEU Mühendislik Fakültesi Fen ve Mühendislik Dergisi.*** 5: 47-52, (2003).

[14] Fengguo. C.. Yansheng. M.. Yuanfang. W.. Jinjuan. F.A.. "Machining techique of superhard materials PCD and

CBN using wire EDM". ***Proc. Int. Symp. For Electromachining (ISEM-10).*** 359-363, (1992).

[15] Kozak. J.. Rajurkar. K.P. Wang. S.Z.. "Material removal in WEDM of PCD blanks". ***ASME Winter Meeting. PED.*** 64: 823-833, (1993).

[16] Luo. Y.F. Chen. C.G. Tong . Z.F... "Investigation of silikon wafering by wire EDM". ***J. Mat. Sci..*** 27: 5805-5810, (1992).

[17] Tosun. N.. Çoğun . C.. Tosun. G.. "A study on kerf and material removal rate in wire electrical discharge machining based on taguchi method". ***J. of Mater. Process. Technol.,*** 152: 316-322, (2004).

[18] James. E.C.. Robert. E.C.. "What happens in EDM. in: E.C. Jameson (Ed.). Elektrical discharge machining tooling. methods and aplications". ***Society of Manufacturing Engineers.*** Dearbern. Michigan. (1983).

[19] Tosun. N.. Çoğun. C.. "An investigation on wire wear in WEDM". ***J. of Mater. Process. Technol..*** 134: 273-278, (2003).

[20] http://www.matbase.com/material/non-ferrous-metals/wrought-copper/cuzn-37/properties (24.08.2011).

[21] TS 10513. "Çelik teller-beton takviyesinde kullanılan". (1992).

[22] TS 10514. "Beton-Çelik Tel Takviyeli-Çelik Telleri Betona Karıştırma ve Kontrol Kuralları". (1992).

[23] JSCE Standard SF-4. "Method of test for flexural strength and flexural toughness of fiber reinforced concrete". (1984).

[24] TS 10515. "Çelik Tel Takviyeli Betonun Eğilme Mukavemeti Deney Metodu". (1992).

[25] ASTM C 1018. "Standard test method for flexural toughness and first-crack strength of fiber-reinforced concrete (Using beam with third-point loading)". (1989).