MECHANICAL PROPERTIES OF CONCRETE CONTAINS WASTE TIRES EXPOSED TO HIGH TEMPERATURE

Siti Nurul Nureda Mohamad Zukri[1], Mariyana Aida Ab. Kadir[1]*, Abdul Rahman Mohd. Sam[1], Nur Nadhira A. Rasid[1], M. Iqbal Khiyon[1] & Nur Farhayu Ariffin[2]

[1] *Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia*
[2] *Faculty of Civil Engineering and Earth Resources, Universiti Malaysia Pahang, 26300 Kuantan, Pahang, Malaysia*

*Corresponding Author: *mariyanaida@utm.my*

Abstract: Concrete contains crumb rubber and steel fiber from waste tires has recently gained interest among researchers as an alternative material to be used in the construction field. Mechanical properties of the concrete containing crumb rubber replacement and steel fiber at high temperature was investigated experimentally. The waste crumb rubber was chemically treated by using sodium hydroxide (NaOH). Water cement ratio of Treated Rubberized Steel Fiber Concrete (TRSF-Con) was modified to get similar strength as Normal Concrete (NC). A microstructure analysis using Scanning Electron Microscopy (SEM) test was conducted to investigate the bonding of crumb rubber in the concrete mix at ambient and high temperature. The TRSF-Con has performed satisfactory on reducing the growth and crack width compared with normal concrete when exposed to high temperature. The concrete containing crumb rubber and steel fiber have high potential to be utilized as insulating or reinforcement materials for non-structural composite member, which ensure the elements of the structure will not collapse for a prescribe period of time.

Keywords: *Concrete, crumb rubber, steel fiber, high temperature, mechanical properties*

1.0 Introduction

The production of waste tires that were dumped to environmental area cause environmental health was increased yearly. In Malaysia, it is estimated that of 57,391 to 8.2 million tons production of waste tires every year where, more than 50% amount of waste tires were disposed wrongly (Thiruvangodan and Sandra, 2006). Rubber tires are non-biodegradable which is not easy to break down naturally. Burning out tires can cause damage towards environment and these activities were prohibits by law in several countries (Isaac and George, 2013). The extensive studies devote to innovate to use of waste rubber materials in many conditions in which can mitigate the environmental hazard. One example of the utilization of scrap tires was used for shock resistance in marine platform for dynamic impact (Najim and Hall, 2010). Besides, concrete that contain rubber could be used for non-structural purposes such road pavement, sidewalk and driveway (Eldin and Senauci, 1993). Transformation from waste into something useful in building materials, as the renewal, reuse, and recycling of resources not only increase the capacity and prolong the life of a structure element but also provide a practical application of the modern concept of environmental protection.

Concrete exposed to high temperature can cause damage by detrimental chemical reactions, reduction in strength, colour change, cracking and spalling. Based on previous study, the strength of concrete reduced as the temperature increased (Omer Arioz, 2006 and Georgali and Tskairidis, 2005). The bonding effects between rubber and cement can be improved by using special cement and magnesium oxychloride (Biel Timothy and Lee 1994). Sodium Hydroxide (NaOH) solution is also used to treat the surface of rubber particles thus enhance the bonding between crumb rubbers and cement paste. From scanning Electron Microscopy (SEM), it is showed the rubber that treated with NaOH enhanced the bonding between rubber and cement paste (Segre and Joekes, 2000).

Furthermore, the amount of replacement crumbs rubber in concrete within range 17% to 20% of the aggregates, which affected differently to concrete durability (Fedroff *et al*., 1997; Thong, 2001; Khatib and Bayomy, 1999). Moreover, crumb rubber had been proven to have good properties when it is exposed to high temperatures, the concrete give reduction risk in explosive spalling and strength loss rate (Yong-chang *et al*., 2014). This is because crumb rubber can protect concrete from explosive spalling due to the space that has been created by crumb rubber during high temperature and allowed the water vapour to escape through that space (Yong-chang *et al*., 2014 and Li *et al*., 2011).

The main goal of this research is to investigate the characteristic of concrete containing treated crumb rubber and steel fiber in concrete constituents subjected to high temperature. The tests conducted in this study were compressive strength, flexural strength, and microstructure analysis. The results were compared with normal concrete.

2.0 Materials and Test Methods

2.1 Materials

In this research, Ordinary Portland Cement (OPC) was used for Normal Concrete (NC) and Treated Rubberized Steel Fiber Concrete (TRSF-Con). The natural fine aggregate passing through 4.75 mm while crush coarse aggregate passing through 10 mm and retained at 5 mm were used. The crumb rubber was treated with Sodium Hydroxide (NaOH) for 20 minutes and rinsed with water then dry for 24 hours at ambient temperature. This process was done to remove the impurities and dust on crumb rubber surface. Figure 1 (a) shows a crumb rubber that passing through 4.75 mm were used as fine aggregate replacement while Figure 1 (b) shows a steel fiber with diameter of 0.30 mm with average length of 2.35 cm.

(a) Crumb rubber (b) Steel fiber

Figure 1: Crumb rubber and steel fiber used

2.2 Mix Design

Table 1 shows the typical mix design used in this study. Table 2 demonstrated the amount of treated fine and coarse aggregate rubber replacement used, while the amount of steel fiber used in this experiment is shown in Table 3.

Table 1: Concrete mix design

Item	*Density (kg/m^3)*
Cement	425
Fine Aggregate	750
Coarse Aggregate	920
Water	233

Table 2: Percentage of treated crumb rubber in concrete mix

Treated Crumb Rubber	*Treated Crumb Rubber (kg/m³)*	*Fine Aggregate (kg/m³)*	*Coarse Aggregate (kg/m³)*	*Cement (kg/m³)*	*Water (kg/m³)*
0%	0	750	920	425	233
10%	75	675	845		
20%	150	600	770		
25%	188	562	732		

Table 3 : Concrete Containing Crumb Rubber and Steel fiber

Treated Rubberised Steel Fiber Concrete	*Density (kg/m³)*	*Name of The Concrete Specimen*
0% Steel Fiber + 0% of Treated Rubber	0	Normal Concrete (NC)
0.50% Steel Fiber + 10% of Treated Rubber	26.7	TRSF1-Con 10
1.00% Steel Fiber + 10% of Treated Rubber	53.4	TRSF2-Con 10
0.50% Steel Fiber + 20% of Treated Rubber	26.7	TRSF1-Con 20
1.00% Steel Fiber + 20% of Treated Rubber	53.4	TRSF2-Con 20
0.50% Steel Fiber + 25% of Treated Rubber	26.7	TRSF1-Con 25
1.00% Steel Fiber + 25% of Treated Rubber	53.4	TRSF2-Con 25

2.3 Sample Preparation and Curing Condition

There were 7 batches of concrete mix. Each batch consists of three cubes for compressive test, and three prisms for flexural test with dimensions of 100×100×100 mm and 100×100×500 mm. The total volume of each batch is 0.022 m^3. In this test, 24 cubic and 24 prism samples were casted and cured in water tank for 7 days and tested for compressive and flexural test.

Both Normal Concrete (NC) and Treated Rubberized Steel Fiber Concrete (TRSF-Con) were exposed to ambient and at 800°C, then the Scanning Electron Microscopy (SEM) was used to evaluate the bonding between crumb rubber and cement paste before and after exposed to high temperature that will be discuss in result and discussions.

3.0 Result and Discussions

3.1 Compressive Strength

Across a large number of previous studies, all researches reported that the compressive strength decreases significantly with increased quantities of rubber aggregate (Güneyisi and Özturan, 2004; Zheng *et al*., 2008). Figure 2 and Figure 3 illustrates the additional percentage of both fine and coarse crumb rubber decreased the value of compressive strength. The 10% of fine crumb rubber with 1% of steel fiber (TRSF2-Con 10) gives adequate compressive strength with 6.89% reduction which is the lowest reductions while the highest strength reduction goes to TRSF1-Con 25 with reduction of 66.98%. Meanwhile, the replacement of 25% coarse crumb rubber with 0.5% steel fiber declined with 88%. The highest percentage of replacement of fine and coarse crumb rubber give reduction in strength.

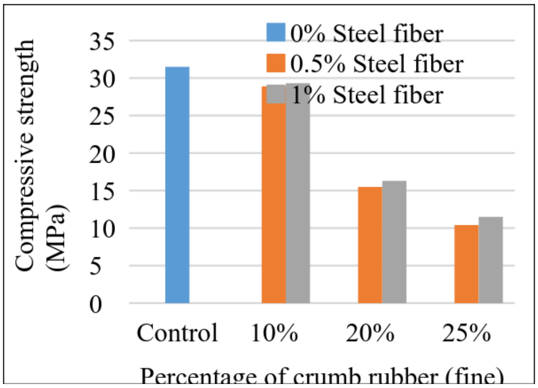

Figure 2: Compressive strength for fine crumb rubber

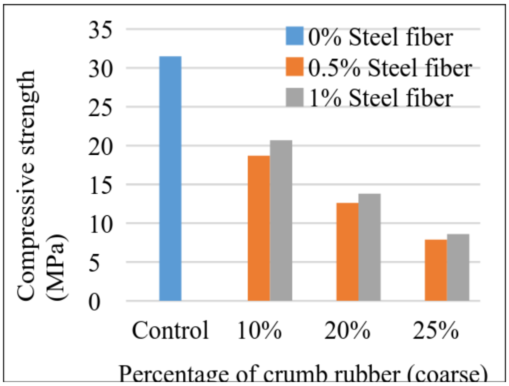

Figure 3: Compressive Strength for coarse crumb rubber

Figure 4 and Figure 5 showing the compressive strength after exposed to high temperature (800°C). Based on the results, the compressive strength of concrete shows drastically decreased with more than 50% reduction as increased the percentage of fine and coarse crumb rubber. Further research need to be done in order to investigate on how to improve the properties of concrete at high temperatures.

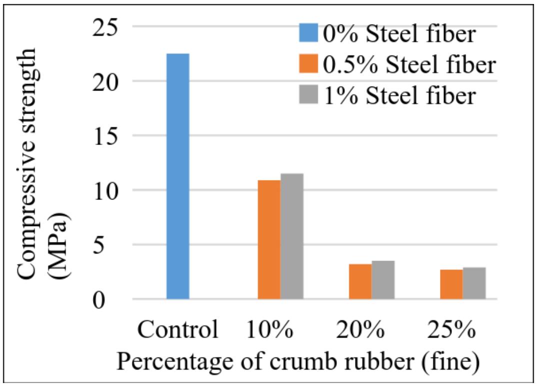

Figure 4: Compressive strength for fine crumb rubber after exposed to high temperature

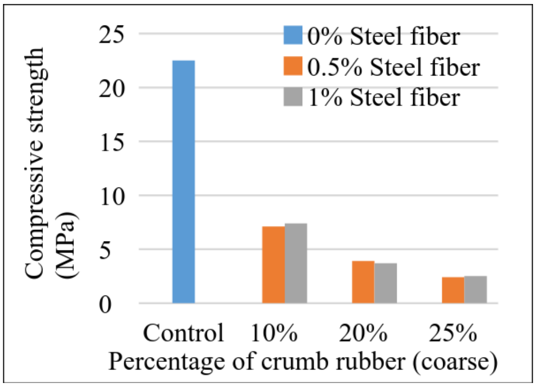

Figure 5: Compressive strength for coarse rubber after exposed to high temperature

The 0.55 water cement ratio was modified for Treated Rubberized Steel Fiber Concrete (TRSF-Con) containing 10% replacement of fine crumb rubber and 1 % steel fiber, to get the similar strength as Normal Concrete (NC) as shown in Figure 6.

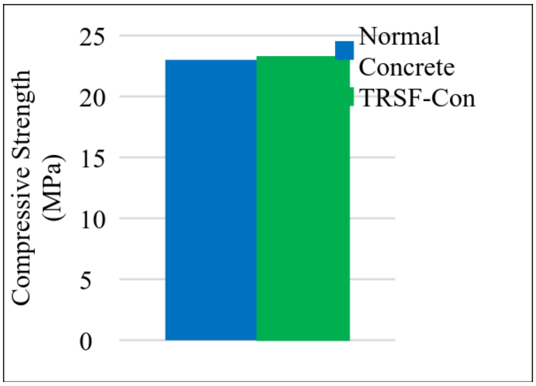

Figure 6: Compressive strength for fine crumb rubber after modification water cement ratio

3.2 *Flexural Strength*

The flexural strength of prism concrete contains NaOH treated crumbed rubberized (fine and coarse) is illustrated in Figure 7 and Figure 8. From the figures, the significant decline in flexural strength for both fine and coarse crumb rubber specimens occurred until 25% of replacement, whereas control specimen is proportionally much greater compared with crumb rubber.

Concrete contains 10% crumb rubber replacement of fine aggregates with 1% of steel fiber (TRSF-Con) with 7.14% reduction show higher flexural strength compared to the concrete contains replacement of 25% coarse crumb rubber with 1% steel fiber (19.64%).

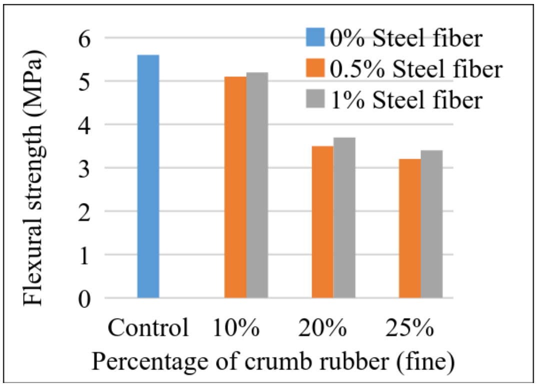

Figure 7: Flexural strength for fine crumb rubber

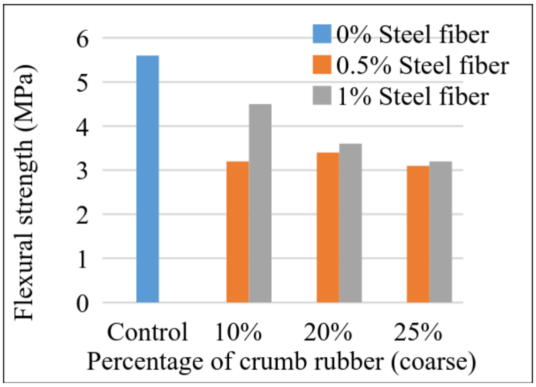

Figure 8: Flexural strength for coarse crumb rubber

After modification of water cement ratio, the flexural strength of TRSF-Con has increased with 3.2% and gives approximately same flexural strength as NC as shown in Figure 9. This has proved that the ideal size of crumb rubber that can be used as a fine and coarse aggregates replacement in concrete mix is between 3 mm to 10 mm. This was supported through the finding by Topcu and Bilir where, it shown that 4 mm size of crumb rubber with 180 kg/m³ aggregate replacement is an ideal replacement (Topcu and Bilir, 2009).

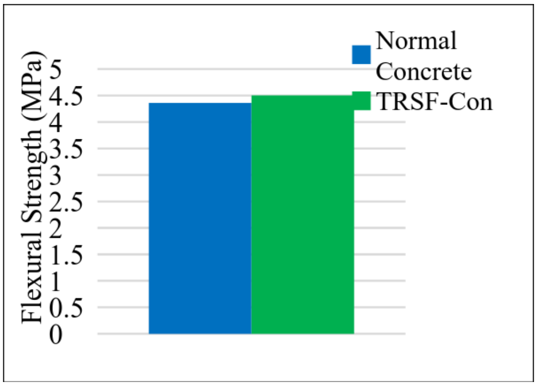

Figure 9: Flexural strength for fine crumb rubber after modification of water cement ratio

3.3 Scanning Electron Micrograph (SEM)

The microstructure analysis specifically using scanning electron micrograph (SEM) was conducted to determine the effect of the high temperature on Normal Concrete (NC) and Treated Rubberized Steel Fiber Concrete (TRSF-Con). The morphology of SEM for NC and TRSF-Con before and after exposed to 800°C temperature is shown in Figure 10 to 13. In Figure 10 and 11, both NC and TRSF-Con before exposed to high temperature clearly shows the formation of crystalline calcium silicate hydrate (C-S-H) gel and massive sheet of hexagonal shape of $Ca(OH)_2$ which was formed from cement hydration process. The SEM morphology after exposed to the high temperature is shown in Figure 12 and 13. From the figures, the pores and micro-crack was formed due to the decomposition of hydration product and weak structures of the concrete after exposed at 800^0C for two hours. After exposed to the high temperature, the reduction of compressive strength due to reduction of moisture content of materials was detected (Morsy *et al*. 2008). Moreover, the bonding between rubber and cement paste has been improved when the rubber was treated with NaOH solution. Thus, TRSF-Con showing less micro-crack compared to NC based on the microstructure observation.

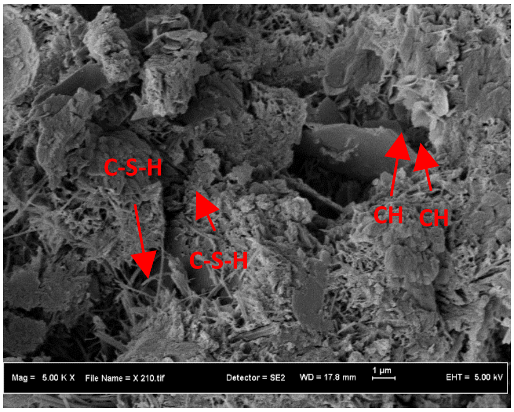

Figure 10: SEM morphology of NC before exposed to high temperature

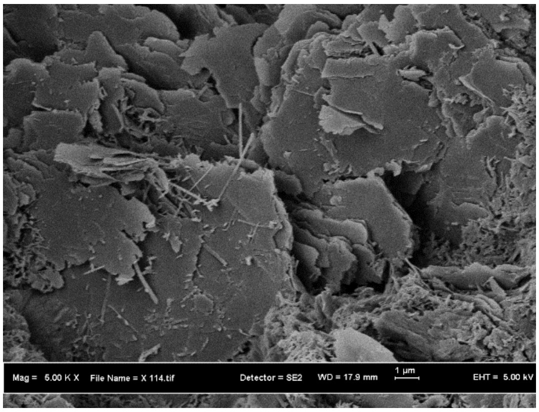

Figure 11 SEM morphology of TRSF-Con before exposed to high temperature

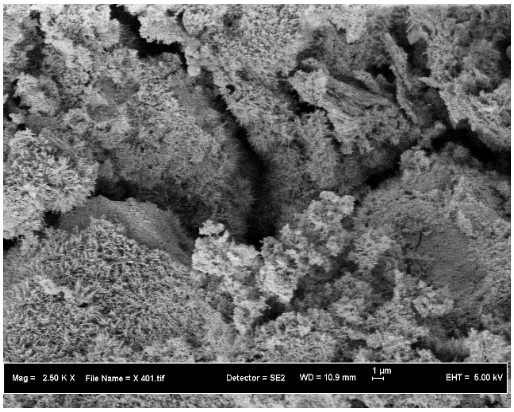

Figure 12: SEM morphology of NC after exposed to high temperature (800°C)

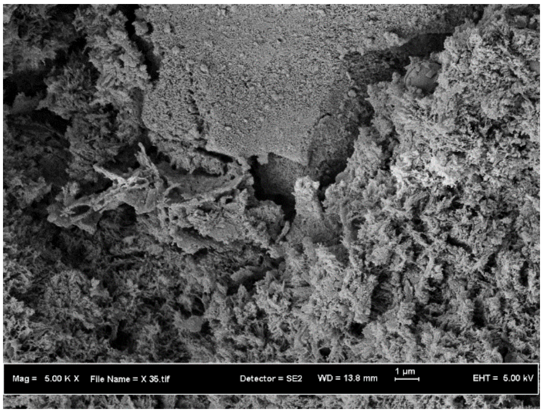

Figure 13: SEM morphology of TRSF-Con specimen after exposed to high temperature (800°C)

4.0 Conclusion

This study highlights the contribution in crumb rubber and steel fiber from waste tires in concrete mix range from 0% to 25% at ambient and high temperatures. The following conclusions are presumed.

a) The increment of crumb rubber contents reduces the compressive strength, lower the flexural strength; however, the lower amount of crumb rubber contents 10 % can produced a reasonable result of compression strength.

b) The modification of water-cement ratio need to be done to improve the compressive and flexural strength of concrete containing crumb rubber and steel fiber. This is due to reduction in water cement ratio. According to Omotola Alawode and Idowu, the strength of concrete increased when water cement ratio decreased (Omotola Alawode and Idowu, 2011). The water cement ratio used for Normal concrete is 0.55 while Treated Rubberized Steel Fiber Concrete (TRSF-Con) is 0.5.

c) Bending strength of the concrete decreased as percentage of crumb rubber increased. However, Treated Rubberized Steel Fiber Concrete (TRSF-Con) does not split into two during flexural strength test due to steel fiber contents, and it could be positive usage in highway barriers or some other similar shock resisting elements.

d) The microstructure morphology of Treated Rubberized Steel Fiber Concrete (TRSF-Con) showed the good bonding between cement pastes and crumb rubber after treated with Sodium Hydroxide (NaOH).

5.0 Acknowledgement

The authors would like to thank Ministry of Education Malaysia and Universiti Teknologi Malaysia (UTM) for providing the financial support under grant Q.J130000.2522.12H44.

References

Biel Timothy, D. & Lee H. (1994). Use of Recycled Tyre Rubbers in Concrete. *Proceeding ofthird material engineering conference, infrastructure: new material and method of repair*. San Diego, CA. 351-58.

Camille A. Isaac & George Salem. (2013). Utilization of Recycled Crumb Rubber as Fine Aggregates in Concrete Mix Design. *Journal of Construction and Building Materials*.42: 48-52.

Eldin, N. & Senouci A. (1993). Rubber-Tyre Particles as Concrete Aggregates. *ASCE Journal of Materials in Civil Engineering*. **5** (4): 478-496.

Fedroff, D., Ahmad, S. & Savas BZ. (1997). Freeze-Thaw Durability of Concrete with Ground Waste Tyre Rubber. *Transportation Research Record 1574*. 80-8 pp.

Georgali B & Tsakiridis PE. (2005). Microstructure of Fire-Damaged Concrete. *Journal of Cement and Concrete Composites*. **27** (2): 255-259.

Güneyisi E, Gesoglu M & Özturan, T. (2004). Properties of Rubberized Concretes Containing Silica Fume. *Journal of Cement Concrete Research*. **34** (12):2309–2317.

Khatib Zaher & F. Bayomy (1999). Rubberized Portland Cement Concrete. *Journal of Material in Civil Engineering*. **11** (3): 206–213.

Li, L.J., Xie,W.F., Liu, F., Guo, Y.C. & Deng, J. (2011). Fire Performance of High-Strength Concrete Reinforced with Recycled Rubber Particles. *Magazine of Concrete Research*. **63** (3): 187-195.

Morsy M. S., Shebl S. S. & Rashad A. M. (2008). Effect of Fire on Microstructure and Mechanical Properties of Blended Cement Paste Containing Metakaolin and Silica Fume. *International Conference on Durability of Building Materials and Components Istanbul*, Turkey. **9** (2): 93-105.

Najim K. B. & Hall M. R. (2010). A Review of the Fresh/Hardened Properties and Applications for Plain (PRC) and Self-Compacting Rubberized Concrete (SCRC). *Journal of Construction and Building Materials*. **24**(11): 2043-2057.

Omotola Alawode and Idowu. (2011). Effects of Water-Cement Ratios on the Compressive Strength and Workability of Concrete and Lateritic Concrete Mixes. *The Pacific Journal of Science and Technology*. **12** (2).

Segre N, Joekes I. (2000). Use of Tire Rubber Particles as Addition to Cement Paste. *Journal of Cement and Concrete Research*. **30** (9):1421–5.

Thiruvangodan, Sandra Kumar. (2006). *Waste Tyre Management in Malaysia*. PhD. Thesis, Universiti Putra Malaysia.

Thong-On A. (2001). *Crumb rubber in mortar cement application*. M.S. Thesis, Arizona State University, Tempe, Arizona.

Topçu, I. B. & Bilir, T. (2009). Experimental Investigation of Some Fresh and Hardened Properties of Rubberized Self-Compacting Concrete. *Journal of Material & Design*. **30** (8): 3056–3121.

Yong-chang, G., Jian-hong, Z., Guang-min, C. & Zhi-hong, X. (2014). Compressive Behaviour of Concrete Structures Incorporating Recycled ConcreteAggregates, Rubber Crumb and Reinforced with Steel Fibre, Subjected to Elevated Temperatures. *Journal of Cleaner Production*. **72**: 193-203

Zheng L, Sharon H.X & Yuan Y, (2008). Strength, Modulus of Elasticity, and Brittleness Index of Rubberized Concrete. *Journal of Material in Civil Engineering*. **20** (11): 692–701.