Al-Azhar University Civil Engineering Research Magazine (CERM)
Vol. (42) No. (1) January, 2020

Self-Healing of Asphalt Mixtures via Microwave Heating

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ملخص البحث

يقدم هذا البحث دراسة موجزة لنتائج المختبر البحثيه حول تعزيز قدرة الشفاء الذاتي لمزيج الإسفلت من خلال تسخين الميكروويف. يمكن أن تكون تقنية الميكروويف تقنية بديلة لزيادة الشفاء الذاتي لمخاليط الإسفلت. من المعروف أن البيتومين يحتوي على جزيئات ثنائية القطب يتم تحفيزها عبر الموجات المشحونة كهربائيًا (حث كهرومغناطيسي)، حيث انه من المعروف ان ذرات الماء والدهون والمعادن تتاثر كهرومغناطيسيا وتهتز وتحتك فيما بينها عند التعرض لموجات الميكروويف، وبالنسبه للبتومين هذه الموجات تتسبب باهتزاز الجسيمات ثنائية القطب الموجوده فى الخليط وبتالى ترتفع درجه حراره البتومين، ومن ثم يحدث انتشار للحراره داخل الخلطه الاسفتليه ككل ، وهذا سيؤدي إلى شفاء سريع وإلتئام الشروخ بالخلطه الاسفلتيه, ولكن ليس من الواضح مقدار الشفاء والمعالجه التي يمكن تحقيقها عن طريق تسخين الاسفلت باستخدام موجات الميكروويف. لهذه الأسباب ، تمت دراسة الخواص الميكانيكية والحرارية المختلفة لمخاليط الإسفلت عالى الكثافه (Dense asphalt) .في هذا البحث, تم اختبار استرداد الشفاء من خلال اختبار الانحناء 3 نقاط (3 Point Bending test) (SCB)، وتم تكسير عينات الأسفلت شبه الأسطوانية بالكامل (cracked) أولاً طبقا لإختبار (SCB) ثم تعريضها لآلة الميكروويف لتسخينها حتى درجات حرارة مختلفة ، أشارت النتائج الرئيسية إلى أن أفضل استرداد للشفاء(Self-Healing Restoration) تحققت عند درجه حراره 90 درجة مئويه ، وكانت نسبة الاسترداد 85 ٪ ، 65 ٪ ، 65 ٪ ، 50 ٪ لدورات الشفاء الأولى والثانية والثالثة والرابعة على التوالي ، تسخين الخلطات إلى درجه حراره 80 درجة مئويه لم يكن كافيا للوصول إلى الحد الأقصى للشفاء ، حيث كانت نسبة الاسترداد 55 ٪ ، 40 ٪ ، 25 ٪ ، 12 ٪ ، لدورات الشفاء الأولى والثانية والثالثة والرابعة على التوالي ، بينما لم يكن هناك اى جدوي من رفع درجات الحرارة أكثر من 90 درجة مئوية ، حيث انها لم تعزز الشفاء ، في الواقع كان الشفاء أقل ، وكان ذلك إثبات أن تسخين الميكروويف يمكن أن يشفي الشروخ في مخاليط الإسفلت.

ABSTRACT

This research provides a brief study of laboratory results of a research about boosting asphalt mixture's self-healing capability via microwave heating. Microwave technology could be an alternative technique to greatly boost the self-healing of asphalt mixtures. It is well known that bitumen has dipolar particles that get stimulated via (induction) microwave electrically charged waves, it's like metal or water atoms that vibrates when being exposed to microwave, dipolar particles' vibration creates heat in the mixture, that heat will be diffused and transferred to the mortar and aggregate of the asphalt mixture during and after heating process, and this will lead to fast and rapid healing. However, it is not clear how much healing via microwave heating of mixtures can be achieved. For these reasons, different mechanical and thermal properties of dense asphalt mixtures have been studied in this research. healing recovery was tested via 3-point bending test, semi cylinder asphalt samples were get completely fractured (cracked) first via SCB test then exposed to microwave machine to heat them up to different temperatures, The

main results indicated that, the best healing recovery was achieved at 90ºC, recovery percentage were 85%,65%,65%,50% for the first, second, third and fourth healing cycles respectively, heating the mixtures up to 80 ºC wasn't enough to reach to the maximum healing. the recovery percentage were 55%,40%,25%,12%, for the first, second, third and fourth healing cycles respectively. Higher temperature more than 90ºC, didn't boost healing, in fact healing was lower, and that was a prove that microwave heating could heal cracking in asphalt mixtures.

Keywords: Asphalt mixture; Microwave radiation heating; Crack healing.

1- Introduction

The asphalt mixture is a material composed of bitumen and aggregates, and it is one of the most widely used materials in the field of pavement construction in the world. One of the most serious defects that may arise in the surface layer of asphalt is cracks, that may arise due to traffic loading or various environmental impacts, the treatment of these cracks at the optimum time is very important to preserve the age of the road. The self-healing of asphalt layer is considered as one of the modern and non-traditional methods for treatment of cracks. In this research self-healing of asphalt mixtures using microwave will be studied and the behavior of asphalt mixtures mechanical properties will be investigated.

2- Background

As a reference, more than 90% of roads and highways worldwide are Hot Mix Asphalt [NAPA]. However, traffic loads combined with environmental conditions contribute to early deterioration of asphalt pavements, reducing their mechanical strength and durability over time [Delgadillo, 2012]. It is well known that asphalt pavements show self-healing capability when they exposed to relatively high temperatures during summer season [Liu Q, 2012], which means that cracks in the road can be closed by themselves. This occurs because bitumen viscosity is correlated with the temperature. Thus, when bitumen reaches certain temperature threshold (30-70ºC), which is different for each type of bitumen, it starts flowing through any possible micro-crack exist in the pavement by the capillary flow action [Schlangen E, 2011]. Therefore, with the assistance of an electromagnetic radiation device such as a microwave oven [Gallego J, 2013], it is possible to locally heat the asphalt mixtures by volumetric diffusion of heat in the dipolar particles in bitumen, thus softening and melting the bitumen to repair opened cracks present in the pavement. [Liu Q, García a, 2011] healing potential in a completely cracked asphalt mastic samples by adding steel fibers to the asphalt mixture, and applying induction machine on the asphalt mastic beam, it make it healed many times, the strength recovery of the samples after the first healing was around 85% of the original value. In the successive cycles, it becomes stable at about 70% of the original value. Finally, it decreases sharply after the sixth healing step. [J. Norambuena-Contreras, 2016] Microwave heating was applied on a semi-circular samples by using a microwave oven, proven than microwave oven could heat asphalt mixtures without steel fibers, that heating process was translated to healing in the mixtures. [Gallego et al ,2013] who consider the Microwave radiation as a non-destructive heating method, [J. Norambuena-Contreras and et al, 2015] studied the self-healing of asphalt mixtures reinforced with steel fibers. Therefore, microwave heating can be effectively applied in cracked asphalt pavements as other heating methods like electromagnetic induction

although it is still not clear how this effect works. For these reasons, the influence of microwave heating on thermal and healing properties of asphalt mixture have been evaluated in this research.

3- Methodology

The main objective of this research is to enhance and boost the self-healing capability of the asphalt mixtures by using the microwave (induction energy radiation) machine, where the previous studies showed that the best factor for improving asphalt self-healing is exposing asphalt to higher temperature followed by a rest period, and also investigate the possibility of applying microwave radiation to the existing roadways, and potentially expand its service life span, where higher temperatures that exceeds the softening point temperature of bitumen, make bitumen flow inside cracks and heal it via diffusion. Figure 1 illustrates the research plan.

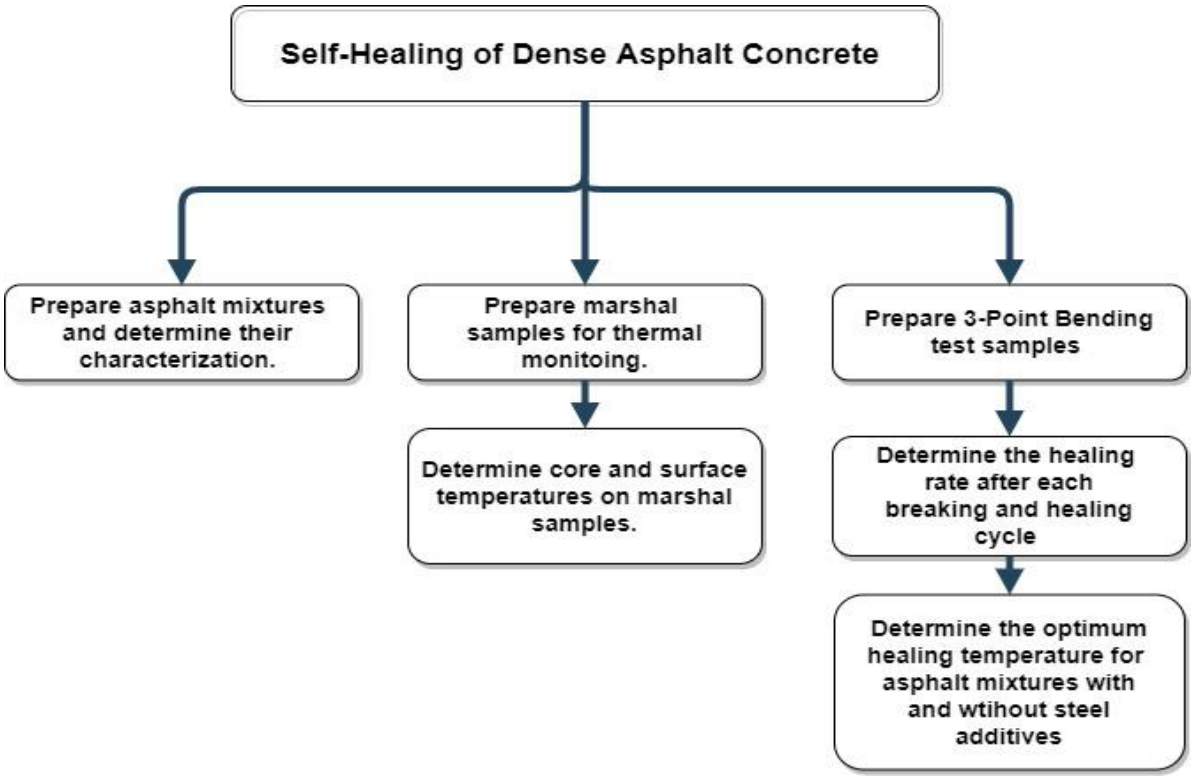

Figure 1: Flow diagram of the research plan.

4- Materials characterization

4-1 Aggregate properties

A dense asphalt mixture has been used in this research. The mixture composition is shown in Table 1. The aggregates consisted of coarse aggregate (size between 22 and 15mm by 10 %), (size between 15 and 12mm by 12 %), (size between 12 and 5mm by 25 %), and sand (size between 5mm and 0.08mm by 50 %), and filler (size <0.08mm by 3 %). The lose angles percentage after 100 rounds = 5% and after 500 rounds = 26%

TABLE 1. Composition of the dense asphalt mixture

Sieve size (mm)	Aggregate passing %	Aggregate mass % retained	Cumulative aggregate mass % retained	Mass (g)
25	100	0	0	0
19	98	2	2	20
12.5	87	11	13	139
9.5	79	8	21	87
No.4	61	18	39	188
No.8	49	12	51	215
No.16	32	17	68	155
No.50	14	18	86	190
No.100	10	4	90	121
No.200	6.5	3.5	93.5	190
<0.063	0	6.5	100	35
Bitumen		% of mass in the mixture	5.4 % = 62.1gm	1150

4-2 Bitumen properties

Table 2 is showing bitumen properties that was used in the mixtures.

Table 2: Properties of bitumen.

Binder grade	**Penetration**	**Softening point**	**Penetration Index**	**Specific gravity**
60/70	64 dmm	49 °C	-0.91	1.020 g/cm^3

5- Experimental work

5-1 Test specimen's preparation

The asphalt mixture was used to manufacture cylindrical Marshall Specimens of approximately 10 cm diameter and 6.7 cm height. These test specimens were compacted using a Marshall compactor, applying 75 blows on each face of the test specimens, then a hole was placed in the middle of the samples using a driller machine as shown in figure 2.

Figure 2: Marshal test specimens for microwave heating.

5-2 Microwave heating

With the purpose of proving that asphalt mixtures can be heated using microwave radiation, Microwave heating experiment was performed on prepared mixtures, by using a microwave oven (figure 3) with a capacity of 900W output and at a frequency of 2.45 GHz that mean, the wavelength is around 12.23 cm. An infrared thermometer (from TACKLIFE-ModelIT-T02) was used to measure the surface temperature of the asphalt samples during heating process, and digital thermometer to measure the core temperature (figure 4) where a hole has been placed in the middle of each sample to measure its core temperature.

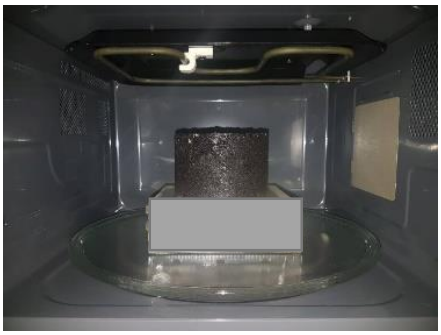

Figure 3: microwave heating set-up.

Figure 4: Infrared and Digital thermometer.

Asphalt samples initial temperature was measured in the core and the surface and it was the same, sample was lifted up to face perfectly to the microwave, and to make sure there is no big gap in temperature distribution on the surface of the asphalt sample between the top and the bottom of the samples, microwave oven set to work at 100% power which is 900W output and the temperature of both surface and core was measured each 40 seconds of heating, figure 5 shows the asphalt sample surface temperatures and figure 6 shows the asphalt samples core temperatures. the mean heating speed during this heating process is defined as the surface temperature increase divided by the heating time. The mean heating speed of the samples is 0.41 ºC/Sec.

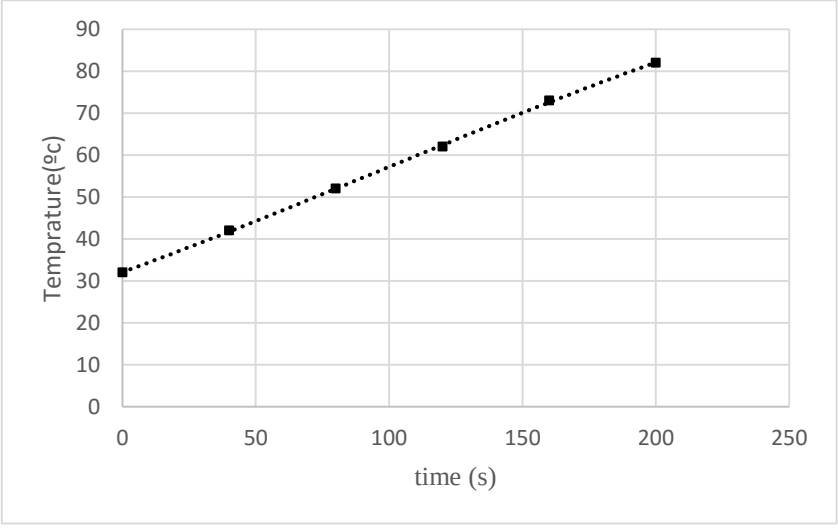

Figure 5: Asphalt surface temperature using 100% microwave power.

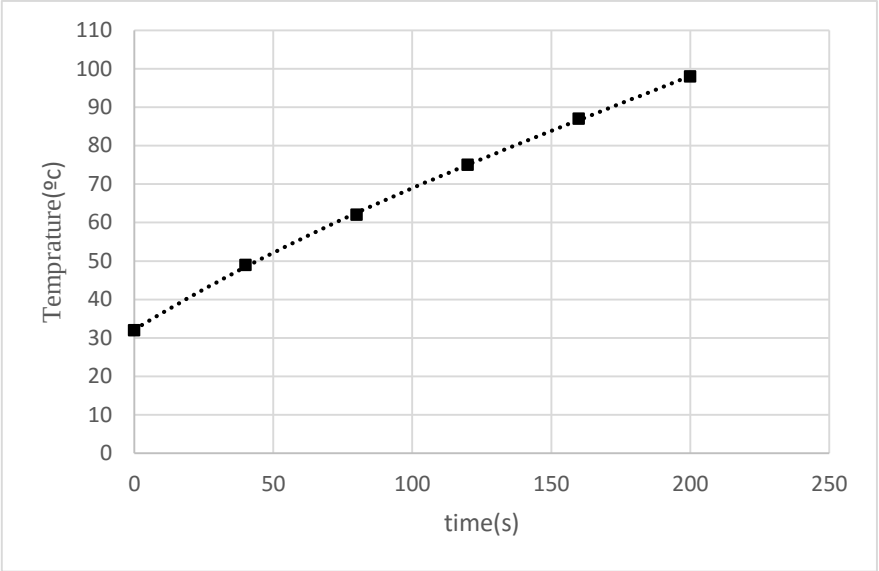

Figure 6: Asphalt core temperature using 100% microwave power.

6- Measurement of self-healing by microwave heating

6-1 Test procedure

Healing of a semi cylinder dense asphalt samples was characterized by measuring the fracture resistance recovery of a semi cylinder samples after fracture.

1- Marshall samples were cut into two equal pieces

2- A notch in the middle of the samples get created using the same cutting machine that cut the samples (the notch dimension is 10mm depth x 4mm width), figure 7 shows SCB sample dimensions and test procedure.

3- The samples were kept at 25ºC in an oven for an hour.

4- Samples get broken via three-point bending test at 0.5mm loading rate until the failure was reached, according to [ASTM D8044] standards, three-point bending setup is shown on figure 8.

5- each three samples got heated via microwave at these selected temperatures 80ºC, 90 ºC,100 ºC,110 ºC ,120 ºC, in these heating experiments, the samples were in the middle of the microwave facing the part where waves emitted from the microwave machine, as shown in Figure 9.

6- Finally, breaking and healing cycles repeated four times to measure degradation and how far healing can occur.

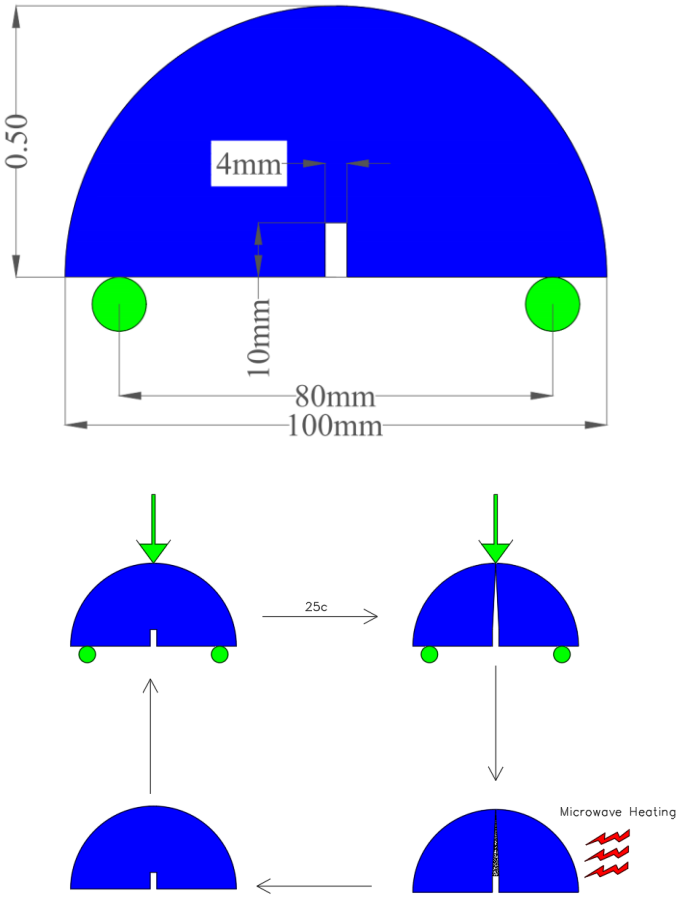

Figure 7: Semi cylinder bending test sample's dimensions and test procedures

Figure 8: Three-point bending set-up

Figure 10, and Figure 11, represent the asphalt sample before and instantly after microwave heating (80°C). It can be seen in Figure 11, that the crack in Figure 10, almost completely disappears after heating, that means that microwave heating close and heals the cracks.

Figure 10: Cracked sample before microwave heating.

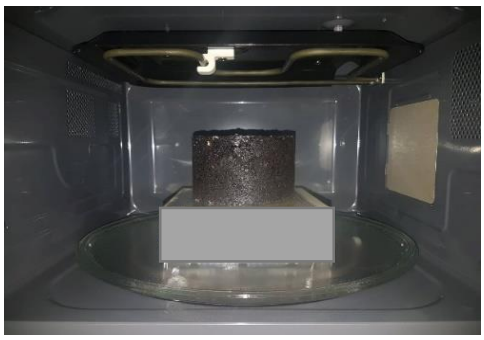

Figure 9: Sample facing microwave emitting sector (magnetron) of the microwave.

Figure 11: Cracked sample immediately after microwave heating

6.2 Test result

The progress of the bending strength of the dense asphalt samples through successive damage-healing cycles is shown in Figure 12. This test was repeated five times for each sample, so in total each sample was healed in the microwave 4 times, the strength recovery of the asphalt samples after the first healing cycle was about 85% of the original breaking value. In the second and third cycle, it recovered 65% of the original breaking value. Finally, Healing was 50% after the fourth healing cycle. That was for the samples that have been heated to 90 C°. It should be noted that the samples were healed just right after the breaking (SCB) test, and the rest period for all samples was 24 hours between each 2 breaking cycles. 80 C° heating temperature wasn't enough to reach to high healing recovery rate, healing in the first cycle was 55%, 40% for the second cycle, 25% for the third one, and finally it was 12.5% for the fourth cycle. Higher temperature more than 90 C° The healing recovery decreases again, this is due to swelling of bitumen and excess temperature that may affecting bitumen negatively.

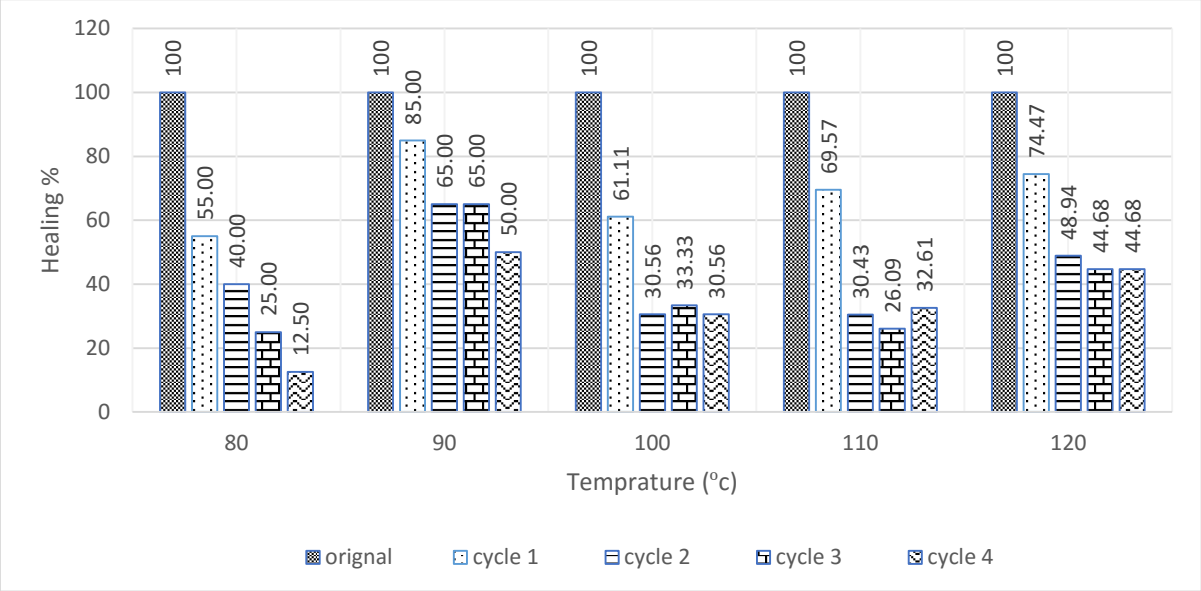

Figure 12: Microwave Healing cycles at different temperatures.

The corresponding healing rates (strength recovery ratios) are compared in Figure 13. Without microwave heating, the cracked samples can't heal themselves at any temperature blow SCB test temperature which is 25°. The capillary flow of bitumen will be much better at higher temperatures, the healing capability got raised significantly from 0% at 25°C to 85% at 90 °C. A slight decrease in healing with more heating exceeding 90°C, overheating (more than120°C) may lead to structural damages to the samples. Swelling of the mortar can be seen in the samples that are being heated up over 100 °C, which may explain why the healing rate at temperatures over 100 °C is lower than the healing at 90°C. also the healing rate at 80 °C was much lower than 90 °C or above, which may be explained by relatively low heating temperature isn't enough to reach to the optimal strength recovery.

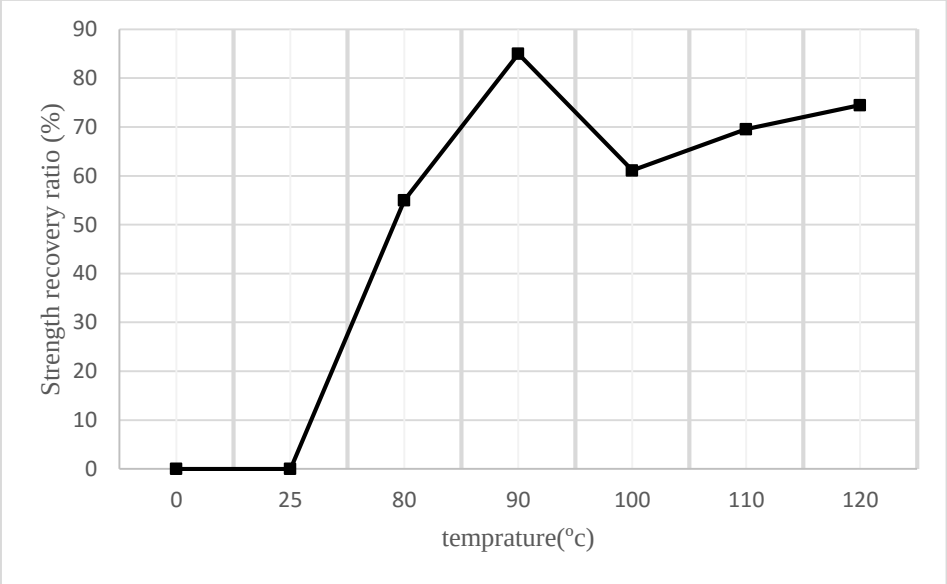

Figure 13: Strength recovery ratios with different microwave heating temperatures.

7- Conclusions

The general conclusions are as follows

1- Bituminous material gets heated up via microwave due to the presence of polar particle in the chemical composition of bitumen that give a great potential for existing roads to get treated via microwave for better self-healing

2- The healing capability of dense asphalt concrete is increased by microwave heating. The completely fractured dense asphalt semi cylinder samples cannot recover or heal themselves at low temperatures, but self-healing for asphalt concrete can be massively accelerated and healed many times by using microwave heating.

3- The optimum healing temperature is 90 ºC. This temperature gives healing strength recovery ratio up to 85% for the first healing cycle. The second and third healing cycles achieve 65% strength recovery ratio. Finally, in the fourth healing cycles the recovery decreases to 50%, that's more than enough to heal asphalt concrete many times.

4- The durability of dense asphalt concrete roadways will be greatly enhanced with microwave heating due to the enhancements in the healing capability, more over this technology could be easily applied to existing roads without any technical issues.

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