Laboratory Evaluation of Hot Mix Asphalt Comprising Coated Aggregate with Glass Waste Mortar and Cured By Microwave

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Abstract

Course aggregate is the main constituent of Hot Mix Asphalt (HMA) in terms of percentage and load carrying mechanism. Practically, crush aggregate is extensively utilized in production of HMA because of its rough shape form that offers high interlocking, consequently, brings high resistance to traffic loads exposed from moving vehicles. The use of round aggregate in paving is not allowed by highway agencies, especially for surface layers, because of its smooth surface that does not give the required engineering properties. Thus, the coating process is suggested to rough the surface of round aggregate by using different materials to increase the strength for resisting the traffic load. In this research work, the coating process was introduced by using cement mortar comprising waste and natural materials, namely the glass waste particles and the natural sand. Low energy curing process is also used to minimize cost and time for curing of coated aggregates. Results of this research attempt showed that there is a significant improvement in the engineering and durability properties of HMA comprising coated round aggregate. Moreover, microwave treatment offers an alternative to relatively long time traditional curing. So, this can be reflected on minimizing the overall cost of construction of different pavement layers and the environmental impact come from crushing aggregate and use of natural materials can be reduced.

Keywords: Coated aggregate, Glass waste, HMA, Microwave energy, Pavement

1. Introduction

Traditionally, there are three types of Hot Mix Asphalt (HMA); namely, Asphalt Concrete, Porous Asphalt Concrete, and Mastic Asphalt concrete. Such mixtures develop their mechanical properties, to resist deformation imposed by traffic, via either interlock-internal friction mechanism (e.g. Porous Asphalt), or mastic mechanism (e.g. Mastic Asphalt), or both mechanisms (e.g. Asphalt Concrete). Interlock-internal friction mechanism highly depends on particle shape and surface texture of aggregate, thus angular shape particles have shown high engineering performance in contrast to round shape particles. In fact, this is due to the development of shear resistance and even tensile strength [1]. The current practice in Iraq adopted Asphalt concrete for surface, binder and base layer constructions. Thus, to guarantee the required interlocking between aggregate particles, the General Specification for Road and Bridge, specified that the degree of crushing for coarse aggregate using for surface and binder layers should be at less 90% [2]. Although some other specifications, such as British Standard argued that specifying the percentage of crushing is not required if mixture deformation resistance is proved by direct measurement [3]. But, such recommendation is critical to be adopted in Iraq due to old-style test deformation measurements that are utilized to characterize mixture properties; i.e. Marshall Method.

Round gravel is widely available all over the world. In contrast with crushed gravel or stone, significant cost and environment benefits are confirmed if round aggregate could be introduced to concrete and asphalt mixtures. Likewise, aggregate quarries spend vast amounts of energy, with associated costs, whereas significant percentage of this energy is expended in crushing process [4]. In the USA quarries crushing stone to the required sizes consumes approximately 1.65 kWh/ton [5]; approximately the same value recognized in the UK as well [6]. Furthermore, as a result of crushing process, an approximately 25% of the quarries products is fine product which is out of market requirement and is sent normally to landfill [6].

Of course, the above reasons, further to loss of time, transport cost, and associated CO2 emissions to crushing process, encouraged industrials and researchers to explore the abilities of other alternatives to replace primary crushed stone and gravel by either secondary aggregate, or recycled aggregate. Secondary aggregates is a by-products materials from non-construction processes, e.g. industrial processes. While, recycled aggregates are produced from reprocessing the materials that have been used already in construction. Some examples of such materials have shown either comparative engineering properties to primary aggregate or in some case explored some improvements; e.g. steel stage [7, 8], recycled asphalt concrete [9, 10], recycled concrete aggregates [11, 12].

On the other hand, theoretically increase aggregate surface texture roughness by coating introduce further shear and adhesion resistance to the asphalt mixture. Limited researchers worked on such approach. Hunter and Button [13] studied coating aggregates, with a polymer called Accorex, to investigate its benefits in upgrading HMA mechanical characteristics. The results of this study showed that coating aggregate with small quantity of this polymer introduced noticeable enhancements in teams of developed mix resistance to cracking and rutting. Another study conducted by Button and Jagadam [1] examined coating round aggregate with cement mortar; paste of cement and water used to coating course and intermediate aggregate and left to cure for seven days before mixing with asphalt and fine to prepare HMA. In contrast between coated and uncoated aggregate, coated aggregate achieved significant improvement in Marshall Stability, low creep compliance. Furthermore, field trial proved the improvement obtained in laboratory results, but it disclosed that coating could be lost due to handling and mixing in the asphalt plant. Thus, the study recommended to use high abrasion materials. Other researchers attempted to coat aggregates with polymer products, whereas Kim et al [14] conducted a laboratory investigation to verify the coating, by fine-grained polyethylene, carpet co-product, and cement with SBR, for smooth, rounded, siliceous river gravel aggregates. Another study conducted by Moghadas Nejad et al.[15], where the aggregate treated by two types of polyethylene (high density polyethylene (HDPE) and low density polyethylene (LDPE)) before being introduced to mix with asphalt cement. Both studies proved the validity of coating process in enhancing the engineering properties of HMA and developing resistance to water damage. The studies concluded that introducing polymers helps in increasing the binding between the aggregates and asphalt cement.

2. Microwave processing application in pavement engineering

Microwave energy application for material processing has been utilized successfully in metals, ceramic, and compositions. Microwave energy heating offers an advantage over the conventional heating in terms of distinctive microstructure and properties, upgrading product yield, energy conservations, manufacturing cost reduction and synthesis of novel materials [16-19]. Obviously, the main difference between conventional and microwave heating is that in conventional one, the heat energy is transferred from the source to surface of heated material then to the bulk of material by redial or /and conduction. While the interactive between material's molecules due to compulsory line-up caused by electromagnetic field result in uniform and fast heat of bulk of material simultaneously[20].

However, researchers in pavement engineering field attempted to benefit from advantage of microwave energy; e.g. Bosisio et al.[21] successfully applied microwave energy source on 12 cm asphalt pavement to seal surface cracks without damage due to overheating to the top layer.

Methods for using microwave for heating asphalt mixture was suggested by different patents and research works [22-26]. In addition, attempt to improve microwave heating efficiency has been achieved by Osborne and Hutcheson [27], they showed that the addition of spinel ferrites and hexagonal ferrites to the asphalt binder help in absorption of microwave radiation, disspate heat uniformly and facilitate melt of asphalt binder faster; 2% of such mentioned material reduced melting time by 3-7 times in contrast with asphalt binder which consists non-microwave absorptive materials. Similar attempts with other microwave absorption materials were conducted by Gallego et al. [28] and Wang et al. [29].

Bishara [30] proved that the microwave heating for neat asphalt binder for 4.5 hrs. can simulate the asphalt ageing under the conventional heating for 1.5 hrs. via rotating thin film oven test (RTFOT) plus 20 hrs. via pressurized aging vessel (PAV) in terms of binder rheology changes; i.e. complex modulus, $|G^*|$, and the phase angle, δ, low-temperature stiffness, S, and the slope m at 60 sec for the stiffness master curves. On another research work, Bishara et al.[31] demonstrated that for modified binder, the microwave ageing is 3hrs. and 10 mins. to simulate the RTFOT+PAV ageing process. Furthermore, other microwave applications in pavement engineering were conducted successfully; e.g. treatment of crumb rubber by microwave to minimize the absorption of light weight components of asphalt binder by rubber [32, 33]. However it can be concluded that although microwave application has been used extensively in pavement engineering field, further application still applicable and promising results can be obtained due to the mentioned advantages facilitated by such technology.

3. Research Aim and Scope

The current research work aims at upgrading natural round gravel, which is widely available locally and use it in HMA, to overcome the restrictions stated by the pavement agencies for using round aggregate in pavement top layers. However, this attempt is to demonstrate the visibility of using low quality materials (round aggregate) instead of crushed aggregate, waste material (glass waste) instead of natural sand, and low energy process (microwave energy) to minimize curing time. Thus, comparisons between HMAs' comprising upgraded and crushed were planned to identify the validity of suggested coating processes. However, to reach this aim, the attempt draws the following objectives:

- Investigating the efficiency of coating process by two types of cement mortars; one includes natural sand and the other includes glass waste.
- investigating the proper gradation of fine aggregate by using three gradations in preparation of cement mortar
- investigating microwave curing process in minimizing curing time required before introducing the upgraded aggregate to HMA

4. Materials and test methods

4.1 materials

Aggregates (course and fine) used in this research work were supplied from local Kerbala quarries. The materials properties requirements were compliance to the Standard Specification for Road and Bridge, except the degree of crushing of round aggregates [2]. Both types of round and crushed gravel were from the same source. Tables 1 and 2 present the physical properties of coarse and fine aggregate used in this research work, respectively. The aggregates were sieved, separated and graded to compliance to the gradation required for binder layer according to the mentioned Iraqi specification. Simultaneously, asphalt binder was supplied from Al-Nasseria refinery, its properties are shown in Table 3. Cement was supplied from Karbala cement plant, Table 4 presents its chemical and physical properties. Glass waste was collected from the waste from local market, then it was grinded and sieved to match the gradation which specified thereafter.

Table 1: Physical Properties of Coarse Aggregates

property .	ASTM designation	Test results		SORB Requirement, (binder course)
		Round Coarse Agg.	Crushed Coarse Agg.	
Bulk specific gravity	C127	2.58	2.56	-
Apparent specific gravity	C127	2.61	2.62	-
Water absorption %	C127	1.53	1.42	-
Percent wear by loos Angeles abrasion ,%	C131	8	9	35% Max
Soundness loss by sodium sulfate,%	C88	1.8	2.4	12% Max
Clay lumps,%	C142	0.49	0.22%	-
Flat and elongated particles,%	D4791	2.6	1.7%	10% Max
Passing sieve NO.200,%	C117	1.67	1.12%	-
Degree of crushing,%	---	1%	97%	90% min

Table 2: physical properties of fine aggregates

Property	ASTM & AASHTO Designation	Test Results	SORB Specification for binder course
Bulk specific gravity	C128	2.66	-
Apparent specific gravity	C128	2.67	-
Water absorption,%	C128	0.5	-
Clay lumps , %	C142	2.4%	-
Passing sieve NO.200,%	C117	2.86%	-
Plasticity index, %	D 4318	NA	4% max
sand equivalent,	T 176	49%	45% min

Table 3: Properties of asphalt binder

Physical testing		
Testing	Result the testing	specification
Initial setting Time (min) Final setting Time (min)	126 327	> 45 min <600 min
Compressive Strength(N/mm2) Age 3 day Age 7 day	 21.3 28.7	 > 15 (N/mm2) > 23(N/mm2)
Chemical testing		
(Sio2)%	21.9	-------
(Cao)%	62	-------
(Al2O3)%	3.8	-------
(Fe2o3)%	4.7	-------
(Mgo)%	1.7	< 5%
(So3)%	1.9	< 2.5%
(%) Fe2o3/Al2o3	0.81	-------
(Free Lime)%	0.892	-------
Loss at fire	3.7	< 4%
Factor of saturation	0.88	1.02-0.66
Material unable for soluble	1	< 1.5%
(C3S)%	48.29	--------
(C2S)%	26.35	-------
(C3A)%	2.12	< 3.5%
(C4AF)%	14.3	--------

Table 4: Chemical and physical properties of cement

Test	ASTM designation	Test results	SORB requirements
Penetration,100 gm. ,25° C,5sec (1/10 mm)	D5	44	40-50
Specific Gravity, 25° C (gm/cm3)	D70	1.03	-
Ductility, 25° C , 5 cm/min (cm)	D113	>100	>100
Flash point, (˚C)	D92	335	>232
Softening point (˚C)	D36	41	-
Solubility in trichloroethylene, (%)	D2042	99.2	>99
After Thin Film Oven test			
Penetration of Residue (%)	D 1754	66	>55
Ductility of Residue, (cm)		97	>25

4.2 coating process

The coating process for round aggregate includes the following:

1. Preparing the specified weight of round aggregates which have minimum size of 4.75 mm.
2. Preparing the coating mortar with a ratio of (1fine materials: 1 cement: 6 water) by weight. Fine materials were two type; i.e. natural sand and glass waste. Three gradations according to ASTM D 1073 [34] were selected for mortar fine materials, namely, Grading (No. 1,3,5), Table 5 shows these gradations, while Figure 1 shows the mid class value of each sieve size for these gradations. The selection represents, coarse fine with filler (gradation no.1), coarse fine without filler (gradation no.5), and fine with filler (gradation no.3) materials.
3. Mixing the mortar with round aggregate for 1 min, then pouring out the total mix in sieve no. 40 to remove the extra mortar.
4. In case of normal curing, the produced material was left to cure in lab temperature for 7 days before being gathered with other aggregate sizes and mixed with asphalt binder to prepare HMA.

5. In case of microwave curing technique, the coated material is subjected to microwave using 2.45 GHz microwave oven after 1.5 hrs. of mixing. The coated materials then is left for additional 24 hrs. before being gathered with other aggregate sizes and mixed with asphalt binder to prepare HMA.

Table 5: Selected gradations for fine materials used for preparing mortar for coating process

Sieve size	Amounts finer than each laboratory sieve(square opening).mass%		
	Grading no.1 (G1)	Grading no.3 (G3)	Grading no.5 (G5)
9.5-mm(3/8-in)	100	_	100
4.75-mm(No.4)	95 to 100	100	80 to 100
2.36-mm(No.8)	70 to 100	95 to 100	65 to 100
1.18-mm(No.16)	40 to 80	85 to 100	40 to 80
600-µm(No.30)	20 to 65	65 to 90	20 to 65
300- µm (No.50)	7 to 40	30 to 60	7 to 46
150- µm (No.100)	2 to 20	5 to 25	2 to 30
75- µm (No.200)	0 to 10	0 to 5	_

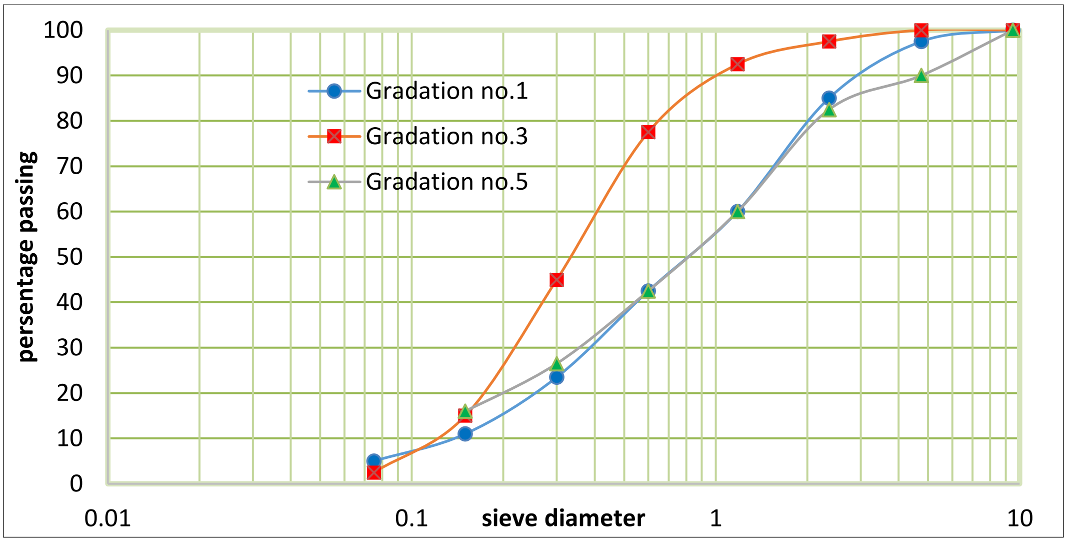

Figure 1: Selected gradations of fine materials for coating mortar

Optimization of the most suitable time (the time required to stick the mortar to the surface of round aggregate) for microwave have been found to be 4 minutes. The same procedure was used for mortar including glass waste or natural sand. However, Table 6 summarizes the testing matrix of this research work.

Table 6: Aggregate coating protocols

Mix Abbr.	Type of coating
CR	HMA prepared with crushed aggregate
RO	HMA prepared with round aggregate
CS	HMA prepared with coated agg by sand mortar (grading 3) and cure in lab temperatu re for 7 days
CG	HMA prepared with coated agg by glass mortar (grading 3) and cure in lab temperatu re for 7 days
MCS1	HMA prepared with coated agg by sand mortar (grading 1) with microwave curing
MCS3	HMA prepared with coated agg by sand mortar (grading 3) with microwave curing
MCS5	HMA prepared with coated agg by sand mortar (grading 5) with microwave curing
MCG1	HMA prepared with coated agg by glass mortar (grading 1) with microwave curing
MCG3	HMA prepared with coated agg by glass mortar (grading 3) with microwave curing
MCG5	HMA prepared with coated agg by glass mortar (grading 5) with microwave curing

CR (crushed), RO(round), C (coated), S (sand), G (glass), M (microwaved), number (gradation type)

4.3 Testing methods

In this research work, mechanical, volumetric, and durability characteristics of the nominated HMAs are determined using the following testing methods:

1. Density and air voids: three cylindrical specimens were prepared for each property, with 101.6 mm diameter x 63.5 mm height specimen, to determine bulk density according to ASTM D 2726 [35] and air void in total mix according to ASTM D 3203 [36].
2. Resistance to plastic flow: three cylindrical specimens were prepared for each property, with 101.6 mm diameter x 63.5 mm height, to determine Marshall stability and flow according to ASTM D 6927 [37]
3. Indirect tensile strength: three cylindrical specimens were prepared for each property, with 101.6 mm diameter x 63.5 mm height, to determine indirect tensile strength according to ASTM D 6931 [38].
4. Index of retaining strength: six cylindrical specimens were prepared for each property, with 101.6 mm diameter x 101.6 mm height, to determine retaining strength according to ASTM D 1075 [39]. Three specimens were conditioned and three were left without conditioning.

5. Results and discussion

5.1 Unite weight and Air voids

Results shown in Figures 2 and 3 illustrate the density and air voids of HMA specimens comprising crushed aggregate and others comprising round aggregate coated with glass and sand mortars. The coated aggregate cured in microwave and normal curing process, as described before. For comparison the results of mixture with crushed and round aggregate is included.

Results indicate that HMA comprised round aggregate has greatest density and less air void in compare with HMA included crushed aggregate, the incensement in density is about 0.88%, while the decrease in air void is about 0.59%. This is expected, due to the smooth surface of round aggregate which provides less friction between aggregate particles, and high ability to aggregate turn over each other’s. Consequently, facilitates the packing of aggregate particles during compaction state.

The results also confirmed that the coating process, in general, increases density and reduced air void; this is might be as result of increasing the fine materials which is separated from coated layer. It was recognized that part of the coating material separated from the aggregate particles due to interaction between mix content during mixing and compaction processes. Furthermore, it can be said that coating process offers a significant variation in volumetric properties of developed HMA; these variations in contrast with HMA comprised uncoated round aggregates are ranged about 0.3-2.9% as growth in density, and about 0.11-0.6 % as drop in air voids.

Additionally, it can be stated that microwave curing offered a comparative values of air void and density with normal curing; whereas less significant variations in density and air voids can be noticed between the results of the two curing processes when we compare CS with MCS3, and CG with MCG3 density and air void values.

On the other hand, the grading no.3 of the fine materials used for coating mortar (for both sand and glass waste) offered the higher variations of density and air voids of the developed HMAs. However, this is because this gradation has the higher percentage of fine material; whereas gradation no. 1 has relatively coarse particles, and gradation no.5 has relatively coarse particle without very fine particles, as it can be seen in Figure 1.

Finally, the results demonstrated relative variations in density and air voids of specimens coated with glass waste and sand. However, this is related to two characteristics of the two fine materials, namely, particles shapes and bonding between particles and cement. Of course, glass waste has more angular particles shape, and less bonding to aggregate interface. While, sand has less angularity but higher bonding.

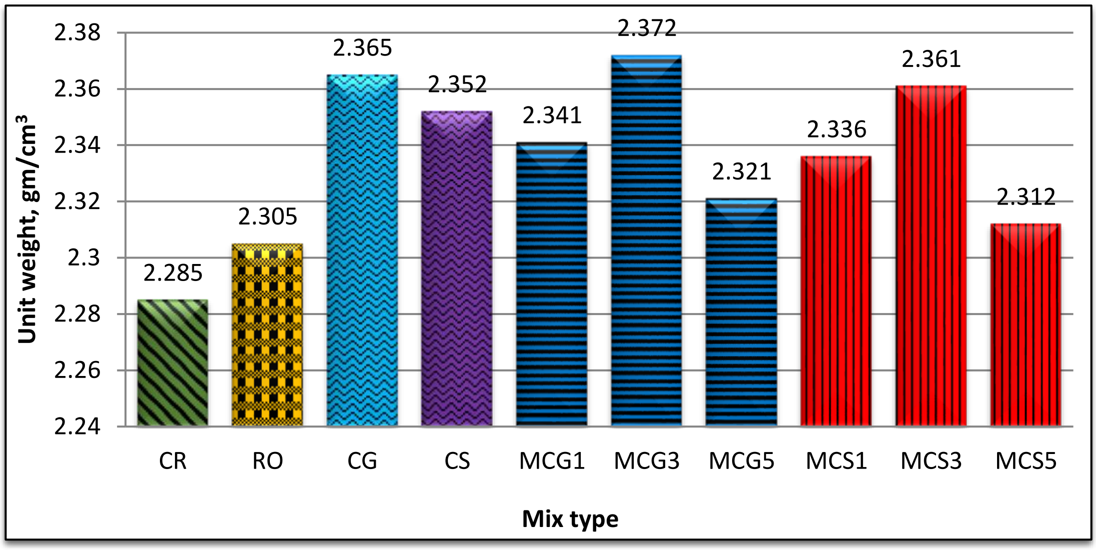

Figure 2: Unit weight variations with different coating mortars and curing techniques

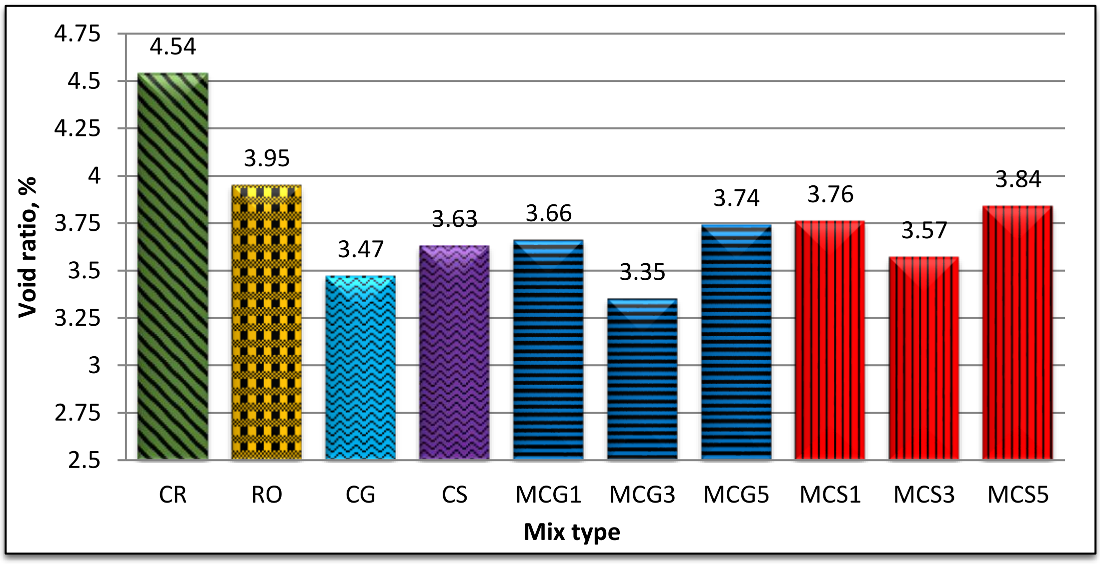

Figure 3: Air void variations with different coating mortars and curing techniques

5.2 Resistance to plastic flow

Marshall Stability and flow are very significant to identify the mechanical properties of the ability of asphalt concrete mixture to resist deformation. Thus the higher value of marshal stability will reflect good deformation resistance, while a Marshall flow should be balanced between two limited values, i.e. 2-4, to ensure that the mix neither brittle nor soft. However, it is clearly proved by the obtained results that the crushed aggregate has superior ability to satisfy resistance to plastic flow; whereas CR mix offered about 79% increment in Marshall stability with about 61% reduction in Marshall flow, in contrast to RO mix, as can be seen in Figures 4 and 5. In fact, this provides an excuse for the highway agencies to prevent the use of round aggregate in top layer where high resistance to plastic flow is required.

From Figures 4 and 5, the significant of coating process is approved. When the Marshall stabilities of coated aggregate mixes are compared with RO mix they were found to be enhanced by range of about 34-64 %, and Marshall flow is reduced by about 2-22%. The results are a consequence of the increase in the interlock of the coarse aggregate within the mix. In addition to the increase in the fine materials that reinforced the asphalt mastic that connect the bigger aggregate particles.

Results also proved the significant of microwave curing process in contrast to normal curing which take longer time; i.e. about 24hrs for microwave curing while 7 days for normal curing. But it has to say that normal curing shows better results of Marshal stability and flow.

On the other hand, gradation no.3 of fine materials used in coating mortar showed better effects on stability and flow in contrast with both gradation no.1 and 5. Again, it could be the fineness of particles after these improvement. Whereas the finer material bonded better to the aggregate surface and consequence better interlock, and when separated and rest within the asphalt mastic, it works as reinforce materials.

Also, glass waste fine materials offer a bit superior Marshall stability and flow compared with sand fine materials. The angularity of the glass waste might be after a 6% increment in Marshall stability, and a 2.7% drop in Marshall flow, when compared MCG3 mix with MCS3 as example.

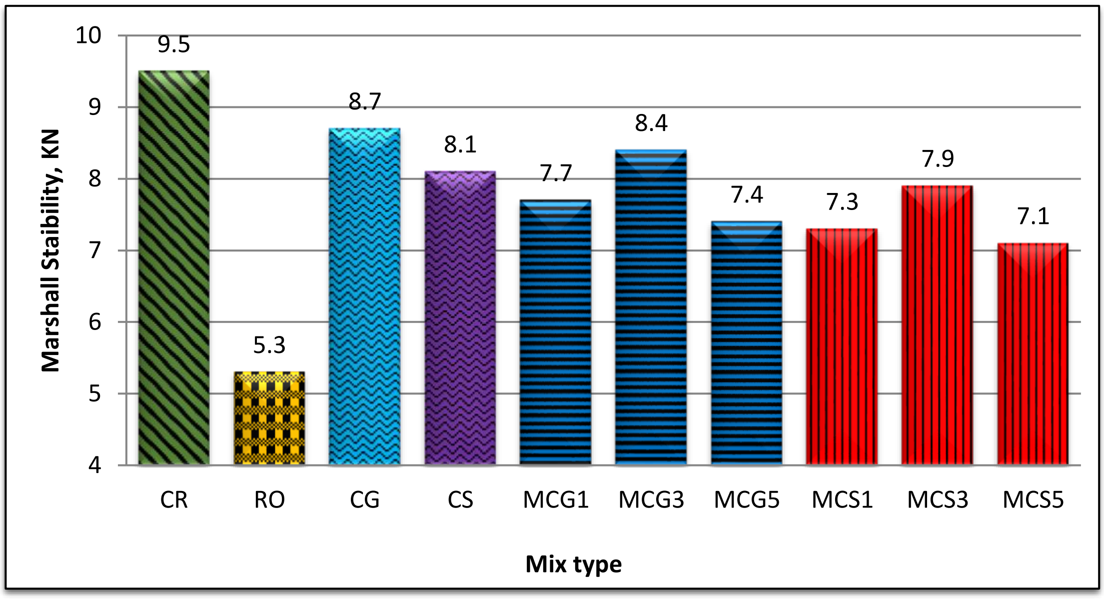

Figure 4: Marshall Stability variations with different coating mortars and curing techniques

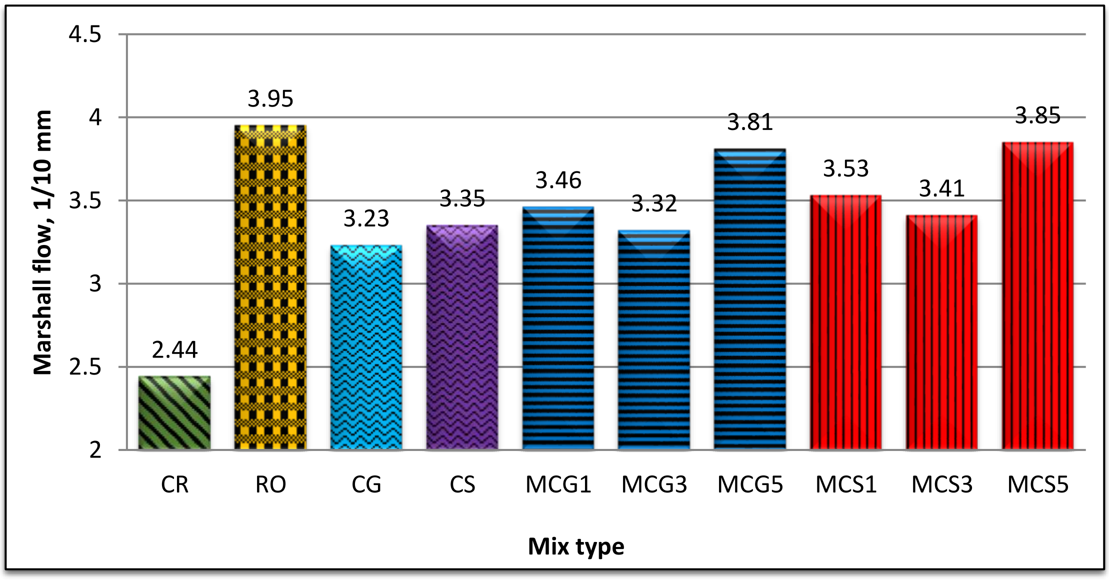

Figure 5: Marshall flow variations with different coating mortars and curing techniques

5.3 Indirect tensile strength (ITS)

Indirect tensile strength is one of the fundamental test which reflects the asphalt mixtures performance against pavement cracking, especially at low temperatures [40]. Thus, it could represent a vital tool to evaluate the performance of the coating protocols. Rustles of such test confirmed the superiority of HMAs that compressing crushed aggregates over HMAs comprising round aggregates; Figure 6 explores this superiority by about 94%. It might be a result of higher affinity between asphalt binder and aggregate surface texture; it is clearly observed that round aggregate is smoother than crushed aggregate, where the former surface is rough due to the crushing process.

It can be said, also, that the coating process upgrades the round aggregate in term of crack resistance, whereas about 22-60 % enhancements were achieved by coating the round aggregates. In addition, natural curing explored a bit advantage over microwave curing; whereas ITS showed about 5% improvements. It might be a result of improving the affinity of bounding due to new interface of aggregate surface and asphalt binder, i.e. coating mortar which offers better bounding to asphalt than smooth aggregate surface.

The last explanation could be true also for the superiority of gradation no. 3 over other two gradations of fine materials that is used with coating mortar; as such mortar recognized more sounds than other mortars with grading 1 and 5 did. Finally, glass waste fine materials introduced a relatively better enhancements in contrast to sand materials, which could be related to the angularity of glass particles that stripped from coating and rest in the asphalt mastic. Obviously, more angularity reflects reinforcement to the mastic resistance to cracking.

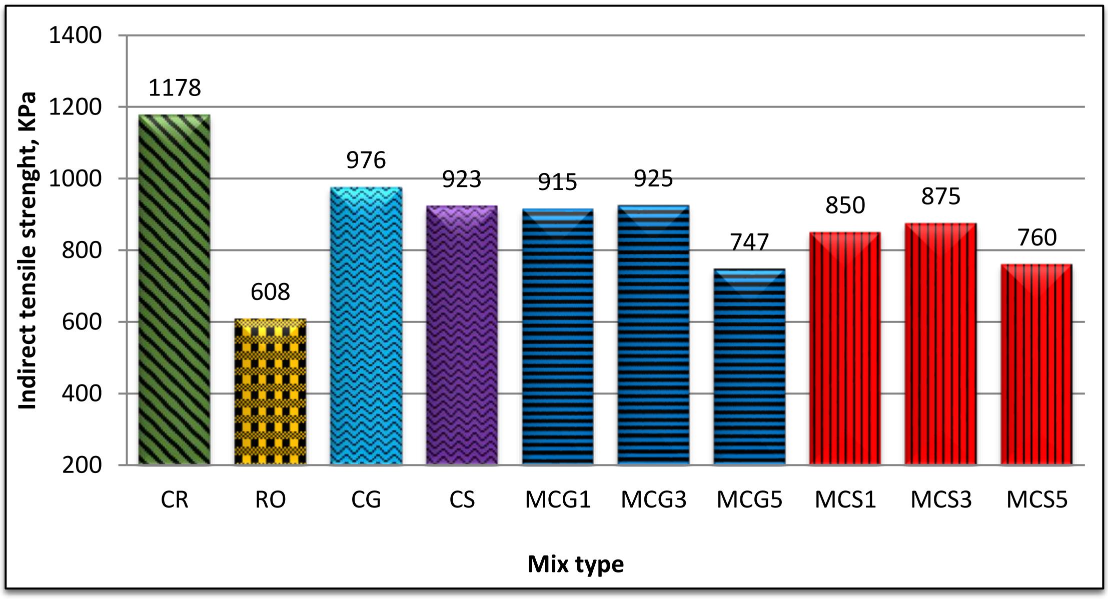

Figure 6: Indirect tensile strength variations with different coating mortars and curing techniques

5.4 durability (water sensitivity)

The water sensitivity of the HMA is one of the importance index of the mix durability. Index of retaining strength, which is the ratio of average compressive strength of conditioning specimens over the average of un-conditioning specimens, as adopted by Iraqi specifications to validate water sensitivity of HMA. Results of the test conducted in this research works demonstrate the inferiority of HMA comprising round aggregates, as itcan be seen in Figure 7; where the specification state that the retaining strength should be over 70%. Actually, the higher density and low air void of RO mix which minimize the ingress of water during conditioning process does not reflect advantage to resist binder stripping. The smooth surface of round aggregates could be after this inferiority.

On the other hand, coating process provided the developed HMAs with anti-stripping agent, i.e. OPC; of course, not all the cement powder complete the hydration process due to curing protocols, thus during conditioning these un-hydrated cement particle free the Ca^{++} ion which neutralized the ions on the aggregate surface and prevented the action of stripping.

What is mentioned above explain the superiority of microwaved curing mixes over the natural curing ones; where the microwave heating removes the free water required to continue the hydration process. From figure 7, about 6 % enhancement can be recognized. Also gradation no.3 still offers a bit better result as compared to other fine materials gradations, a range of 6% enhancement can be present. Furthermore, the angularity of fine glass waste could be after the superiority over the sand in improving the retaining strength of developed HMA.

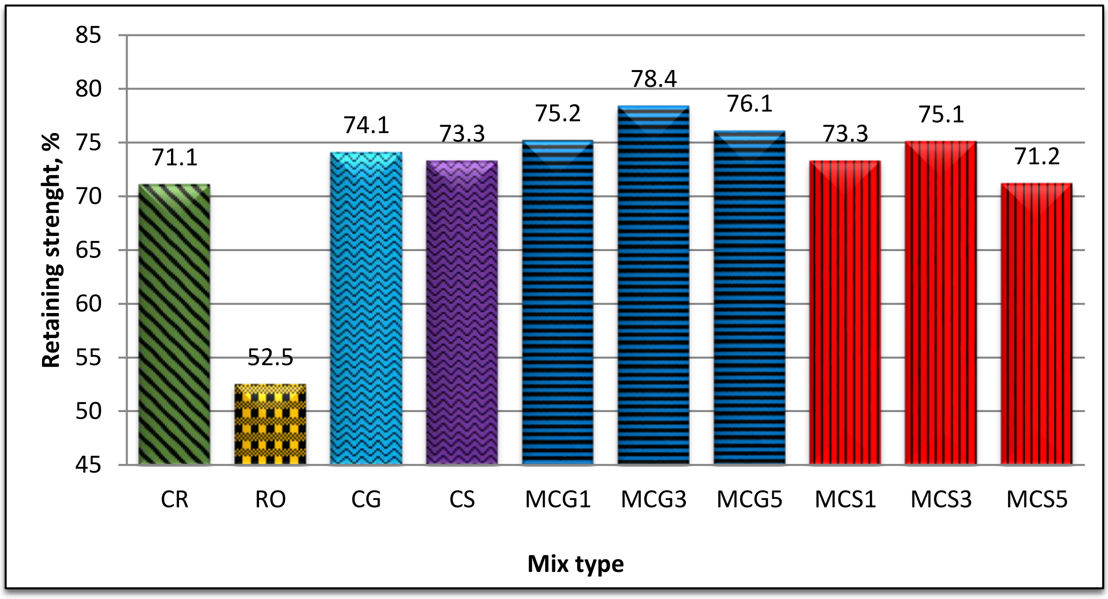

Figure 7: Retaining strength variations with different coating mortars and curing techniques

6. Conclusions

From the current lab scale experimental works which is planned to rise the restriction of using round aggregate in HMA by coating aggregate with traditional curing and novel low energy process, the following can be concluded:

1. The engineering properties of HMA comprising natural round aggregates offer critical levels without treatment such as crushing or coating.
2. Coating round aggregate by cement mortar with fine materials suppose a significant improvement to the HMA in terms of engineering and volumetric characteristics, e.g. 79% increment in Marshall stability with about 61% reduction in Marshall flow.
3. Microwave curing, which offers significant time conservation, could be a vital alternative to normal curing; whereas no significant difference is noticed in Marshall stability and flow, indirect tensile strength and index of retaining strength between microwave and normal curing protocols.
4. Different gradations of fine materials, which are used in the mortar for coating process, offer noticeable variations in the engineering and volumetric characteristics of the developed HMAs. Gradation 3 which was the finer and more comprehensive particle size showed the best results.
5. Glass waste fine materials when introduced with coating mortar, could be a significant alternative to the natural sand; it could suppose cost and environmental benefits to the paving industry.

Conflicts of Interest

The author declares that they have no conflicts of interest.

References

[1] J. W. Button and V. Jagadam, "Cement Coating Marginal Aggregates for Use in Asphalt Pavements," Texas Transportation Institute, College Station,Texas, 778431992.

[2] *GENERAL SPECIFICATION FOR ROADS AND BRIDGES*, 2003.

[3] *PD 6682-2: Aggregates Part 2: Aggregates for bituminous mixtures and surface treatments for roads, airfields and other trafficked areas – Guidance on the use of BS EN 13043*, 2009.

[4] I. S. Lowndes and K. Jeffrey, "SUSTAINABLE PROVISION OF AGGREGATES: OPTIMISING THE EFFICIENCY OF PRIMARY AGGREGATE PRODUCTION," in "Universities of Nottingham & Leicester, Minerals Industry Sustainable Technology (MIST) research programme," 2008.

[5] G. Adel, T. Kojovic, and D. M. Thornton, "Mine to mill optimization of aggregate production," Department of Mining and Minerals Engineering Virginia Polytechnic Institute & State University Blacksburg, Virginia2006.

[6] C. J. Mitchell, P. Mitchell, and R. Pascoe, "Quarry fines minimisation : can we really have 10mm aggregate with no fines? ," in *Proceedings of the 14th Extractive industry geology conference*, EIG Conferences, 2008.

[7] P. Ahmedzade and B. Sengoz, "Evaluation of steel slag coarse aggregate in hot mix asphalt concrete," *Journal of Hazardous Materials,* vol. 165, no. 1–3, pp. 300-305, 2009.

[8] M. Pasetto and N. Baldo, "Experimental evaluation of high performance base course and road base asphalt concrete with electric arc furnace steel slags," *Journal of Hazardous Materials,* vol. 181, no. 1–3, pp. 938-948, 2010.

[9] M. L. Afonso, M. Dinis-Almeida, L. A. Pereira-de-Oliveira, J. Castro-Gomes, and S. E. Zoorob, "Development of a semi-flexible heavy duty pavement surfacing incorporating recycled and waste aggregates – Preliminary study," *Construction and Building Materials,* vol. 102, Part 1, pp. 155-161, 2016.

[10] M. Dinis-Almeida and M. L. Afonso, "Warm Mix Recycled Asphalt – a sustainable solution," *Journal of Cleaner Production,* vol. 107, pp. 310-316, 2015.

[11] S. Paranavithana and A. Mohajerani, "Effects of recycled concrete aggregates on properties of asphalt concrete," *Resources, Conservation and Recycling,* vol. 48, no. 1, pp. 1-12, 2006.

[12] J. Mills-Beale and Z. You, "The mechanical properties of asphalt mixtures with Recycled Concrete Aggregates," *Construction and Building Materials,* vol. 24, no. 3, pp. 230-235, 2010.

[13] D. D. Hunter and J. W. Button, "Evaluation of Accorex-An Asphalt Mixture Additive," Texas Transportation Institute, College Station, Texas, Research Foundation Report 49741984.

[14] M.-G. Kim, J. W. Button, and D.-W. Park, "COATINGS TO IMPROVE LOW-QUALITY LOCAL AGGREGATES FOR HOT MIX ASPHALT PAVEMENTS," Texas Transportation Institute, Texas A&M University System, College Station, Texas 77843-31351999.

[15] F. Moghadas Nejad, M. Arabani, G. H. Hamedi, and A. R. Azarhoosh, "Influence of using polymeric aggregate treatment on moisture damage in hot mix asphalt," *Construction and Building Materials,* vol. 47, pp. 1523-1527, 2013.

[16] S. Das, A. K. Mukhopadhyay, S. Datta, and D. Basu, "Prospects of microwave processing: An overview," *Bulletin of Materials Science,* vol. 31, no. 7, pp. 943-956, 2008.

[17] E. T. Thostenson and T. W. Chou, "Microwave processing: fundamentals and applications," *Composites Part A: Applied Science and Manufacturing,* vol. 30, no. 9, pp. 1055-1071, 1999.

[18] Y. V. Bykov, K. I. Rybakov, and V. E. Semenov, "High-temperature microwave processing of materials," *JOURNAL OF PHYSICS D: APPLIED PHYSICS,* vol. 34, pp. 55-75, 2001.

[19] D. E. Clark, D. C. Folz, and J. K. West, "Processing materials with microwave energy," *Materials Science and Engineering: A,* vol. 287, no. 2, pp. 153-158, 2000.

[20] D. E. Clark and W. H. Sutton, "Microwave processing of materials," (in English), *Annual Review of Materials Science,* Review vol. 26, pp. 299-331, 1996.

[21] R. Bosisio, G, J. Spooner, and J. Granger, "AsphaltRoad Maintenance with a mobile Microwave power Unit," *Journal of Microwave power,* vol. Vol. 9, no. 4, pp. 381-386, 1974.

[22] M. R. Jeppson, "Energy conserving paving method and apparatus using microwave heating of materials," 1981.

[23] M. R. Jeppson, "Paving method and pavement construction for concentrating microwave heating within pavement materials," Patent 4594022, 1986.

[24] X. LI, L. SHI, and S. YANG, "Bituminous pavement microwave heating device ", 2010.

[25] R. A. Sindelar and D. J. Alexander, "Method and apparatus for asphalt paving," USA Patent 4347016, 1982.

[26] A. A. Al-Ohaly and R. L. Terrel, "Effect of microwave heating on adhesion and moisture damage of asphalt mixtures," *Transportation Research Record,* no. 1171, pp. 27-36, 1988.

[27] T. L. Osborne and W. R. Hutcheson, "Asphalt compounds and method for asphalt reconditioning using microwave radiation," ed: USA Patents 4849020, 1989.

[28] J. Gallego, M. A. del Val, V. Contreras, and A. Páez, "Heating asphalt mixtures with microwaves to promote self-healing," *Construction and Building Materials,* vol. 42, no. 0, pp. 1-4, 2013.

[29] Z. J. Wang, P. Zhao, T. Ai, G. Y. Yang, and Q. Wang, "Microwave Absorbing Characteristics of Asphalt Mixes with Carbonyl Iron Powder," *Progress In Electromagnetics Research,* vol. Vol. 19, pp. 197-208, 2011.

[30] S. W. Bishara, "Method of accelerated aging of neat asphalt binder using microwave radiation process," ed: USA Patents 6571648, 2003.

[31] S. W. Bishara, R. E. Robertson, A. Shenoy, and D. Mahoney, "Rapid Microwave Aging of Modified Asphalts," presented at the The 82nd Annual Meeting of TRB, 2003.

[32] G. X. Yu, Z. M. Li, X. L. Zhou, and C. L. Li, "Crumb Rubber-Modified Asphalt: Microwave Treatment Effects," *Petroleum Science and Technology,* vol. 29, no. 4, pp. 411-417, 2011.

[33] Z. Ding, C. Shen, J. Jiang, and S. Y. He, *Research on Comprehensive Utilization of Waste Rubber and Aged Asphalt* (Mechanical Engineering and Green Manufacturing, Pts 1 and 2). 2010, pp. 1526-1531.

[34] Standard Specification for Fine Aggregate for Bituminous Paving Mixtures, 2001.

[35] Standard Test Method for Bulk Specific Gravity and Density of Non-Absorptive Compacted Bituminous Mixtures, 2005.

[36] Standard Test Method for Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures, 2005.

[37] Standard Test Method for Marshall Stability and Flow of Bituminous Mixtures, 2005.

[38] Standard Test Method for Indirect Tensile (IDT) Strength of Bituminous Mixtures, 2012.

[39] Standard Test Method for Effect of Water on Compressive Strength of Compacted Bituminous Mixtures, 2011.

[40] D. W. Christensen and R. F. Bonaquist, "Evaluation of Indirect Tensile Test (IDT) Procedures for Low-Temperature Performance of Hot Mix Asphalt," NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM, Report No. 530, Transportation Research Board, USA2004.

تقييم مختبري لخلطات اسفلتية حارة تحتوي ركام مطلي بملاط فضلات الزجاج ومنضج بالمايكرويف

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الخلاصة

يمثل الركام الخشن المكون الرئيسي في الخلطات الاسفلتية الحارة من ناحية النسبته والية نقل الاحمال. يستخدم الركام المكسر بشكل واسع في انتاج الخلطات الحارة وذلك لشكله الخشن والذي يسبب تداخل عالي وبالنتيجة يجلب مقاومة عالية للاحمال المرورية الناتجة من حركة المركبات. من جهة اخرى فان استخدام الركام المدور غير مسموح به من قبل مؤسسات الطرق وبالاخص في الطبقات السطحية العليا لملمسه الناعم وشكله والذي لا يحقق الخواص الهندسية المطلوبة. في البحث تم اقتراح الطلاء لتخشين سطح الركام باستخدام مواد مختلفة لزيادة مقاومة الاحمال. في هذا العمل البحثي، تم استخدام الطلاء بملاط اسمنتي مع مواد طبيعية وفضلات وهي الرمل الطبيعي وركام فضلات الزجاج. فضلا عن استخدام عملية إنضاج بطاقة قليلة لتقليل الكلفة والوقت لعملية الطلاء. تبين من نتائج هذا العمل البحثي ان عملية الطلاء تسبب تحسن ملحوظ في الخواص الهندسية و الديمومة للخلطات الحاوية ركام مدور مطلي.بالاضافة الى ان معالجة الركام بالميكرويف يشكل بديل لعملية الانضاج التقليدية و الطويلة نسبيا. وعليه فان النتائج قد تنعكس على تقليل الكلفة الكلية لانشاء طبقات الطرق وتقليل المخاطر البيئية الناتجة عن عملية تكسير الركام واستخدام الموارد الطبيعية.

الكلمات الدالة: الركام المطلي، فضلات الزجاج، الخلطات الاسفلتية الحارة، طاقة الميكرويف، التبليط