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Development of Interlocking Chained Plasti-beadsfor Use in Stone Mastic Asphalt

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ABSTRACT

The main objective of this study is to design and fabricate chained plastic beads as reinforcing and interlocking strands for use in asphalt mixtures such as Stone Mastic Asphalt mixtures (SMA). This research looks into the shape, size, dimension and type of plastic materialsto be fabricated into chained plastic beads that can be used in SMA to provided added resistance in terms of fatigue and rutting. Waste plastics of Nylon 66 type was used in this study as it met the characteristic of melting point of above 220°C. A preliminary analysis was carried out to determine an appropriate shape that could provide a better interlocking in between the aggregates. Finally a diamond shape was adopted for the beads with two different selected sizes of 4mm and 6mm in diameter. The reason for the adoption 4 and 6 mm sizes is that small sized beads provide a better flexibility with the links compared to larger bead and link sizes which may pose rigidity problems during construction. The beads then were linked up with two different sizes of string of 0.5and 1.0mm in diameter with the beads spaced at 20mm interval. With two different diameters for beads sizes and two different diameters for stringor chained sizes, this study was carried out in eight matrix combinations consisting of two and three beads system to be incorporated in the mix composition of SMA14 using the Malaysian Public Works Department's (PWD) specifications.A preliminary analysis on the plastic beads showed promising results. The percentage loss of soundness test ranged between 0.7% to 2.1% while the resilient modulus test results showed that, the 2 beads system performed up to 98% bettercompared to the 3 beads system. Overall none of the SMA mixtures with the chained plastic beads performed lower than the control mix. The wear and tear due to compaction of the mixtures was analyzed using an Asphalt Extraction Test that showedthat the maximum tear of the chained plastic beads wasless than 16%.

INTRODUCTION

The plastic industry is one of the most dynamic and vibrant growth sectors whether in developed or developing countries. The Malaysian manufacturing sectoris no exception. The Malaysian plastics industry has developed into a highly diversified sector producing anything small and tiny such as electrical and electronic parts to anything on a big scale like the containers, automotive components and other household goods. However besides its versatile characteristics, plastics also contribute a lot of problem especially its contribution to environmental pollution and the critical global warming issues. Plastic is very hard to decay and most of them are non-degradable. To overcome this problem, many countries are making policies to ban the use of plastic bags to save the world for the future generations. Another effort that is undertaken is the reuseand recycling of the ever mounting plastic wastes. Therefore many researchers are making efforts to recycle waste plastics for use in the construction in industry.Some used them as aggregates as replacement and others as an additive to serve as a binder modifier.(Zoorob and Suparma, 2000) introduced 'Plastiphalt' Mixtures by using recycled Low Density Polyethylene (LDPE) in pallet form (granulate shape) replacing a 30% of 2.36–5mm aggregates, that showed a 250% increase in Marshall Stability and improved the Indirect Tensile Strength (ITS) although reduced the mix density by 16%.(Justo and Veeraragavan, 2002) used recycled plastics (PE film) at 0.4% of mixture weight as bitumen modifier, that increased the Marshall Stability by 3.3 times. (Mustafa Tuncan*et al.*, 2003) used waste grocery bag, dry cleaning and household plastics as a modifier from a single size range between the No. 4 and No. 10 sieves at 5%, 10%, and 20% by total weight of asphalt cement (melted).The results showed significant increase in the softening point, indirect tensile strength, and Marshall Stability. However, Flynn (1993) reported that the use of recycled plastic is acceptable in highway construction industry

Some of the concerns about the use of recycled plastic as an asphalt cement modifier are performance, durability, cost effectiveness, availability, recyclability, health and environmental impacts. In addition to work

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done by other researchers a different approach was undertaken in harnessing the potential of using waste plastics in road construction. This study presents findings of the laboratory test aimed to investigate the compatibility ofthe newly developed chained plastic-beads used as interlocking reinforcing strands in SMA.

MATERIAL AND METHODS

Design and Fabrication of Chained Plastic-beads:

Types of Plastics:

There are two main types of plastics namely thermosets and thermoplastics. Thermoset plastic has unique characteristics and becomes permanent once molded and affect its durability and strength whilst thermoplastics melt under heat and can be reformed repeatedly but offer versatility and a wide range of applications. For the development and fabrication of chained plastic beads virgin plastic materials were used for the start as recycled plastics have many different types and is quite difficult to sort out and clean. With various opinions and considerations among the experts and fabricators in plastic industry, Nylon 66Mapex AT0110GNfound to be the best type of thermoplastics that can be used to fabricate chained interlocking plastic beads. This type of plastic could meet the criterion of melting point up to 200^{0}C as the mixing temperature for asphalt mixture range from 165^{o}C to 170^{o}C. Table 1 below shows some of the mechanical properties of Nylon 66 Mapex AT0110GN.

Table 1: Typical Values for Nylon 66 MapexAT0110G.

Properties	Unit	Test Method	Mapex AT0110GN 01
Mechanical			
Yield Tensile Strength	psi	D-638	7000
Break Tensile Elongation	%	D-638	80
Flexural Strength	psi	D-790A	10000
Flexural Modulus	psi	D-790A	225000
Rockwell Hardness	R-Scale	D-785	105
Thermal			
Melting Point	°C	D-789	260
Other			
Specific Gravity	-	D-792	1.06
Water Absorption	% 23°C,24 hour	D-570	0.8
Remark	Unreinforced Nylon66, Super toughness, Semi-dull, RoHS certification		

Shape and Dimension:

The purpose of the new design development of chained interlocking plastic-beads is to act as reinforcing agents through interlocking mechanism in the aggregate skeleton. The fundamental approach of this study is to fill up beads in the voids between the fine and coarse aggregate giving an interlocking strength through the chainedplastic system as shown in the schematic diagram in Figure 1. In order to make the beads workable, shape, size and surface texture play key roles as many researchers reported that particle size, shape and texture influence the performance and service ability of asphalt pavement(Brown *et al.*,1989; Khandal*et al.*, 1992; Kim *et al.*, 1992). Rounded and angular aggregates are the most popular shape that providethe best performance although there is no specific shape for the aggregates as they all come inirregular shapes. Furthermore it is not practical to design and fabricate exactly like an aggregate where the shape of the aggregate itself is naturally irregular upon crushing that display similarity in terms of shape, size and surface texture.Based on this circumstances diamond shape was determined to be adopted as the shape for the beads. Diamond shape is round and has the angularity to some extent.

The sizes of the diamond beads worked out be between 4 mm and 6 mm in diameter which is a rough estimate of the void space between the aggregates in the skeleton matrix. The beads then continuously linked with 0.5mm and 1.0mm in diameter chains.The size of 0.5mm and 1.0mm of chained diameter was chosen as the chained plastic beads need to be flexible and to ease the blending and compaction process. The spacing of the beads was fixed to 20mm interval. The rationale of choosing 20mm interval is to provide the possibility of chained plastic beads that would tie-up or link-up for two aggregates at one time. (The mixture with nominal aggregate size of 9.5mm and below). The full schematic diagram for the chained plastic beads is shown in Figure 2 below.

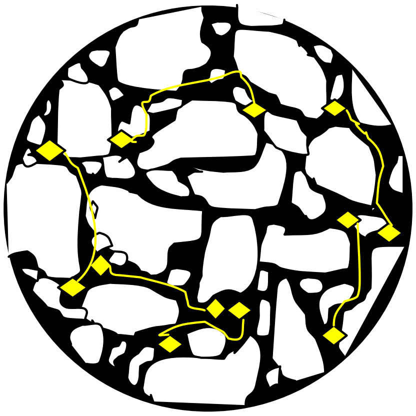


Fig. 1: Chained Plastic beads incorporated in SMA .

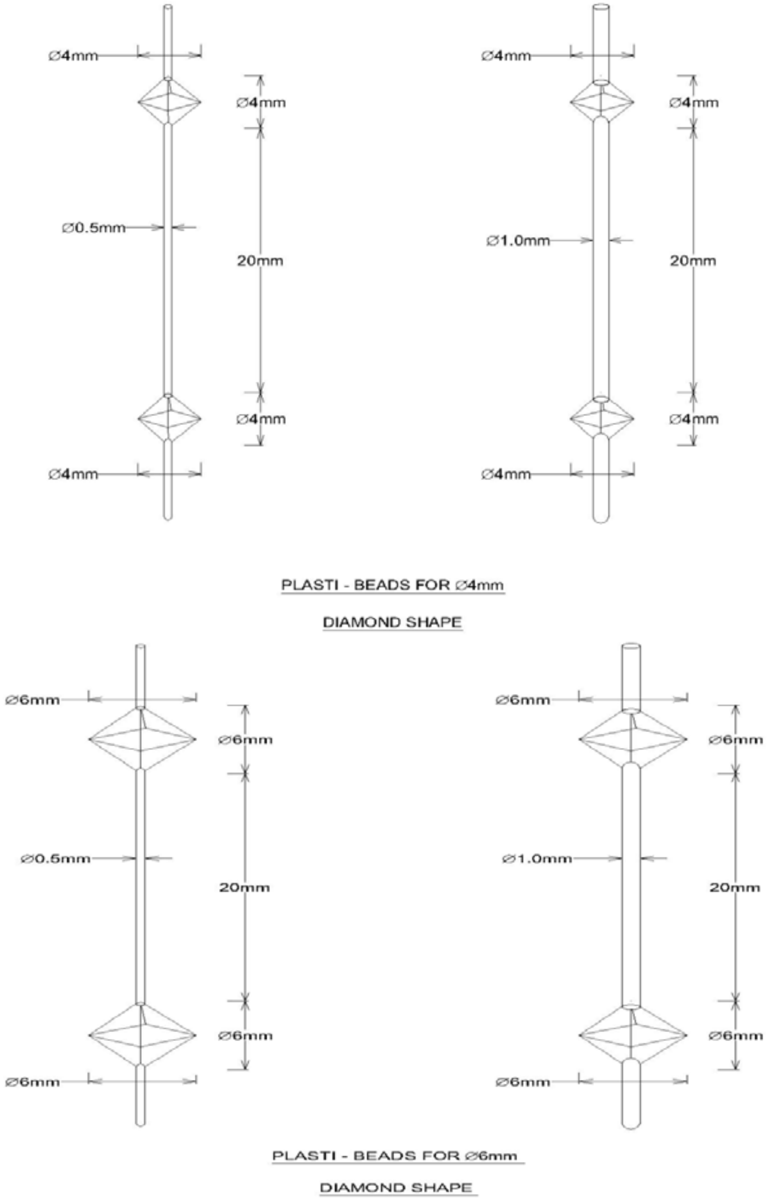


Fig. 2: Shape and Dimension of Chained Interlocking Plastic beads.

Fabrication of Chained Interlocking Plastic beads:

A special mold was prepared to fabricate the req2uired plastic bead shape in terms of shape and dimension.The beadswere produced by the Plastic Injection Molding Process. A molten plastic Nylon 66 resins added with white colorant material was injected into the designed mold with controlled speed and pressure. The material then was allowed to cool and solidify into the desired shape and then ejected and released from the mold. The cycle was then repeated for multiple units. The chained plastic beads come in six (6) numbers of beads per set. They were trimmed into two and three beads system.

RESULTS AND DISCUSSION

Matrix Combinations of Chained Plasti-beads:

Table 2 shows the classification of eight matrix combinations of the chained interlocking plastic beads selected for this study. The chained interlocking plastic beads were divided in two and three bead system based on the dimensions.

Table 2: Chained Interlocking Plastic beads Matrix Combinations.

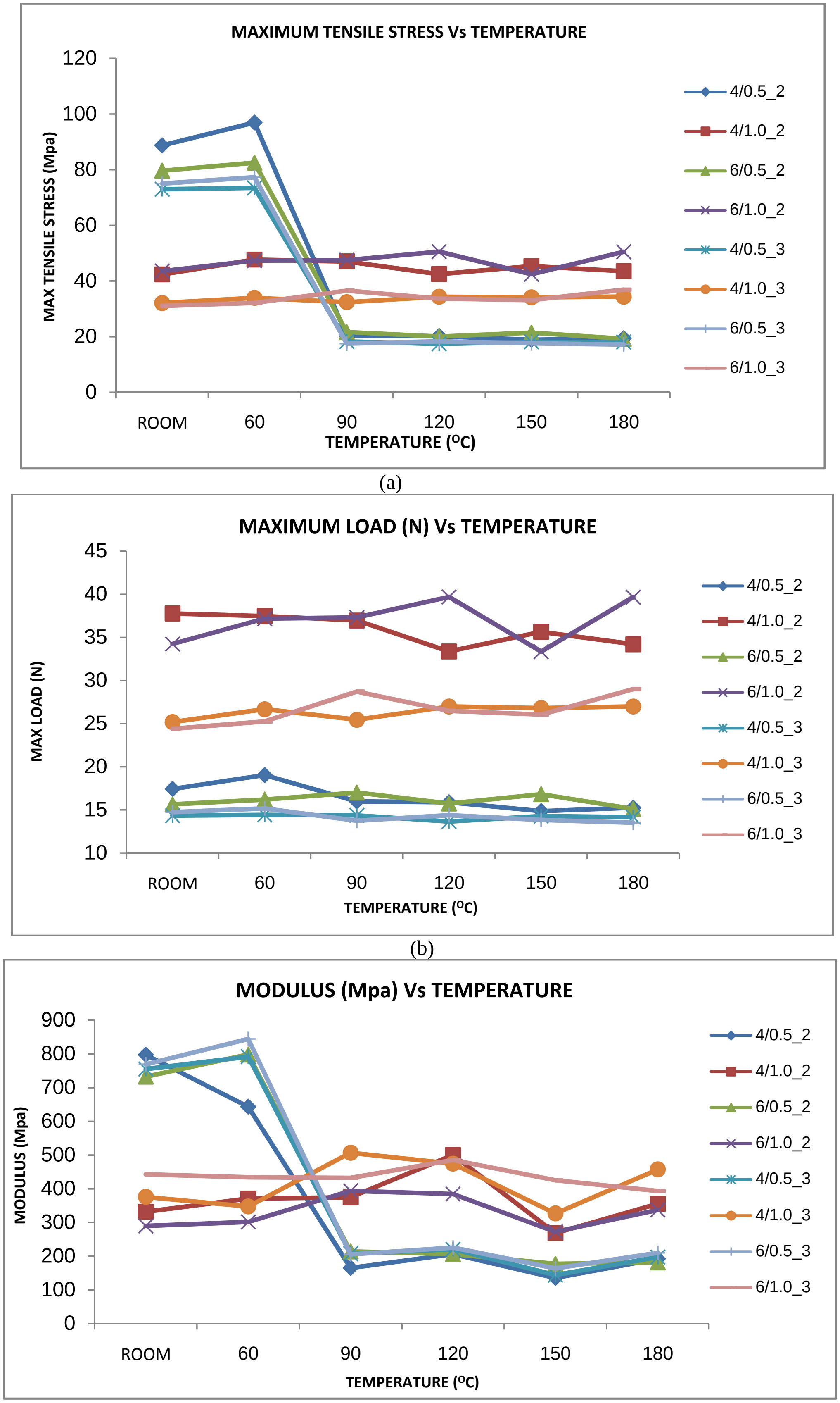
Bead sizes	String sizes	Bead system
4mm	0.5mm 1.0mm	2_4/0.5 3_4/0.5 2_4/1.0 3_4/1.0
6mm	0.5mm	2_6/0.5 3_6/0.5
	1.0mm	2_6/1.0 3_6/1.0

Tensile Strength Test:

The chained interlocking plastic beads were tested for their mechanical and physical properties to ensure their compatibility and to be incorporated in SMA mixtures. Tensile and compressive strength tests were conducted using usingInstron Universal Tester. The test was carried out in accordancewith ASTM D638 standards to measure the force required to break the chained interlocking plastic beads. Through the tensile test procedure the breaking point was determined when the specimen was stretched out or elongated. This test will also determine whether the chained interlocking plastic beads produced the same results that correspond to the supplier's specification in Table 1.Since the physical and mechanical properties of many plastics materials especially thermoplastics can vary depending on ambient temperatures, it is appropriate to test the specimen at different temperaturesduring mixing, compacting, laying and service temperature that simulate intended use. In this investigation, the chained interlocking plastic beads were conditioned for one hour in the oven at five different temperatures i.e 60^{0}C, 90^{0}C, 120^{0}C, 150^{0}C and 180^{0}C. As for comparison, the virgin chained interlocking plastic beads were also tested at room temperature. The chained interlocking plastic beads of three specimens at each matrix combinations were placed in the grips of the InstronUniversal Testerat specified grip separation and pulled apartuntil failure. The test speed was set at 5mm/min for measuring the strength, elongation and modulus. Figure 3 shows the result of ultimate tensile strength and strength at rupture, tensile modulus and maximum load trend for each matrix combination at various temperatures respectively. It was noticed that the chained interlocking plastic beads with 0.5mm diameter link either 2 or 3 beads system revealed the same trend which 60% drop in ultimate strength and tensile modulus respectively after conditioned at 90^{o}C and maintain till 180^{o}C. However for the chained interlocking plastic beads with 1.0mm diameter link, the results exhibited that there is no significant difference in strength for 2 or 3 bead system under various temperature. This could be explained that there is no deformation on the molecular structure of the polymer with thicker link. The maximum load required for the chained interlocking plastic beads to fail shows that 2 beads system could resist higher tensile load compared to 3 beads system for 1.0mm diameter link. For the 0.5mm diameter link both 2 and 3 beads system showed almost the same load value.

Compressive Test:

The compressive strengthtest was carried out on the chained interlocking plastic beads using Instron Universal Testerin accordance with ASTM D695 to measure the force per unit area that can withstand in compression.The specimen is placed between compressive plates parallel to the surface. The specimen is then compressed at a uniform 1mm/min rate. This test is in contrast to the more commonly measured tensile strength. The ultimate compressive strength is the stress required to rupture a specimen. The plastic beads like most other plastics do not rupture and it can have their results reported as the compressive strength at a specific deformation such as 1%, 5%, or 10% of the test sample's original height.Figure 4below shows the maximum compressive load of 1% deformation. The ultimate compressive strength shows same results for both 4mm and 6mm diameter of chained interlocking plastic beads.



(a)

(b)

(c)

Fig. 3 (a,b,c): Results of chained plasti-beads at various temperatures

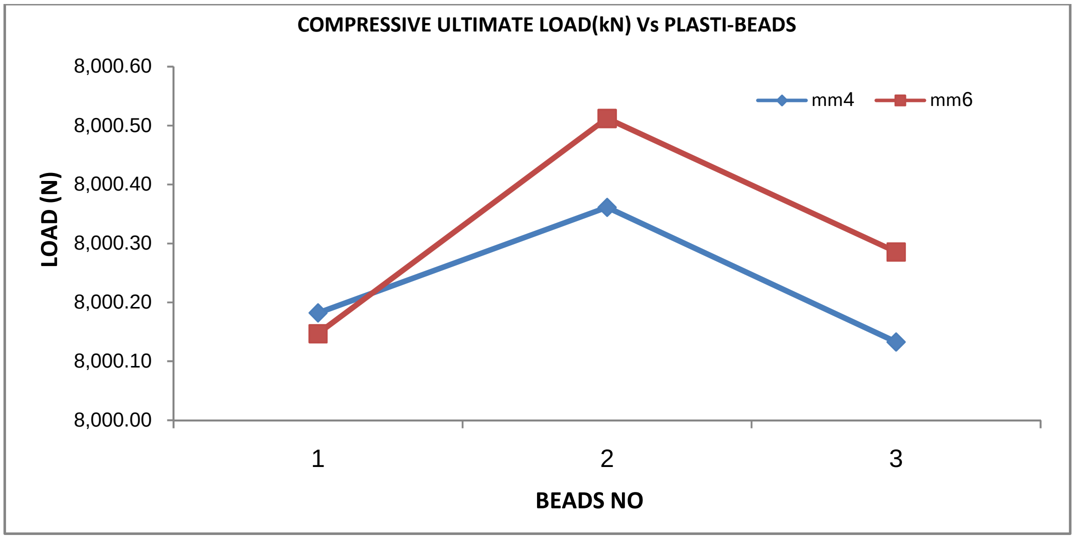


Fig. 4: Compressive Test results.

Soundness Test (ASTM C88):

The same method and procedures for measuring aggregates resistance to weathering in soundness test in accordance to ASTM C88 were adoptedfor the chained interlocking plastic beads. Magnesium sulfate solution was used to immerse the chained plastic beads for approximately 18 hours and then remove, drain and dry the specimens at 105 to 110^{0}C. After cooling them to room temperature, the specimenswere weighed to observe the weight decrease. This process was repeated for alternate immersion and drying for 5 days or 5 cycles. After completion of the final cycle and free from any magnesium sulfate solution, the percentage of loss for each matrix combination was calculated based on the loss weight. Table 3 shows the percent of loss for each combination respectively and the maximum loss in weight is only 2.14% less than 12% as compared to aggregates specifications and it is prove that the chained plastic beads have a higher resistance to weathering properties.That particular chained plastic beads again being tested for tensile strength for comparisons of their performance before and after the soundness test. The result shown in Figure 5below revealed that the performance ofthe chained plastic beads present about the same values as compared to plastic beads conditioned at 90^{0}C up to 180^{0}C for each size and dimension.This could be explained that the performance of chained plastic beads did not have severe impact due to weathering and climate change.

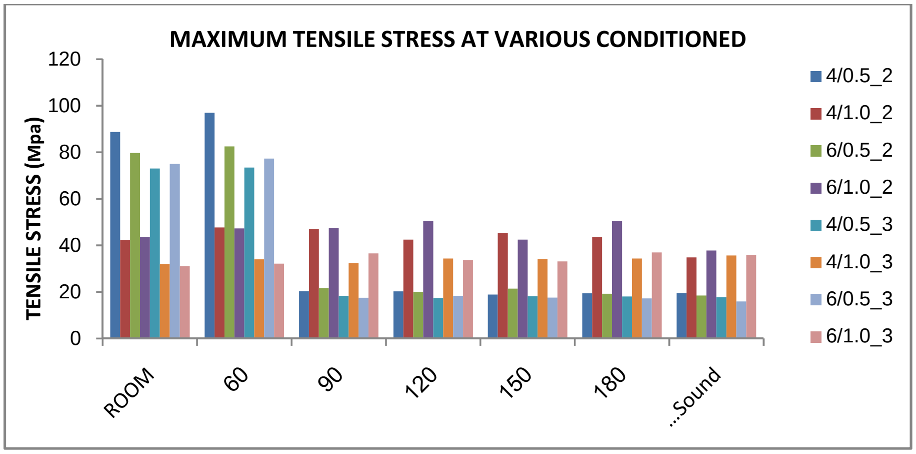


Fig. 5: Maximum Tensile strength at various conditions.

SMA14 Marshall Specimen Preparation:

As for the evaluation of chained plastic beads compatibility to asphalt mixture, the total of twenty four (24) Marshall Specimens were prepared in accordance to Malaysian JKR's SMA14 gradation which correspond to three specimens for each matrix combination. For this purpose, 5grams of chained plastic beads were added in average gradation mix design as shown in Figure 6. The mix design used 80/100 grade penetration asphalt at 6% asphalt contentwithout any fiber. The specimens were compacted at 50 blows for each side. The mixing and compaction temperature were 165^{o}C and 135^{o}C respectively. Three specimens without chained plastic beads were also prepared as control for comparison purposes.

Table 3: Results of Soundness Test for chained Plastic beads.

Beads size (mm)	Weight of beads before testing (G)	Weight of beads after testing						Percent loss(%)
		Day 1 (g)	Day 2 (g)	Day 3 (g)	Day 4 (g)	Day 5 (g)	Average	
4mm @ 0.5mm	10.512	10.511	10.509	10.465	10.408	10.319	10.442	0.66
4mm @ 1.0mm	10.511	10.511	10.510	10.289	10.198	10.128	10.327	1.75
6mm @ 0.5mm	10.511	10.511	10.508	10.312	10.264	10.225	10.364	1.40
6mm @ 1.0mm	10.213	10.209	10.199	9.998	9.995	9.569	9.994	2.14

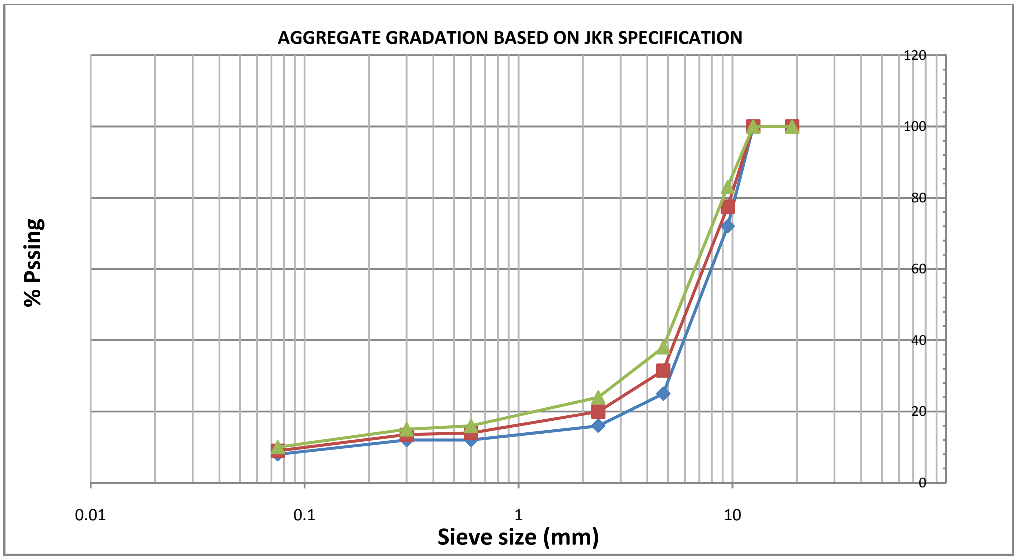


Fig. 6: Aggregates Gradation.

ResilientModulus Test(ASTM D4123):

The Resilient Modulus Test is carried out to measure the stiffness modulus of asphalt mixture with and without chained plastic beads. The test results can also be used as an indicator to prove the hypothesis of this study that mix design with reinforced chained plastic beads performed better than control mixed. All specimens were kept for 2 hours at a temperature of 25^{o}C in the MATTA Machine before tested in accordance to ASTM D4123 procedures. The average of Resilient Modulus results for each matrix combination is as shown in Figure 7 below. It was noticed that specimen with 2 beads system for both 4mm and 6mm diameter shows a significant increase in resilient modulus results at range between 13% to a higher as 98% whilst for 3 beads system recorded an increase of 5 to 20% only. This could be explained that 5g of chained plastic beads contained more numbers of 2 beads system compared to 3 beads system due to weight difference between the matrix combination and with that circumstances 2 beads system play more role as an interlocking mechanism. Furthermore this scenario can be supported by the results of 2 beads system, 4mm diameter beads forboth 0.5mm and 1.0mm diameter string which show among the highest results. Figure 7 also indicated that 2 beads system performed better than 3 beads system and none of the asphalt mixture with chained plastic beads performed lower than control mixed.

Asphalt Extraction Test (ASTM D2172):

Asphalt extraction Test as per ASTM D2172 was carried out to separate bitumen from the aggregates. Each compacted Marshall Specimen was heated at 80^{o}C for few minutes until it could be separated within aggregates and then placed in centrifuge extractor equipment. Methylene Chloride solution was poured in the extractor until the color of the discharge solution became clea. After that the chained plastic beads were separated from the aggregates by sieving process. This test is to observe the percentage of wear and tear of chained plastic beads in the mixture. Table 4 shows an average percentage wear and tear of chained plastic beads in the asphalt mixture respectively. The maximum percentage wear and tear of chained plastic beads is only 16% from the original number of 5g add-on occurred in 3 beads system of 4mm diameter and 0.5mm diameter string. In addition, all 3 beads system regardless of any sizes show a higher percentage of tear off compared to the 2 beads system. It was found that the 3 beads system tend to tear off one number of beads and left two beads in good condition. This observation might reveal that the 3 beads system is not fully functionableas an interlocking mechanism. The chances of the 3 beads system to get interlocked throughout the mixture not as good as the 2 beads system. Therefore one number of the beads could be easier tear off due to compaction activities.

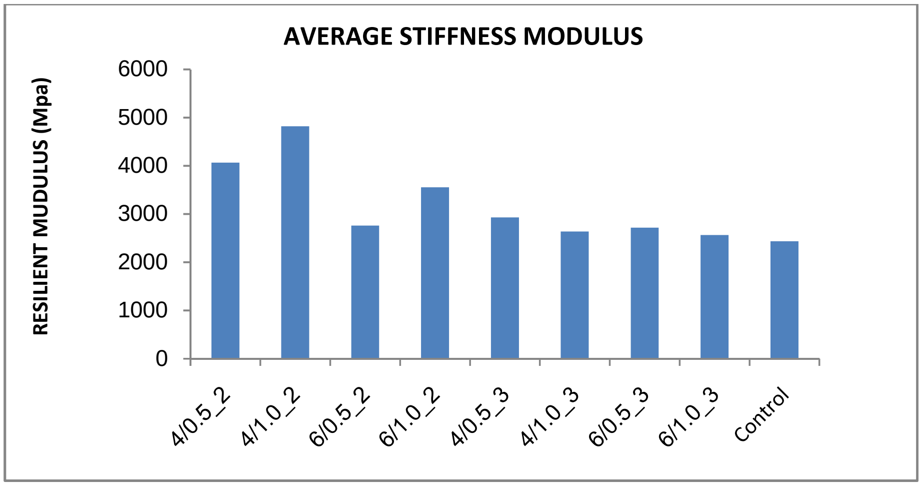


Fig. 7: Average Results for Resilient Modulus Test.

Table 4: Percentage wear and tear for chained plasti-beads combination.

No	Specimens	Number of chained plasti-beads in 5g	Average wear and tear per sample	Percentage (%)
1	2 - 4 /0.5	136	4	3
2	3 - 4 / 0.5	93	15	16
3	2 - 6 / 0.5	56	3	5
4	3 - 6 / 0.5	38	3	8
5	2 - 4 / 1.0	107	1	1
6	3 - 4 /1.0	69	6	9
7	2 - 6 / 1.0	48	1	2
8	3 - 6 / 1.0	32	2	6

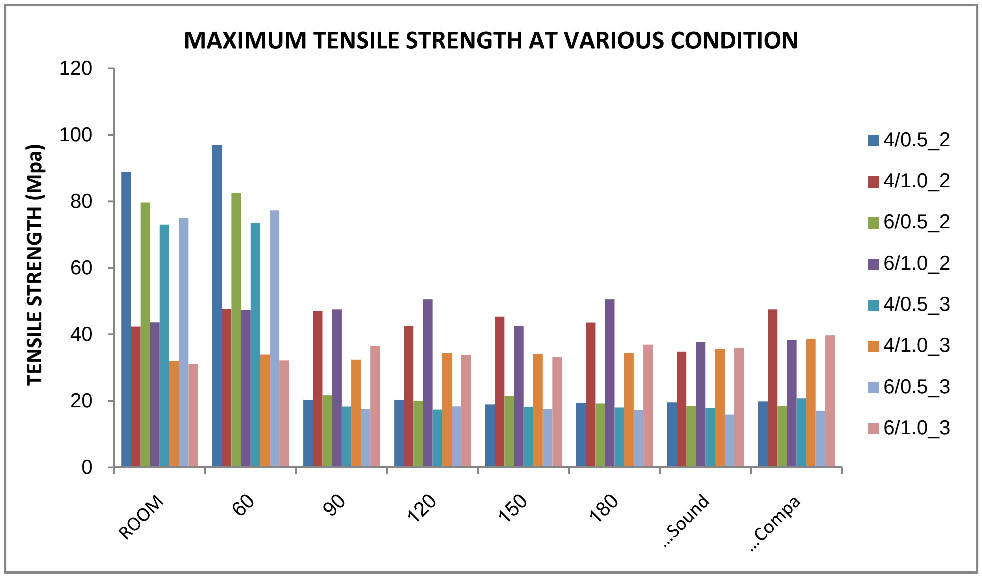


Fig. 8: Maximum tensile strength at various conditions.

Tensile strength test after compaction:

After analyzing of wear and tear, the chained plastic beads then were tested for their tensile strength. From the resultsexhibit in Figure 8 below, it was observed that there is no significant drop in tensile strength of chained plasti-beads after condition at 90°C, soundness test and even after compaction.The strength trend of chained plasti-beads seems to be maintained and stable after being through various conditioned.

Conclusions:

The incorporation of diamond shape chained plasti-beads with 4mm and 6mm diameter size, 0.5mm and 1.0mm diameter string at 20mm interval for each beads as a reinforced through interlocking mechanism to asphalt mixture composition give encouraging results with a wide range of various temperature and conditions. The chained plasti-beads foundto be weather and chemical resistance based on 2.14% loss in weight only in soundness test. The chained plasti-beads able to withstand without rupture with ultimate compressive load of 8kN show their compatibility to asphalt mixture due to vehicle loading impact. The resilient modulus results indicated that, in general, the additional of chained plasti-beads were beneficial in improving the stiffness values for mixture with chained plasti-beads compared to mixture without plasti-beads. The 2 beads system with 4mm diameter found to be more efficient in introducing reinforced agent through interlocking mechanism. As for tensile test result, the most prominent of chained plasti-beads properties is the stability in tensile strength even though after conditioned at 90°C up to 180°C or been through in chemical process or even after being compacted. This shows that the chained plasti-beads could sustain in various conditioned and compatible to asphalt mixture. However more cautious should be put in when come to mixing in bulk as the homogeneity ofplasti-beads dispersion could be a problem.

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