EFFECT OF HOLDING TIME TO THE WORKABILITY, STIFFNESS AND STRENGTH OF CRUMB RUBBER MODIFIED ASPHALT CONCRETE

Iswandaru Widyatmoko[1] *and Richard Elliott*[2]
[1]*URS, 12 Regan Way, Nottingham NG9 6RZ. Daru.Widyatmoko@urs.com*
[2]*URS, 12 Regan Way, Nottingham NG9 6RZ. Richard.Elliott@urs.com*

ABSTRACT

This paper presents the findings from testing of reclaimed tyre rubbers from trucks and cars, prepared at ambient temperatures and by cryogenic techniques. Crumb Rubber Modified Asphalt Concrete (CRMAC) and the control mixtures were manufactured using a wide range of UK materials and assessed to UK Standards. The raw materials used in the study comprised 2 bitumen sources (each with 2 bitumen grades), 3 aggregate types, 3 rubber types and sources, 2 CRMAC mixture designs and 2 control asphalt mixtures. A two step process was adopted, the first being a screening assessment (workability assessment) of twelve Rubberised Asphalt (RA) mixtures and four control mixtures and the second being mechanical assessment of the eight best performing blends from the screening assessment and two control mixtures, i.e. Porous Asphalt (PA) and Stone Mastic Asphalt (SMA). From the screening assessment, it was found that almost all the rubberised asphalt mixtures had improved workability compared with the control mixtures, probably as a result of the higher mixing temperature and higher binder content. Bulk densities generally remained constant throughout mixing and holding, whereas the RA mixtures showed improved load spreading ability compared to the control mixtures. The tensile strength values of all the RA mixtures were greater than 600 kPa, indicating good quality material. This work demonstrated that the blending of Crumb Rubber with hot Paving Grade bitumen could be very beneficial to the resulting asphalt mixtures.

Keywords: asphalt, crumb rubber, workability, performance, waste, sustainability

1. INTRODUCTION

This paper presents findings from a research project entitled "Rubberised Asphalt Testing to UK Standards", funded by WRAP (Waste & Resources Action Programme). One of the aims of this study was to provide information to potential users of rubberised binder on the properties that can be expected from various sources/types of crumb rubber available in the UK, when blended with typical UK bitumens.

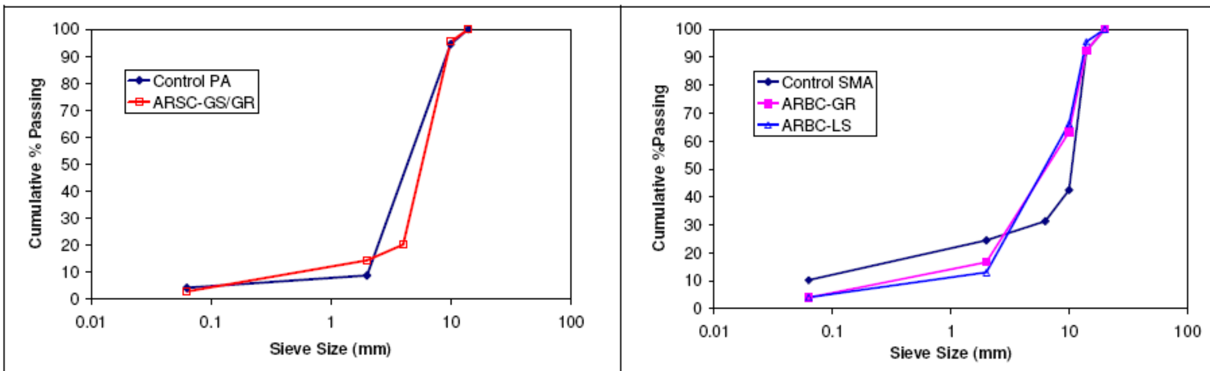
Asphalt rubber undergoes continuous reaction throughout the production stages at the mixing plant until the completion of compaction, specifically:

a) Preblending rubberised bitumen: reaction time (sometimes referred to as 'digestion time') is the period when the bitumen and rubber particles are being blended together at elevated temperatures during the mixture production. In this period, the rubber particles absorb aromatic oils and light fractions from the bitumen, and at the same time the bitumen phase hardens because of loss of oils.
b) Manufacturing asphalt rubber: the digestion of rubber continues during the manufacturing process, which may be evident from the extra force or energy required to blend the coated material;
c) Transportation to site: after the completion of manufacturing, the blend will be transported to site at high temperatures and during this period of transportation the properties of the blend may also change.

This work described in this paper assessed the above effect of holding time for a number of rubberised asphalt (RA) blends, specifically during the stage of manufacturing asphalt rubber and transportation to site. Discussion on preblending rubberised bitumen has been presented elsewhere [1].

2. MATERIALS FOR TESTING

The constituent materials used in the study comprised 2 bitumen sources (each with 2 bitumen grades), 3 aggregate types and 3 rubber types and sources; these were used in 2 RA mixture designs and 2 control asphalt mixtures. Two families of asphalt mixture historically used in the UK, specifically Porous Asphalt (PA) and Stone Mastic Asphalt (SMA), were selected for use as the control surface course and binder course mixtures, respectively, whereas the RA mixtures adopted the composition (grading and binder content) normally used for open and gap graded rubberised asphalts, respectively, as presented in Figure 1.



BS Sieve Size (mm)	Control PA		ARSC - GS/GR
	Range	Target	
14	100	100	100
10	90 – 100	95	95
4	-	-	20
2	5 – 25	9	15
0.063	2 – 10	4	3

BS Sieve Size (mm)	Control SMA		ARBC	
	Range	Target	GR	LS
20	100	100	100	100
14	90 – 100	92	93	95
10	35 – 60	42	63	66
6.3	23 – 35	31	-	-
2	17 – 29	25	17	14
0.063	8 – 13	10	4	4

Note: ARSC-GS/GR = Asphalt Rubber Surface Course containing Gritstone or Granite respectively.
ARBC-GR/LS = Asphalt Rubber Binder Course containing Granite or Limestone respectively.

Figure 1: Asphalt Mixture Gradation

It should be noted, however, that the rubberised asphalt gradings exclude the grading of filler additives (around 2%). The target binder contents adopted for the control PA and SMA were 4.5% and 5.8% by weight of the total mixture, respectively, and those for the RA mixtures ranged from 8.7% to 9.0%.

The four control asphalt mixtures are referenced by Asphalt type-Aggregate type-Binder penetration, for example; PA-GS-125pen indicates porous asphalt (PA) with Gritstone aggregate (GS) and a binder with a 125 penetration (i.e. 100/150); and SMA-GR-50pen indicates a Stone Mastic Asphalt (SMA) with Granite aggregate (GR) and a binder with a penetration of 50 (i.e. 40/60). The twelve RA mixtures are referenced by applicable pavement layer-Aggregate type-Blend type. For example ARSC-GR-1 indicates an Asphalt Rubber (AR) in the surface course layer (ARSC) containing Granite aggregate (GR), all mixed according to Blend type 1. ARBC-LS-2 indicates an Asphalt Rubber (AR) in the binder course layer (ARBC) containing Limestone aggregate (LS), all mixed according to Blend type 2. The three rubberised bitumen blends selected from the binder assessment, previously reported by Widyatmoko et al [1], were used, specifically:

- 81.5% VE 40/60 + 18.5% ambient car tyre rubber (Blend 1), where VE is bitumen of Venezuelan origin;
- 81.5% VE 40/60 + 18.5% cryogenic car tyre rubber (Blend 2);
- 84% ME 40/60 + 16% ambient car tyre rubber (Blend 3) , where ME is bitumen of Middle Eastern origin.

The respective references for the four control and twelve rubberised asphalt mixtures are presented in Table 1.

Table 1: Sample References

SURFACE COURSE				
Aggregate	**Control Bitumen**	**Rubberised Bitumen Blend 1**	**Rubberised Bitumen Blend 2**	**Rubberised Bitumen Blend 3**
	-	**VE 40/60 + 18.5% ambient car**	**VE 40/60 + 18.5% cryogenic car**	**ME 40/60 + 16% ambient car**
Gritstone	PA-GS-125pen	ARSC-GS-1	ARSC-GS-2	ARSC-GS-3
Granite	PA-GR-125pen*	ARSC-GR-1	ARSC-GR-2*	ARSC-GR-3*
BINDER COURSE				
Limestone	SMA-LS-50pen	ARBC- LS-1	ARBC- LS-2	ARBC- LS-3
Granite	SMA-GR-50pen*	ARBC- GR-1*	ARBC- GR-2	ARBC- GR-3*

Note: *following the workability (screening) tests, these mixtures were not selected for further mechanical assessment.

This study involved a two step process, the first being a screening assessment (workability assessment) of twelve RA mixtures and four control mixtures and the second being mechanical and durability assessment of the eight best performing blends from the screening assessment and two control mixtures, i.e. PA and SMA. This paper focuses upon the first process i.e. workability assessment.

3. WORKABILITY ASSESSMENT

A screening assessment on twelve number RA mixtures (six surface course and six binder course materials) and four sets of control asphalt mixtures was carried out on mixtures prepared in the laboratory using bespoke workability test protocols, developed by URS Scott Wilson. These workability tests were targeted at assessing any change in mixture characteristics and performance due to variations in sample manufacturing and holding time.

The "viscosity" of loose coated RA mixtures was assessed over a period of 10 minutes of mixing and represented as mixture resistance to the mixing torque applied (measured and recorded during high temperature mixing) per unit weight. A suitably instrumented asphalt mixer (Figure 2) was used throughout the testing.

No	Type	Binder content	Fibre	Target Mixing Temperature	Actual Mixing Temperature
1	PA-GS-125pen*	4.5%	0.3%	140 +/- 5	137.0
2	PA-GR-125pen*	4.5%	0.3%	140 +/- 5	140.0
3	SMA-LS-50pen*	5.8%	0.3%	165 +/- 5	160.0
4	SMA-GR-50pen*	5.8%	0.3%	165 +/- 5	170.0
5	ARSC-GS-1	9.0%	-	165 +/- 5	169.6
6	ARSC-GS-2	9.0%	-	165 +/- 5	168.2
7	ARSC-GS-3	9.0%	-	165 +/- 5	160.5
8	ARSC-GR-1	9.0%	-	165 +/- 5	175.0
9	ARSC-GR-2	9.0%	-	165 +/- 5	168.0
10	ARSC-GR-3	9.0%	-	165 +/- 5	170.7
11	ARBC- LS-1	8.7%	-	165 +/- 5	171.0
12	ARBC- LS-2	8.7%	-	165 +/- 5	166.0
13	ARBC- LS-3	9.0%	-	165 +/- 5	171.5
14	ARBC-GR-1	8.7%	-	165 +/- 5	168.0
15	ARBC-GR-2	8.7%	-	165 +/- 5	167.0
16	ARBC-GR-3	9.0%	-	165 +/- 5	167.5

Note: *Control asphalt mixtures

Figure 2: Asphalt Mixer with Automated Torque Recorder

Lower resistance to mixing torque per unit weight is considered to be an indication of better workability. With the exception of the PA mixture which was tested at 140°C, all other mixtures were tested at 165°C; a summary of mixing temperatures is shown in Figure 2. The workability test data and the results for surface and binder course samples are summarised in Figures 3 and 4.

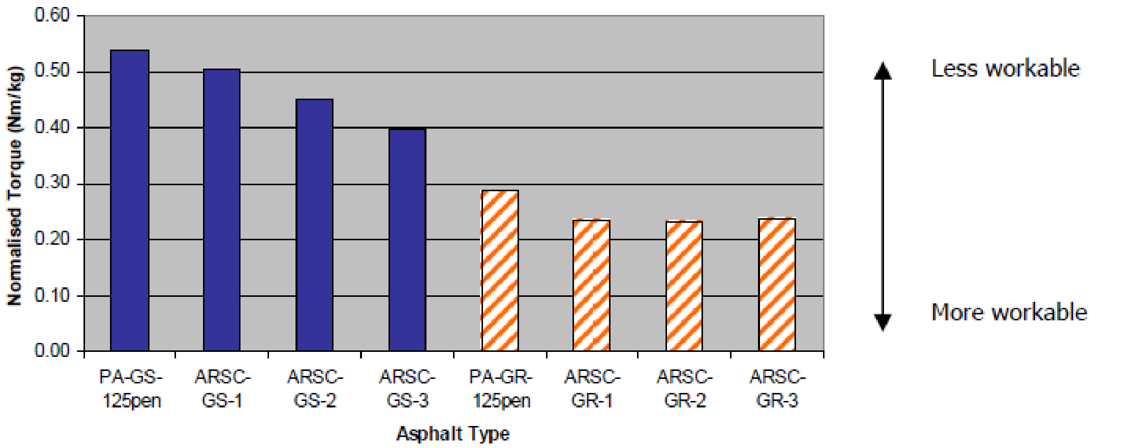


Figure 3: Workability Test Results – Surface Course

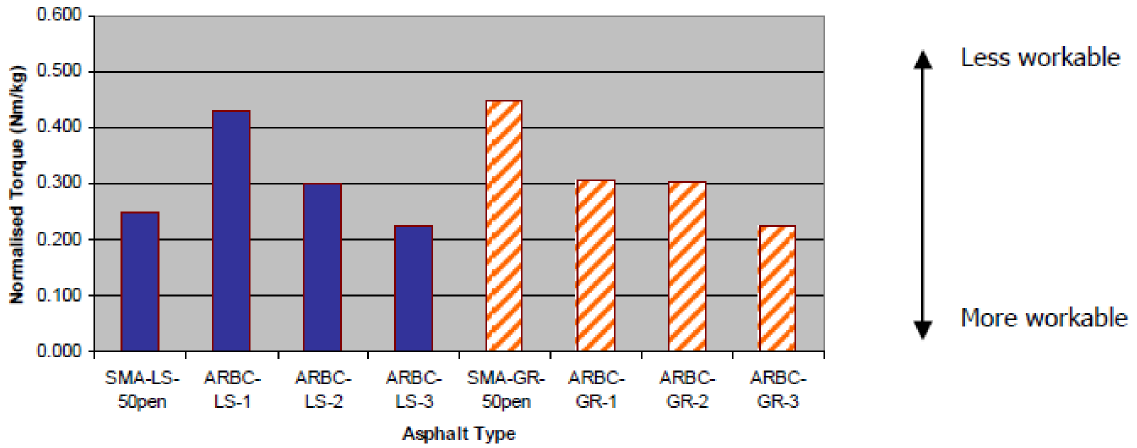


Figure 4: Workability Test Results – Binder Course

The torque values were average of 5 samples recorded at 40 rotations per minute (rpm). The coefficient of variation was typically 7% which correlates to a standard deviation of 0.03 Nm/kg.

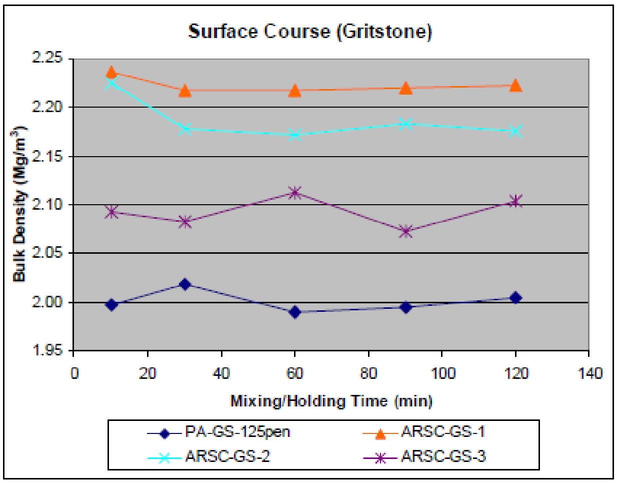
From the above figures, it can be seen that all gritstone and granite ARSC mixtures require a lower mixing torque compared to their respective control (PA) mixtures. This suggests that the mixtures have improved workability compared with their respective control mixtures. Although rubberised bitumen is more viscous than the control bitumen, in the respective mixtures it has been found, in this case, to have improved workability, probably because of the higher mixing temperature (in the case of surface course samples) and higher binder content (typically 3-4% higher). Figures 2 and 3 also show that in the case of gritstone mixtures, workability gradually increases from Blend 1 through to Blend 3 whereas the workability of the granite mixtures remains roughly the same.

4. THE EFFECT OF HOLDING TIME

Loose coated asphalts were retained at the respective mixing temperature in the asphalt mixer for a 'holding time' lasting up to 120 minutes. The 120 minute period was adopted to simulate the possible effects of mix storage (e.g. in the haul truck, during the delivery period from the mixing plant to site). Sub-samples were taken after 10, 30, 60, 90 and 120 minutes from the start of testing, compacted using a Marshall hammer with 50 blows per face and then subjected to an assessment of mixture volumetrics (bulk and maximum density), stiffness and strength over the holding periods.

5. MIXTURE VOLUMETRICS

The bulk densities [2] of the RA mixtures as well as the control mixtures were determined for samples compacted after 10, 30, 60, 90 and 120 minutes holding time at the respective mixing temperatures. For the surface courses, the bulk density was determined by dimensions, whilst that for the binder courses was determined by the sealed method (using self-adhesive aluminium foil). The results of these tests have been summarised in Figures 5 and 6; each data point was an average value from two samples.



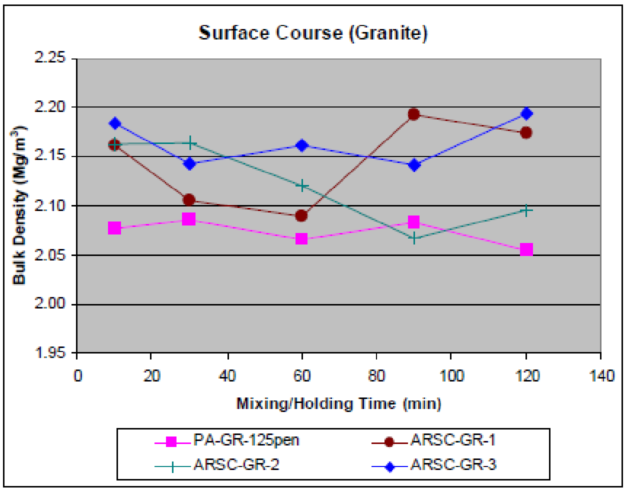


Figure 5: Bulk Densities of Surface Course Mixtures

The results in Figure 5 show that although there are slight variations of bulk density with mixing/holding time, the average bulk density of each mix generally remains constant throughout the period of "holding" at high temperature. The surface course control mixtures had the lowest bulk densities for each type of aggregate. The gritstone mixtures showed an initial decrease in bulk density value with holding time for Blend types 1 and 2, with Blend 1 having the highest bulk density and Blend 3 the lowest. The granite mixtures did not exhibit a clear variation of bulk density with blend type although Blends 1 and 3 showed an initial decrease in bulk density and Blend 3 generally had the highest average bulk density and was more consistent.

With regard to the binder course, all the mixtures (except limestone Blend 3) showed a slight decrease in the value of bulk density initially, as shown in Figure 6. The ARBC mixtures showed a general increase in bulk density with mixture blend type i.e. Blend 1 had the lowest bulk density value while Blend 3 had the highest bulk density value for both limestone and granite mixtures.

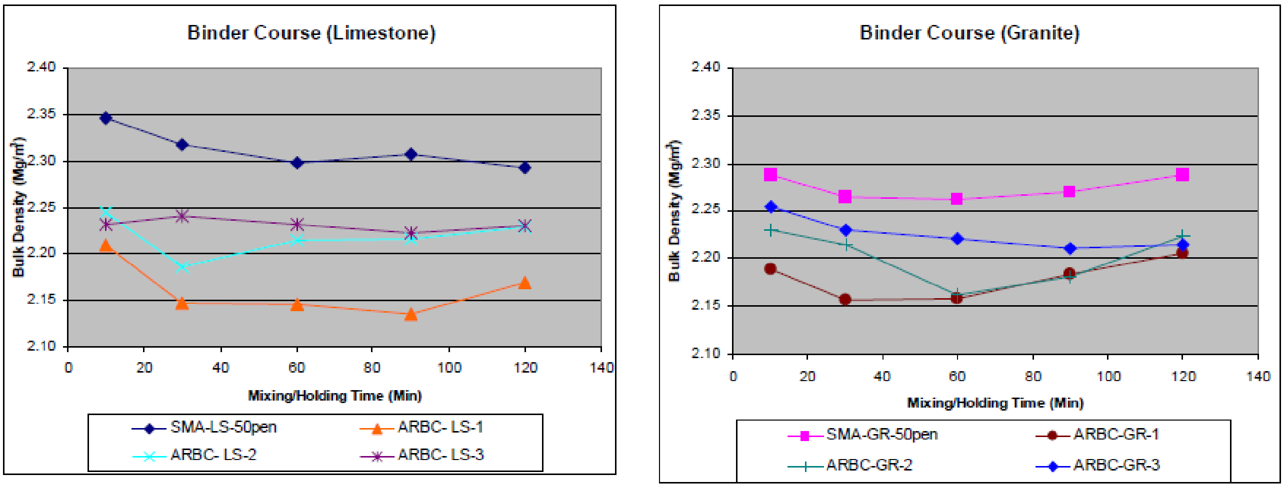


Figure 6: Bulk Densities of Binder Course Mixtures

Maximum density measurements [3] of the RA mixtures and the control mixtures were carried out on samples manufactured after 10 minutes and 120 minutes of mixing/holding time, respectively. Results of these tests have been summarised in Figure 7.

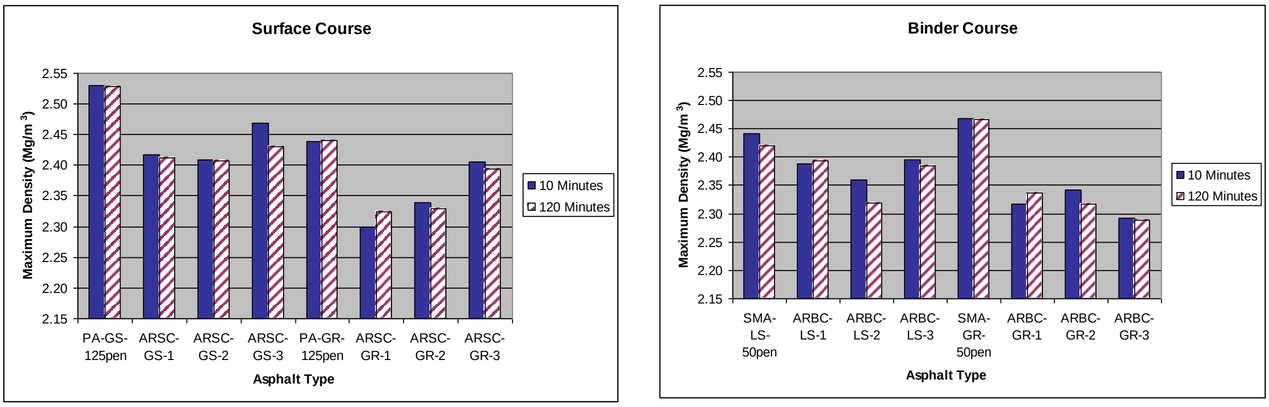


Figure 7: Maximum Densities of Surface and Binder Course Mixtures

The maximum densities of the mixtures after 10 minutes of mixing/holding were not significantly different from those after 120 minutes of mixing/holding.

6. STIFFNESS AND TENSILE STRENGTH

Sub-samples were taken at intervals and compacted to produce cylindrical asphalt specimens. Subsequently, an assessment of the effect of holding time on the compacted asphalt mixture stiffness at 20°C was carried out, using the Indirect Tensile Stiffness Modulus (ITSM) test procedure in the Nottingham Asphalt Tester (NAT), to BS EN 12697-26 Annex C [4]. In addition, assessment of the effect of holding time on mixture tensile strength at 25°C was carried out using the Indirect Tensile Test at a loading rate of 50mm/minute, to BS EN 12697-23 [5].

Figure 8 shows that surface course mixtures generally showed an increase in mixture stiffness with increase in mixing/holding time. The control mixtures showed significantly lower values of stiffness in comparison with the rubberised asphalt mixtures. This indicates improved load spreading ability of the RA mixtures compared with that of the PA control samples. Binder course mixtures also showed a small increase in mixture stiffness with increase in mixing/holding time. Apart from ARBC-LS-1, mixture stiffness values were generally similar for all the SMA mixtures. Overall, extended holding time (up to 120 minutes) does not lead to a reduction in stiffness. It should be noted that all RA mixtures exceeded the minimum stiffness value of 1700 MPa which was recommended in the WRAP UK Rubberised Bitumen Testing Specification (October 2007).

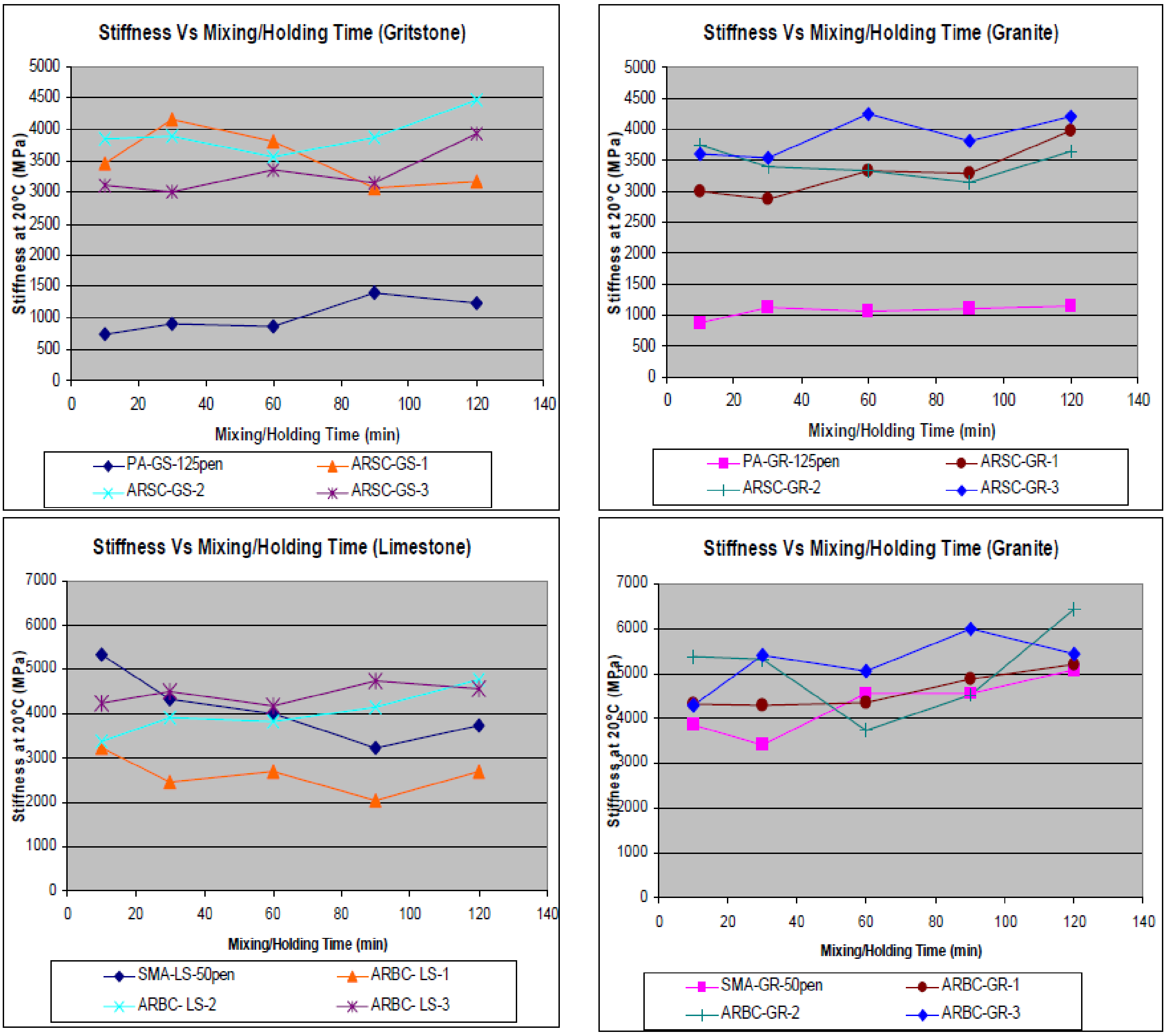


Figure 8: Stiffness Assessment – Results at 20°C

Apart from samples manufactured using granite aggregate, surface course and binder course mixtures did not show a significant change in tensile strength with increase in mixing (holding) time, as presented in Figure 9. The surface course control mixtures showed significantly lower values of tensile strength; those of the RA mixtures were 2 – 3 times higher. The tensile strength of gritstone Blends 2 and 3 initially decreases then either stabilises or increases. Blend 1 shows the most consistent results of the gritstone blends. Regarding the binder course, limestone Blend 2 had tensile strength values similar to those of the control mixture, with those of Blend 3 being slightly lower and those of Blend 1 more significantly so. The low tensile strength values of limestone Blend 1 are consistent with its low values of stiffness.

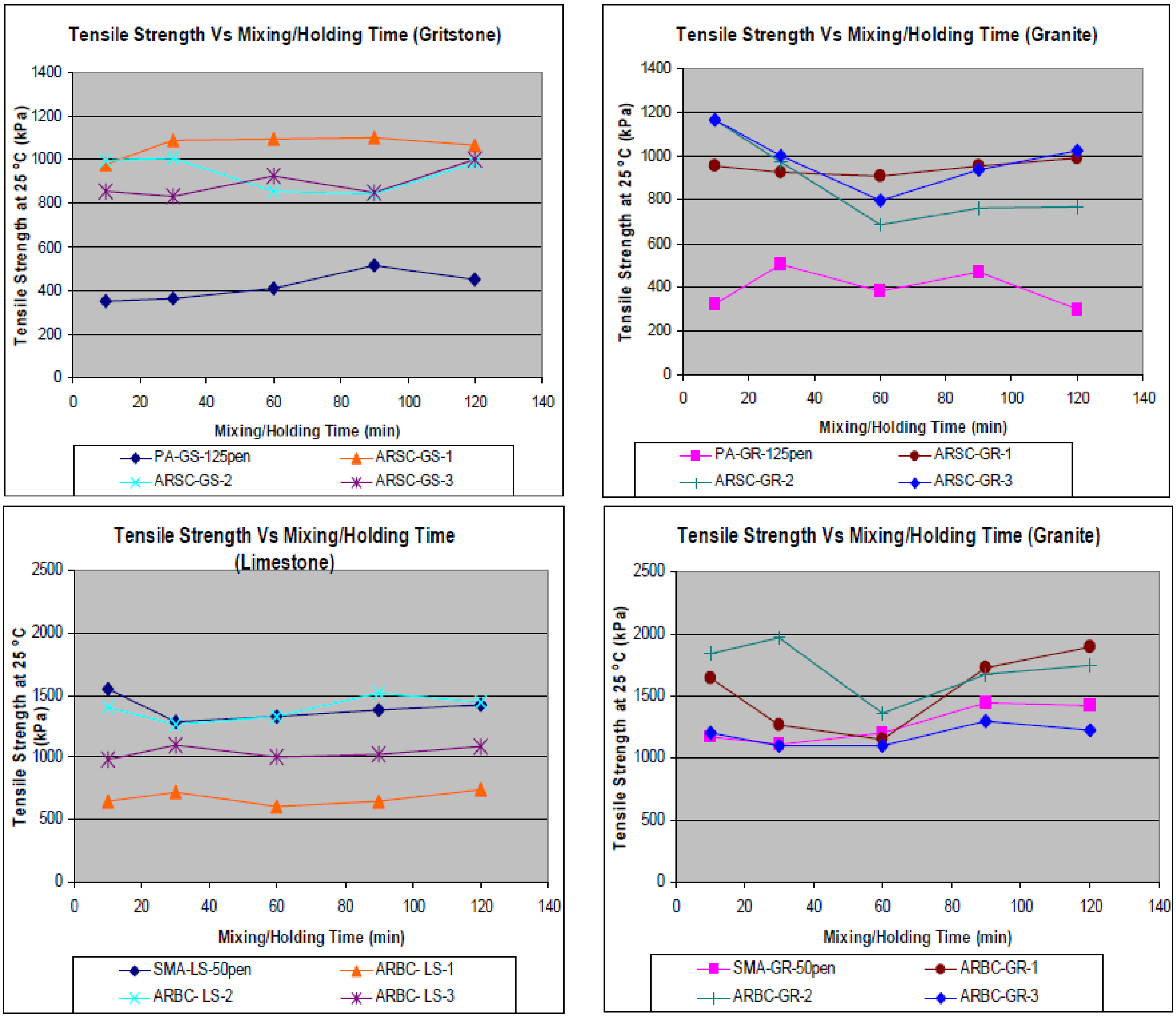


Figure 9: Tensile Strength Assessment – Results at 25°C

Research by De Beer *et al* [6] on tyre/pavement contact stresses reported horizontal stresses due to the tyres of B-747 aircraft ranging between 260 and 500 kPa. The above laboratory test results from rubberised asphalt mixtures exceeded 600 kPa, indicating sufficiently good quality material. Overall, the results suggest that prolonged hot storage (up to 120 minutes), such as that experienced in a delivery lorry during transportation of asphalt materials from the mixing plant to site, does not have a detrimental effect on the mixture's performance.

7. CONCLUDING REMARKS

The use of rubberised bitumen in porous and dense gap graded asphalt mixtures has been evaluated, together with two traditional UK materials, Porous Asphalt (PA) and Stone Mastic Asphalt (SMA). The workability assessment concluded rubberised asphalt (RA) materials were at least as workable as the control mixtures and retained their mechanical properties over a two hour holding period.

8. ACKNOWLEDGEMENT

The main work was awarded by competitive tender by WRAP to URS Scott Wilson in partnership with NTEC. WRAP helps individuals, businesses and local authorities to reduce waste and recycle more, making better use of resources and helping to tackle climate change; more information on WRAP's work can be found on www.wrap.org.uk. Contributions from Aggregate Industries, Tarmac, Nynas, UK Bitumen, Moncton Rubber Technology, Tyregenics, Allcock and Sons, and Singleton Birch, in providing the materials, and the streams of advice from the Project Manager and Technical Advisor to WRAP, Mr Steve Waite and Mr Ian Walsh, respectively, are all greatly appreciated.

REFERENCES

[1] Characteristics of Rubberised Bitumen Blends, I Widyatmoko, R Elliott, J Grenfell, G Airey, A Collop and S Waite, Asphalt Rubber 2009, Nanjing, China, November 2-4, 2009.

[2] Bituminous mixtures □ Test methods for hot mix asphalt □ Part 6: Determination of bulk density of bituminous specimen by hydro static method. EN 12697-6.

[3] Bituminous mixtures Test methods for hot mix asphalt Part 5: Determination of the maximum density, EN 12697-5.

[4] Bituminous mixtures □ Test methods for hot mix asphalt □ Part 23: Indirect tensile test, EN 12697-23.

[5] Bituminous mixtures □ Test methods for hot mix asphalt □ Part 26: Stiffness. EN 12697-26.

[6] Determination of Pneumatic Tyre/Pavement Interface Contact Stresses under Moving Loads and some Effects on Pavements with Thin Asphalt Surfacing Layers, M De Beer, C Fisher and F Jooste, Transportation Research Board Meeting, National Academy of Science, Washington, 1999.