Visco-Elastic Characteristic of Bitumen Incorporating Nano Silica

Khairil Azman Masri, Ramadhansyah Putra Jaya, Mohamad Idris Ali, Noram Irwan Ramli, Haryati Awang, Ahmad Kamil Arshad, Mohamad Saifullah Samsudin, Mohd Khairul Idham Mohd Satar, Dewi Sri Jayanti

Abstract*: Conventional asphalt binder usually has a few deficiencies such as poor deformation resistance especially under various temperature and heavy repetitive loads. To certify that problem, the properties of the asphalt binder will be improved by utilising polymers. But, the utilisation of polymer materials will lead to poor stability of specimens as well as reducing the resistance towards the ageing condition. Another promising material that is used for asphalt modification is nanomaterial such as nano-silica. Therefore, this study utilised nano silica as an asphalt modifier. This study emphasizes on the resistance enhancement of NS modified asphalt binder (NS-MB) towards repetitive stresses, various temperature and ageing conditions. The test involve was Multiple Stress Creep & Recovery (MSCR) evaluation using Dynamic Shear Rheometer (DSR). The results show that modified NS-MB produced a lower value of accumulated strain & non-recoverable creep compliance (Jnr) compared to unmodified NS-MB for various temperature and ageing conditions. The results also show that the addition of 2% NS produced the highest value of Recoverable Strain (R), thus it can be concluded that NS is capable in enhancing the visco-elastic behaviour of asphalt binder under repetitive loads.

***Index Terms*: Creep, Nanosilica, Recovery, Strain, Stress**

I. INTRODUCTION

Nanotechnology involves in a few research developments which are at the macrostructure, molecular level, at the atomic level and nano molecule level [1]. Nanotechnology provides a high quality of structure design [2]. This is due to small but effective nano-particles [3]. This is proved by a study by [4], where the finding showed that the dimension of material contributes to better dispersion and stability of the modified design. The evolution of the used of nanotechnology for binder modification is rapidly increasing in recent years. A study by [5] used A/SBS nanomaterial for their study on the effect of surround temperature towards the properties of the binder. They found that the temperature in the reflective binder is lower compared to the unmodified binder. Therefore, the temperature fatigue of the binder can be reduced thus prolong the pavement's life. This study also produced a Finite Element model to predict the effect of surround temperature more accurately, but there is no study on the rheological performance of nano-SBS modified binder. [6] studied the use of nanocarbon to evaluate the rheological properties of asphalt binder. They found that nano carbon modified binder increased failure temperature, complex modulus, elastic modulus and rutting resistance of binder. However, they did not investigate the effect of nanocarbon in detail towards the asphalt mixture. A study by [7] utilised nano clay as an additive to modify binder and mixture. They found nanocarbon can significantly enhance the rutting resistance of asphalt mixture. However, this study did not include statistical analysis to strengthened their findings. [8] found that the presence of nano silica-enhanced the mechanical properties and durability of modified material. According to [9], the usage of nano titanium can provide the additional service life of asphalt mixture about a year. But, this type of nanomaterial is very costly and complex production. Hence, it shows that different type of nanomaterials has its own ability and drawbacks [10].

From the extensive literature review presented, nanomaterial has good potential to be an effective modifier for asphalt modification. There are various types of nanomaterials, one of them is nano silica [11]. Nanosilica is a by-product of natural sources that high content amount of silicate. Nanosilica is expected to enhance the visco-elastic properties of the asphalt binder. Due to severe repetitive loads, the elastic behaviour of asphalt binder should be adequate in order to minimise the permanent deformation of the asphalt mixture. Thus, it is crucial to determine the performance of the asphalt binder with the addition of nanosilica.

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Khairil Azman Masri, Faculty of Civil Engineering & Earth Resources, Universiti Malaysia Pahang, Pahang, Malaysia.

Ramadhansyah Putra Jaya, Faculty of Civil Engineering & Earth Resources, Universiti Malaysia Pahang, Pahang, Malaysia.

Mohamad Idris Ali, Faculty of Civil Engineering & Earth Resources, Universiti Malaysia Pahang, Pahang, Malaysia.

Noram Irwan Ramli, Faculty of Civil Engineering & Earth Resources, Universiti Malaysia Pahang, Pahang, Malaysia.

Haryati Awang, Faculty of Civil Engineering & Earth Resources, Universiti Malaysia Pahang, Pahang, Malaysia.

Ahmad Kamil Arshad, Institute for Infrastructure Engineering and Sustainability Management (IIESM), Universiti Teknologi MARA, Selangor, Malaysia.

Mohamad Saifullah Samsudin, Faculty of Civil Engineering, Universiti Teknologi MARA, Selangor, Malaysia.

Mohd Khairul Idham Mohd Satar, Faculty of Engineering, School of Civil Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia.

Dewi Sri Jayanti, Faculty of Agricultural, Syiah Kuala of University, Banda Aceh, Indonesia.

II. MATERIAL AND METHODS

A. Asphalt Binder

The type of asphalt binder used in this study was penetration grade (60/70) that is recommended by the Malaysian Public Work Department for Road Works Specification [12]. Table I shows the physical properties of the asphalt binder used.

Table I. Physical Properties of PEN 60/70

Properties	Value
Softening Point	52.3°C
Penetration at 25°C	65.0 mm
Penetration Index at 25°C	+0.1
Ductility at 25°C	140 mm

B. Nanosilica

Amount of nano silica used was in the range of 0% to 5% with the increment of 1%. The colloidal form of nano silica is used in this study. The properties of nano silica are shown in Table II [13].

Table II. Properties of Nanosilica

Properties	Value
Appearance	Slight Milky Transparent
SiO_2 (%)	30 %
Na_2O (%)	0.5 %
pH level	8.5-10.5
Density in g/cm^3	1.19-1.22 g/cm^3
Average Size	10-15 nm

C. Ageing Procedure

There are two types of ageing conditions for this study which are unaged condition and short-term aged condition. Both aged specimens were used to determine accumulated strain, non-recoverable creep compliance and recovery strain of NS-MB under various temperature and repetitive loads. Rolling thin film oven (RTFO) equipment was used to prepare short-term aged specimens in accordance with ASTM D2872 [14].

D. Dynamic Shear Rheometer

The test involved is multiple stress creep & recovery test (MSCR) that is formerly known as stress sweep. MSCR was performed to obtain accumulated strain value, non-recoverable creep compliance value and recoverable strain value. Besides that, MSCR was also performed to indicate the strain behaviour of asphalt binder. This test in accordance with AASHTO TP 70 [15].

Three test temperatures were involved which were 58°C, 64°C and 70°C, while two stress levels involved which were 100 Pa and 3200 Pa. This test involved two main phases which were creep and recovery. During testing, for the first one-second load was applied to represent creep phase, then the next 9 seconds for the recovery phase. Every time the load is applied, strain increase rapidly and gradually decreases during recovery phases. This process is repeated until ten cycles completed for each stress level. This process explained the ladder trend of the graph. Some of the creep due to load can be recovered, but some of it doesn't. Thus, the unrecovered creep will be the permanent strain for asphalt binder and accumulated along the MSCR process

III. RESULT AND DISCUSSION

A. Accumulated Strain

Fig 1 to Fig 6 shows the value of accumulated strain of unaged and short-term aged NS-MB at three different test temperatures (58°C, 64°C and 70°C). This test involved two stress levels which were 100 Pa and 3200 Pa. As seen in figures, the first 100 seconds was for 100 Pa stress (low-stress level) while the next 100 seconds was for 3200 Pa stress (high-stress level). The different value of accumulated strain for both stress levels was obtained where the strain value was only around 10% for low stress and rapidly increased around 100% for high stress. In terms of temperature and types of specimens, higher temperature produces higher strain while modified NS-MB produced lower strain compared to unmodified NS-MB. In terms of types of ageing condition, both unaged and short-term aged specimens produce almost similar graph trend. From the graphs, it could be seen that the addition of NS was capable of maintaining the visco-elastic behaviour of asphalt binder and at the same time minimise the permanent strain. From Fig 1, 2 and 3, it could be seen that maximum strain value increase with increases temperature from 58°C to 70°C for unaged specimens.

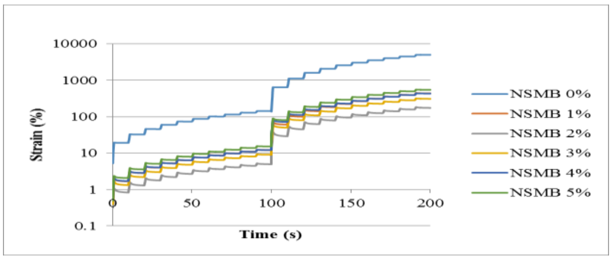

Fig 1 Accumulated Strain for Unaged NS-MB at 58°C

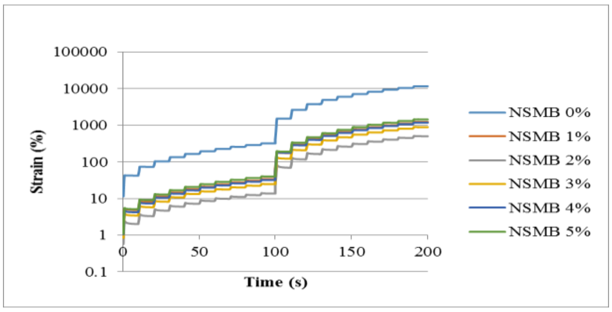

Fig 2 Accumulated Strain for Unaged NS-MB at 64°C

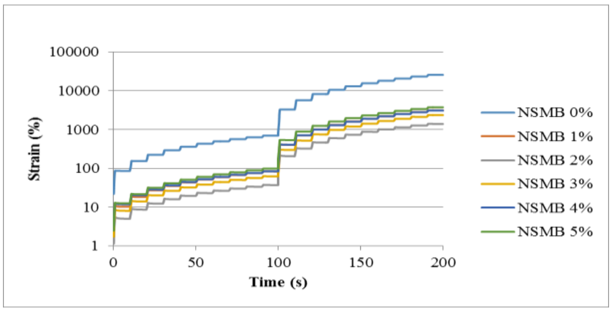

Fig 3 Accumulated Strain for Unaged NS-MB at 70°C

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Fig 4, 5 and 6 show the strain value for RTFO aged specimens at three different temperatures (58°C, 64°C and 70°C). At 58°C, the maximum strain value for unmodified specimen was more than 1000% while for modified specimens, the values were in the range of 200% to 500%. But, strain values increase at a higher temperature where the maximum strain value at 70°C was 10000% for the unmodified specimen and 1000% to 4000% for modified specimens. It shows that temperature can significantly increase the strain value of the binder.

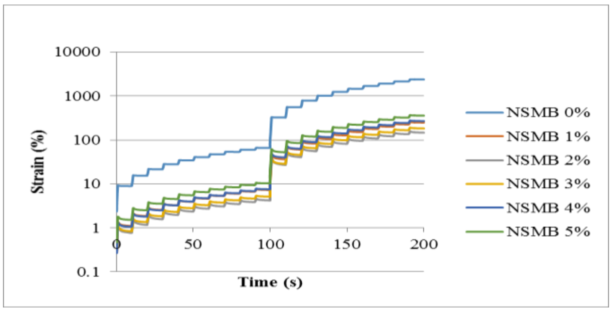

Fig 4 Strain for Short-term Aged NS-MB at 58°C

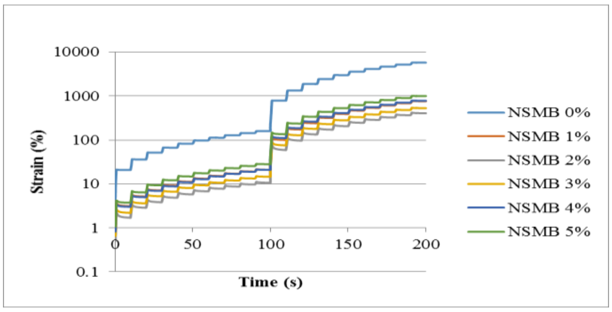

Fig 5 Strain for Short-term Aged NS-MB at 64°C

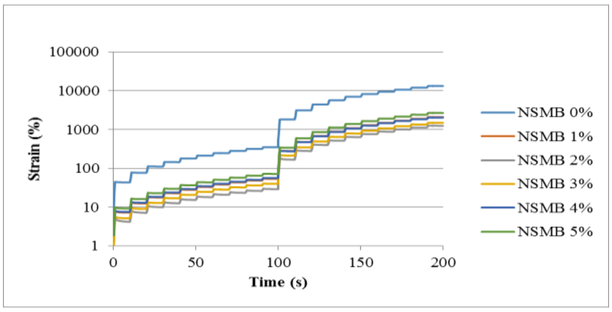

Fig 6 Strain for Short-term Aged NS-MB at 70°C

B. Non-recoverable Creep Compliance, Jnr

The evaluation of the MSCR test was further performed to indicate the resistance of asphalt binder towards permanent deformation due to repeated load. Two main parameters were achieved from this test which was non-recoverable creep compliance (Jnr) and recoverable strain (R). The lower Jnr value and higher R-value are favourable for asphalt binder in reducing the permanent deformation. Fig 7 to Fig 10 shows the Jnr value for both unaged and short-term aged NS-MB specimens at three different test temperatures (58°C, 64°C and 70°C). From the graphs, it clearly shows that the Jnr value increases when the temperature increases and decreases with the addition of NS. In terms of stress level, both unaged and short-term aged specimens show the same pattern where the Jnr value slightly increases as the stress level increases. Fig 7 and Fig 8, Jnr values for unaged 0% NS-MB were in the range of 0.001 to 0.007 at 100 Pa stress, while 0.001 to 0.008 at 3200 Pa stress. For unaged 1% to 5% NS-MB, the Jnr values were in the range of 0 to 0.001 at both 100 Pa and 3200 Pa stresses. Furthermore, when comparing the unmodified and modified specimens, the value of Jnr rapidly decreased with the addition of NS with 2% NS-MB producing the lowest Jnr value for both stress levels and types of ageing conditions. Hence, from the results of this test, it could be seen that the addition of NS significantly enhanced the rutting resistance of the asphalt binder.

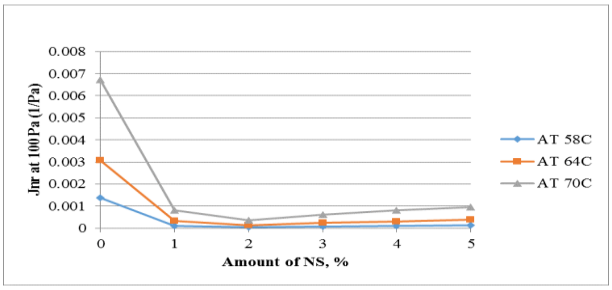

Fig 7 Jnr for Unaged NS-MB at 100 Pa Stress Level

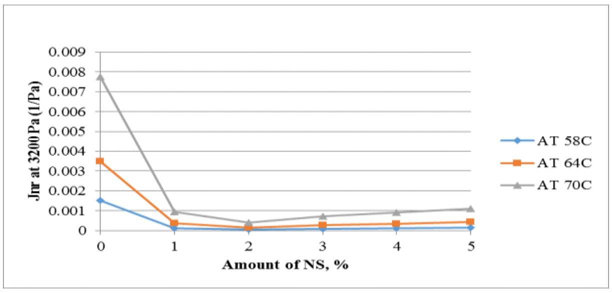

Fig 8 Jnr for Unaged NS-MB at 3200 Pa Stress Level

Fig 9 and Fig 10 presented the Jnr values for short-term aged specimens at 100 Pa and 3200 Pa stress levels with three different test temperatures. Jnr values for short-term aged 0% NS-MB were in the range of 0.0005 to 0.0035 at 100 Pa stress, while 0.0005 to 0.004 at 3200 Pa stress. For unaged 1% to 5% NS-MB, the Jnr values were in the range of 0 to 0.001 at both 100 Pa and 3200 Pa stress levels. Thus, again it shows that the addition of NS was capable in increasing the resistance of binder towards permanent deformation at various temperatures and stress levels.

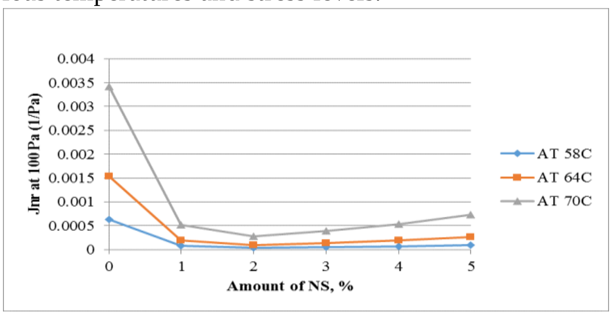

Fig 9 Jnr Short-term Aged NS-MB at 100 Pa Stress Level

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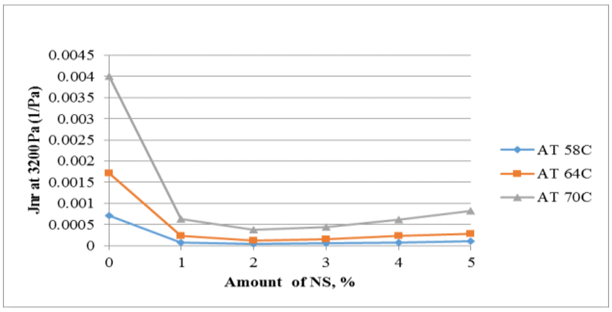

Fig 10 Jnr Short-term Aged NS-MB 3200 Pa Stress Level

C. Percentage of Recoverable Strain, R

The main characteristic of asphalt binder is its visco-elastic properties. Thus, the percentage of recoverable strain (R) is commonly used to represent the elastic properties of asphalt binder under repeated loading. This property is crucial in determining the capability of asphalt binder to recover after deformation during continuous loading. Thus, the higher value of R is favourable for asphalt binder to resist permanent deformation. Fig 11 to Fig 14 show the R values for both unaged and short-term aged NS-MB specimens under two different stress levels and test temperatures. From those figures, higher temperature reduces the R-value for both unaged and short-term aged specimens. In addition, there is a slight reduction in R-value when the stress level increases. In terms of asphalt modification, the modified specimens increased the R-value compared to unmodified specimens for both stress levels and ageing conditions. For Fig 11 and Fig 12, the R-value for unaged 0% NS-MB at three different temperatures were about 3% at 100 Pa stress and only 1% at 3200 Pa stress. For unaged 1% to 5% NS-MB, R values were in the range of 4% to 23% at 100 Pa stress and 2% to 22% at 3200 Pa stress. Furthermore, 2% NS-MB produced the highest R-value for all temperatures, stress levels and types of ageing. Thus, it can be stated that the addition of NS was capable of enhancing the recoverable ability and rutting resistance of asphalt binder.

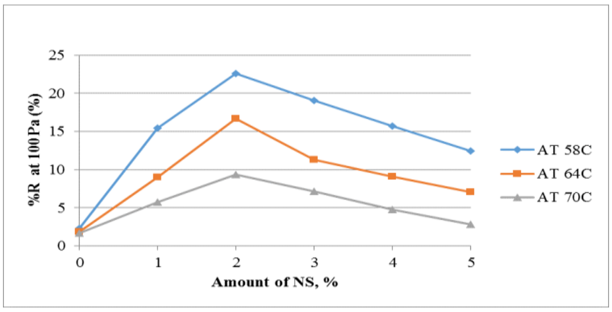

Fig 11 R for Unaged NS-MB at 100 Pa Stress Level

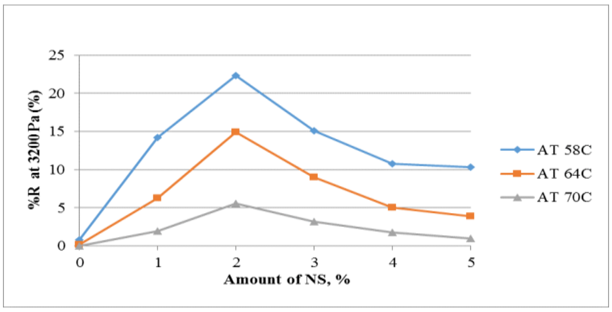

Fig 12 R for Unaged NS-MB at 3200 Pa Stress Level

Fig 13 and Fig 14 show the R values for short-term aged specimens. The R-value for short-term aged 0% NS-MB at three different temperatures were about 3% at 100 Pa stress and only 1% at 3200 Pa stress. For short-term aged 1% to 5% NS-MB, R values were in the range of 6% to 30% at 100 Pa stress and 3% to 27% at 3200 Pa stress. Thus, it shows that the addition of NS was capable of maintaining the elastic properties of the binder.

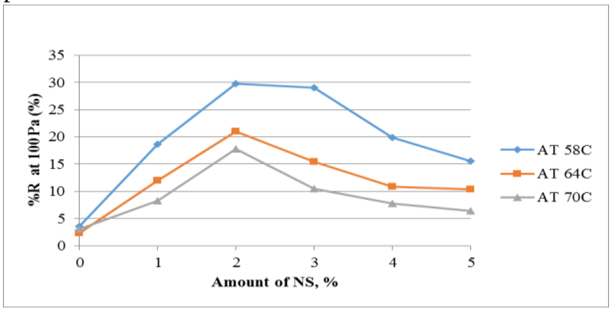

Fig 13 R Short-term Aged NS-MB at 100 Pa Stress Level

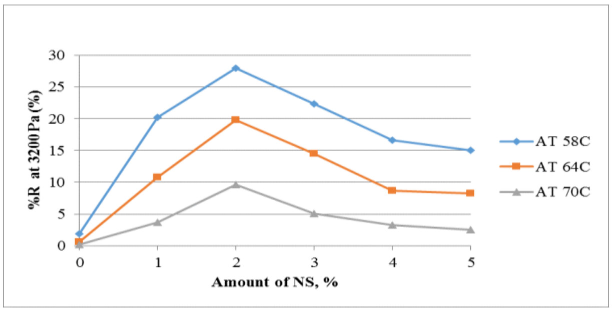

Fig 14 R Short-term Aged NS-MB at 3200 Pa Stress Level

IV. CONCLUSIONS

The effect of nano silica on the visco-elastic behaviour of asphalt binder was evaluated in this study. From the result of accumulated strain, non-recoverable creep compliance and recoverable strain, it shows that nano silica improved the performance of asphalt binder especially under various temperature, stress levels and ageing conditions. However, the addition of more than 3% NS is not significant in enhancing the performance of asphalt binder in terms of permanent deformation resistance.

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