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Rubber Roads for the Rubber City: Testing the Suitability of Rubberized Asphalt for Roads in Northeast Ohio

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Abstract

This research paper explores the benefits of using rubberized asphalt concrete (RAC) versus normal asphalt concrete (NAC) and why it is environmentally important. New road construction and repair of roadways due to potholes are always occurring in Northeast Ohio. Recently, the city of Akron's transportation budget has increased, which includes projects such as reconstructing asphalt and resurfacing pavements throughout the city of Akron. Using rubberized asphalt may improve the quality of our roads and reduce roadway degradation which will likely save cities money.

Using rubberized asphalt recycles old tires, which do not decompose, and creates a positive use for them when normally they would be disposed of in landfills and illegal stockpiles. RAC is possibly more effective than NAC for roadways in Northeast Ohio's climate due to the increased stiffness at cold temperatures and increased elasticity at warmer temperatures caused by the ground tire rubber additive to the binder. To test which type of asphalt, RAC or NAC, will perform at a higher quality, various Indirect Tensile (IDT) tests were performed to compare the ultimate tensile strengths of RAC & NAC at three temperatures.

Rubberized and normal asphalt cores were manufactured by mixing warm (135°C) binder and aggregate and then compacting this mixture to a low porosity in a mold. After compaction, these cylinders cured at room temperature for at least 48 hours. The cylinders were sliced perpendicular to their length to make short cylinders with a height which is approximately half of the diameter of the cylinder. Strength testing was performed according to AASHTO method T 322-03 (indirect tension test or IDT) using an 810 Material Test System located in the Civil Engineering Department at the University of Akron. Strength tests were performed at three temperatures which exceeds the natural range of temperatures in northeast Ohio (-75°C, 0°C, and

25°C). The results from the IDT testing demonstrates that adding ground tire rubber to asphalt increases the stiffness, maximum load capacity, and calculated strength when compared to regular asphalt.

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1.0 Introduction

1.1 Problem

Illegal tire dumping and tires disposed of in landfills continues to be a prevalent issue in 2016. Since tires do not biodegrade, they pose a number of significant environmental risks. When left in stockpiles, tires act as hosts for pests, like mosquitoes and rodents, which are also carriers of infectious diseases harmful to humans. Rodents are carriers of the Hantavirus and Plague; mosquitos are carriers of significant illnesses such as encephalitis and dengue fever. (*Don't Trash Our Land Prevent Illegal Dumping,* EPA). Mosquitos can breed 100 times faster than usual in the stagnant waters tire stockpiles provide. These stockpiles and infestation can lead to decreased property value for neighborhoods causing cities to lose money.

Tires are extremely flammable and stockpiles pose a significant fire hazard. Reisman's (1997) air emissions study observed that once tire stockpiles catch fire, they are hard to extinguish and release criteria pollutants, non-criteria hazardous air pollutants (HAP), and various metals.

One solution to preventing illegal tire stockpiles is to reuse end of life tires (ELT) by finding other recreational applications for them, such as Rubberized Asphalt Concrete (RAC).

1.2 Benefits

RAC helps prevent damage to roadways caused by significant loads and weather exposure by providing additional properties that help improve the durability and strength of the asphalt and binder. During the heated blending process, the flexible properties of the fine ground tire rubber particles are fused with the binder, allowing the RAC to handle greater stress before failure (Brown, et. al., 2009).

According to Brown, et. al. (2009), the purpose of adding rubber to hot mix asphalts (HMA) is to:

1. Make HMA stiffer at high service temperatures
2. Make HMA more elastic to resist fatigue cracking at intermediate service temperatures
3. Make lower or unchanged stiffness at low service temperatures resist thermal cracking.

1.3 Finance

According to the city of Akron's 2015 Capital Expenditure Summary, the city dedicated $43,562,466 to transportation which is a $19,280,645 increase from 2014's transportation budget of $24,281,821. Repaving roadways every year is expensive, but by using rubberized asphalt, it may prolong the life of roadways and may help the city of Akron to save money by having to repave less. Rubberized asphalt can also be installed at reduced thickness versus traditional asphalt overlays, saving the amount of material required for the project, which can also lead to cost savings (CalRecycle, 2016).

1.4 Purpose of Research

The purpose of this study is to compare the physical properties of two types of asphalt, RAC versus NAC, and determine which would perform more efficiently in Northeast Ohio's climate, specifically in the Akron, OH area using IDT testing.

2.0 Materials and Methods

The following section describes the method, materials, and testing procedures completed throughout this study in greater detail. The materials used to create cylinders were 94.6 wt% limestone gravel from Mar Zane Materials (blend size: 12.5 mm nominal maximum aggregate size (NMAS)) and 5.7 wt% asphalt binder. The rubberized asphalt binder used in RAC cylinders was prepared by hot mixing 90 wt% asphalt binder (PG 64-28) with 10 wt% ground tire rubber. The asphalt binder used in NAC cylinders is 100 wt% unmodified PG 64-28 asphalt binder.

We made a total of twelve 4 inch high, 6 inch diameter (101x152mm) cylinders of asphalt concrete: six RAC cylinders and six NAC cylinders. We preformed IDT testing using an 810 Material Test System on each sample loaded at rate of 2 inches per minute until failure at various temperatures that exceed the variability of northeast Ohio's climate: 1 cylinder of each at -75^{o}C (dry ice), 2 cylinders of each at 0^{o}C, and 3 cylinders of each at 25^{o}C (room temperature).

2.1 Asphalt Fabrication

Limestone aggregate was sieved into different grain size fractions using a Gilson Sieve Machine in separate 3/8 (2.6%), #4 (38.6%), #8 (18.8%), #16 (12.5%), #30 (8.4%), #50 (7.2%), #100 (5.9%), #200 (3.1%), and pan (3.1%) size sieve fractions (Fig. 2). Once sorting was completed, the fraction from sieve size #50 was dried to prevent clumping using a Humboldt MFG. Co. laboratory bench oven (Fig. 2).

Rubberized asphalt concrete mixtures were prepared by mixing 10 wt% ground tire rubber, 5.7 wt% PG 64-28 asphalt binder and 84.3 wt% limestone aggregate. The added ground tire rubber was mixed with the asphalt binder using a shear mixer at 150^{o}C for 15 minutes. This process modifies the asphalt binder and rubber. The rubberized asphalt binder is mixed with the limestone aggregate at 155^{o}C for 2.5 minutes in an automated mixer. The mixture was then hand-mixed to ensure an even distribution of the asphalt binder prior to mixing again for 2.5 minutes in the automated mixer. Normal asphalt concrete samples were mixed using the same procedure, except that no rubber was added and the proportions of asphalt binder and limestone aggregate were 5.7 and 94.3 wt%, respectively.

After mixing, the asphalt concrete was placed in a 101.6 x 152.4mm cylinder mold and compressed. After compression, asphalt cylinders were pushed out of the mold and cooled for 5 minutes using a floor fan. Fan cooling eases transfer to a clean surface. The cylinders were then cooled at room temperature for 16 hours.

2.2 ID Test Information

IDT tests were performed in accordance with AASHTO T 322 at three different temperatures: -75^{o}C, 0^{o}C, and 25^{o}C. IDT tests conducted at -75^{o}C and 0^{o}C were performed using the 810 Material Test System (MTS), which has a system to maintain asphalt cylinder temperature at ~0^{o}C. Asphalt cylinders for experiments performed at -75^{o}C and 0^{o}C were cooled immersing the samples in dry ice or the cooling system of the MTS for two hours prior to loading, respectively. IDT tests conducted at 25^{o}C were performed using the Universal testing machine (UTM). These cylinders sat at room temperature for two hours prior to loading in the apparatus. Each cylinder was loaded at the same displacement rate (2 in/min) until the sample yielded and failed.

The following equation from the ASTM standard test method for indirect tensile (IDT) strength of bituminous mixtures was used to determine the tensile strength (kPa) of each sample:

$$S = \frac{2000 * P}{\pi * t * D}$$

Where *S* is the IDT strength in kPa, *P* is the maximum load in Newtons, *t* is the cylinder height in mm, and *D* is the specimen diameter in mm.

3.0 Results

Six RAC cylinders were deformed at three temperatures: -75^{o}C (one cylinder), 0^{o}C (two cylinders), and 25^{o}C (three cylinders). Six NAC cylinders were used to perform a duplicate set of experiments. During each experiment, sample loading was performed at two inches of ram displacement per minute. Load increased slowly as non-parallel contacts between the sample and loading surfaces were closed (Fig. 7), but then increased rapidly until yielding once all surfaces were in good contact. After yielding, most samples deformed plastically for a small displacement until the sample developed a through-going fracture and failed (Figs. 3a & 3b).

Six asphalt concrete cylinders, three RAC cylinders and three NAC cylinders, were deformed at 25^{o}C using the IDT method. Peak load measurements of the RAC cylinders were 21,919 N, 20,735 N, and 20,169 N which correspond to tensile strengths of 893 kPa, 845 kPa, and 822 kPa, respectively (Fig. 4, Table 1). Peak load measurements of the NAC cylinders at 25^{o}C were 14,985 N, 15,839 N, and 15,795 N, which correspond to tensile strengths of 610 kPa, 645 kPa and 643 kPa, respectively (Fig. 5, Table 2).

Although measurement of strain in the centers of the asphalt cylinders was not measured in order to determine the true elastic properties of the different asphalt concretes, the force per displacement relationship during elastic loading is a reasonable approximation of elasticity. Therefore, one can compare the relative elasticity of the two asphalt concrete cylinders. The relative elasticity of RAC at 25^{o}C varied from 6,009 to 7,090 N/mm displacement (Table 1, Fig.

10a). The relative elasticity of NAC at 25°C varied from 4,537 to 5,607 N/mm displacement (Table 2, Fig. 10a).

Four asphalt concrete cylinders, two RAC cylinders and two NAC cylinders, were deformed at 0°C using the IDT method. Peak load measurements of the RAC cylinders were 49,400 and 50,575 N which correspond to tensile strengths of 2,012 and 2,060 kPa, respectively (Table 1, Fig 10b). Peak load measurements of the NAC cylinders at 0°C were 40,847 and 44,144 N, which correspond to tensile strengths of 1,664 and 1,798 kPa, respectively (Table 2, Fig. 10b).

The relative elasticity of RAC at 0°C varied from 17,071 and 22,543 N/mm displacement (Table 1, Fig. 10a). The relative elasticity of NAC at 0°C varied from 21,396 and 24,252 N/mm displacement (Table 2, Fig. 10a).

Two asphalt concrete cylinders, one RAC and NAC cylinder each, were deformed at -75°C using the IDT method. The peak load measurement of the RAC cylinder was 46,311 N, which corresponds to a tensile strength of 1,886 kPa (Table 1, Fig 10b). The peak load measurement of the NAC cylinder at -75°C was 26,878 N, which corresponds to a tensile strength of 1,095 kPa (Table 2, Fig. 10b).

The relative elasticity of RAC measured at -75°C was 28,435 N/mm displacement (Table 1, Fig. 10a). The relative elasticity of NAC measured at -75°C was 24,899 N/mm displacement (Table 2, Fig. 10a).

4.0 Discussion

The peak strengths for each RAC cylinder exceeded the peak strengths for each NAC cylinder for each experimental temperature (Table 1). Tensile strengths for each RAC cylinder exceeded the tensile strengths of each NAC cylinder for each experimental temperature, as well (Table 2 and Figure 10b). Figure 10a shows calculated elasticity of RAC vs. NAC. All RAC cylinders had higher levels of elasticity, except at 0^{o}C where elasticity varies between RAC and NAC (Figure 10a). Figure 10b shows failure tensile strengths of RAC vs. NAC. All RAC cylinders were able to withstand heavier amounts of weight than NAC cylinders for each tested temperature. RAC cylinders had a lower drop in tensile strength (kPa) between 0^{o}C and -75^{o}C (Table 1) versus NAC cylinders (Table 2). This means that RAC tested stronger than NAC and that ground tire rubber was successful at increasing stiffness and strength, which will help asphalt resist plastic deformation and resist cracking for cold climate temperatures.

According to the U.S. Department of Transportation FDWA’s "User Guidelines for Waste and Byproduct Materials in Pavement Construction,” adding crumb rubber to asphalt using the wet process in Ontario, Canada seems promising for their colder climate and improves durability of the asphalt. This study supports this statement due to the increased calculated strengths and higher maximum load capacities for the RAC samples. Nordgren and Tykesson (2011) completed a study in Northern Sweden to test the life-span and durability of rubberized asphalt in that area. They incorporated rubber into dense-graded asphalt concrete with soft binder, and the results showed that using rubberized asphalt increases flexibility and an anticipated longer life span. Flexibility was determined by the individual slopes against temperature; adding ground tire rubber to asphalt increased flexibility for each of the tested temperatures, except for 0°C where the cylinders experienced variable elasticities.

There were a few limitations to this study. BBR tests could not be performed, so flexibility was not directly measured, but elasticity was able to be measured by calculating the slopes and plotting them versus temperature. Asphalt core samples could not be obtained from previously installed pavements. This is a limitation because our samples that we made were not subjected to initial weathering and because of this we were unable to determine the long term strength and capacity of both sample types. This poses an area for future experiments.

5.0 Conclusions

This study demonstrates how RAC outperforms NAC determined by IDT testing over three selected temperatures representing Northeast Ohio's climate: -75^{o}C, 0^{o}C, and 25^{o}C. From the peak strengths generated by IDT testing, we were able to calculate each cylinder's failure, tensile strength, and individual slopes to determine each cylinders measure of elasticity.

The RAC cylinders were able to withstand heavier amounts of weight (Table 1 Figure 10b) and had greater elasticity (Figure 10a) for each tested temperature, with some variability at 0°C, than the NAC cylinders. This means that RAC is stronger and stiffer for all conditions than NAC and would effectively withstand temperatures representing colder climates, like Northeast Ohio. Adding ground tire rubber to asphalt provides better roadways and a better use for waste tires.

6.0 References

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7.0 Tables and Figures

Sample Name	Temp °C	P (N)	t (mm)	D (mm)	Tensile Strength (kPa)	Slope (F/displacement)
RS1	25	21,919	152	102	893	6,009
RS2	25	20,735	152	102	845	6,414
RS3	25	20,169	152	102	822	7,090
RS4	0	50,575	152	102	2060	17,071
RS5	0	49,400	152	102	2012	22,543
RS6	-75	46,311	152	102	1886	28,435

Table 1. Calculated strengths (kPa) and slopes for RAC cylinders.

Sample Name	Temp °C	P (N)	t (mm)	D (mm)	Tensile Strength (kPa)	Slope (F/displacement)
NS1	25	14,985	152	102	610	4,537
NS2	25	15,839	152	102	645	5,607
NS3	25	15,795	152	102	643	4,644
NS4	0	40,847	152	102	1664	24,252
NS5	0	44,144	152	102	1798	21,396
NS6	-75	26,878	152	102	1095	24,899

Table 2. Calculated strengths (kPa) and slopes for NAC cylinders.

Figure 1: Overview of sieving area with Gilson Sieving machine (left) and buckets containing the sieved aggregate based on size (right).

Figure 2: Shown above is the Humboldt MFG. Co. laboratory bench used to dry aggregate sieve size #50.

Figure 3a. Example of through-going tensile fracture in RAC cylinder (RS3, 20℃).

Figure 3b. Example of through-going tensile fracture in NAC cylinder (NS3, 20℃).

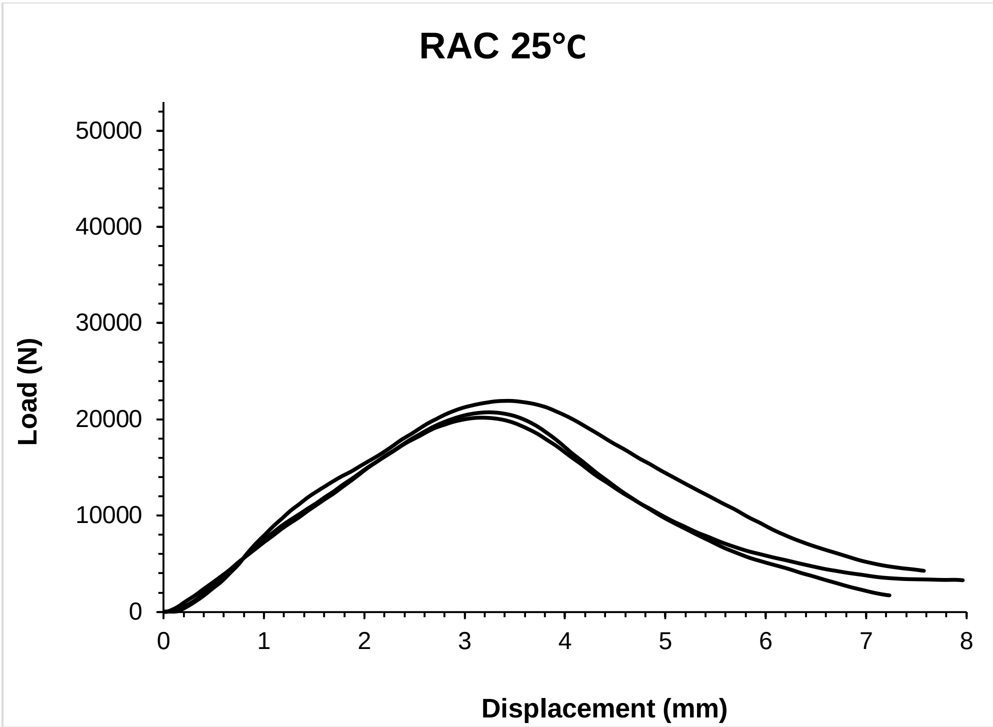


Figure 4. Load vs. displacement for RAC samples (RS1, RS2, & RS3) at 25^{o}C.

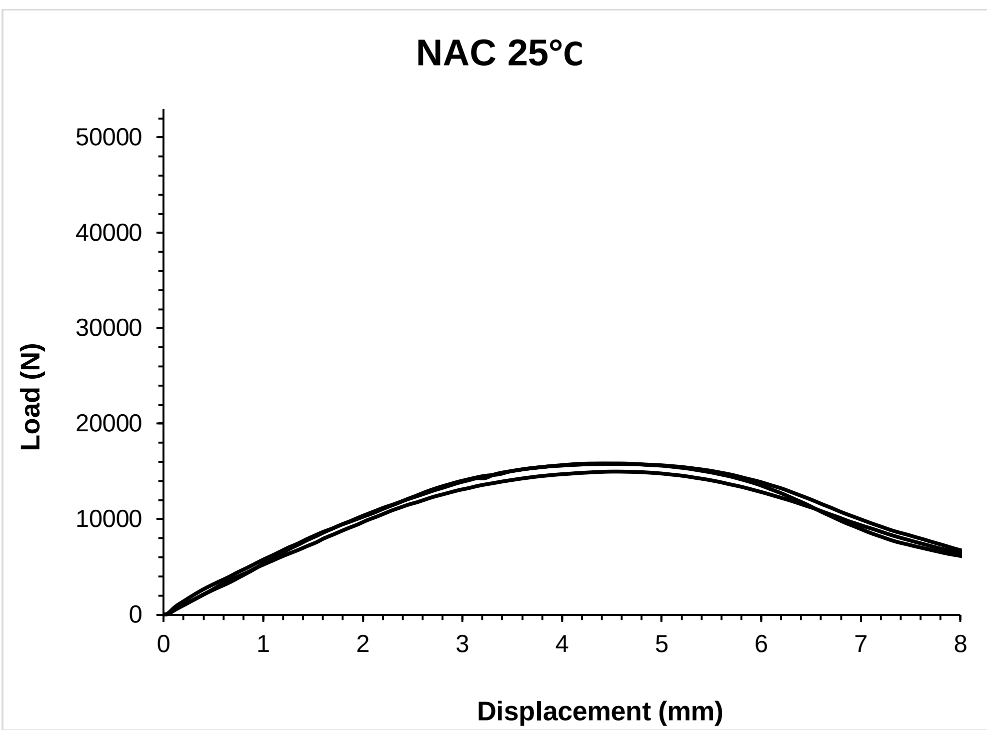


Figure 5. Load vs. extension for regular asphalt concrete samples (NS1, NS2, & NS3) at 25^{o}C.

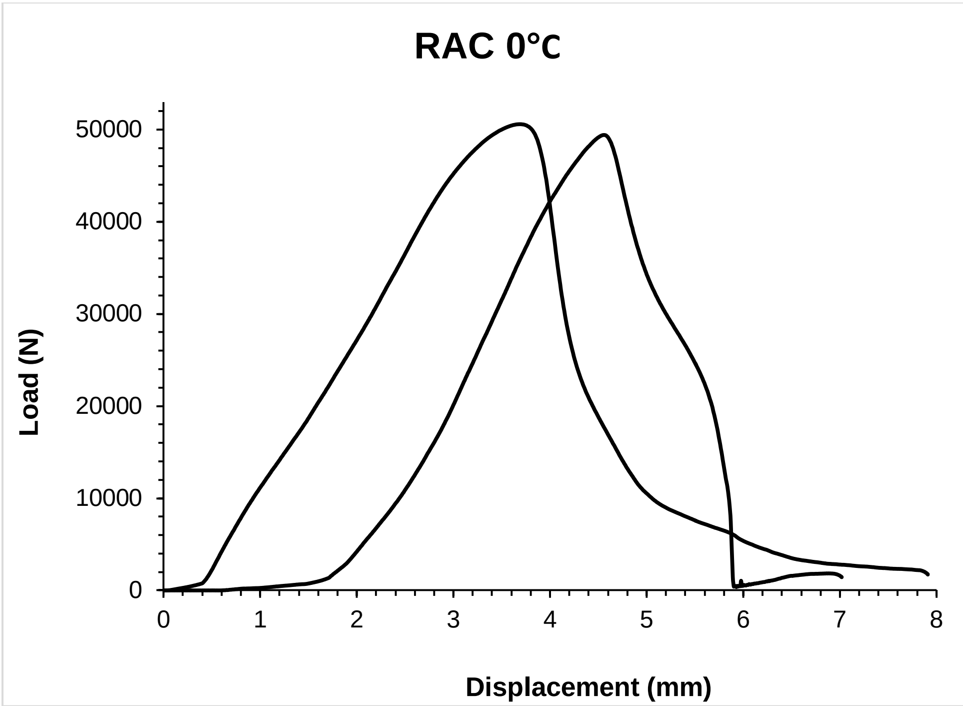


Figure 6. Load vs. extension for RAC samples (RS4 and RS4) at 0^{o}C.

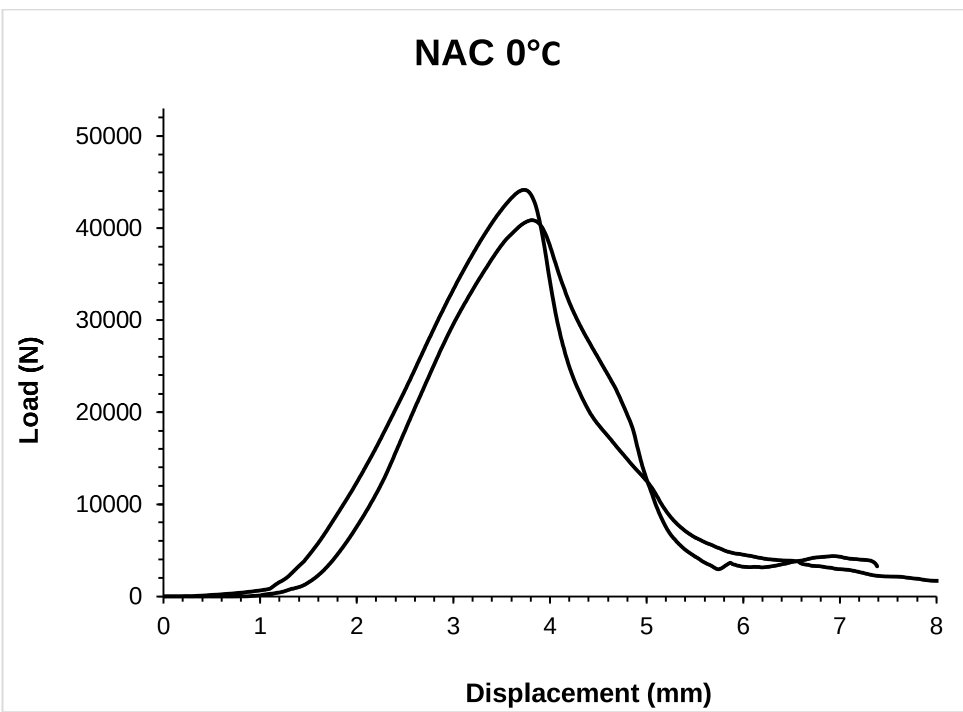


Figure 7. Load vs. extension for normal asphalt concrete samples (NS4 and NS5) at 0^{o}C.

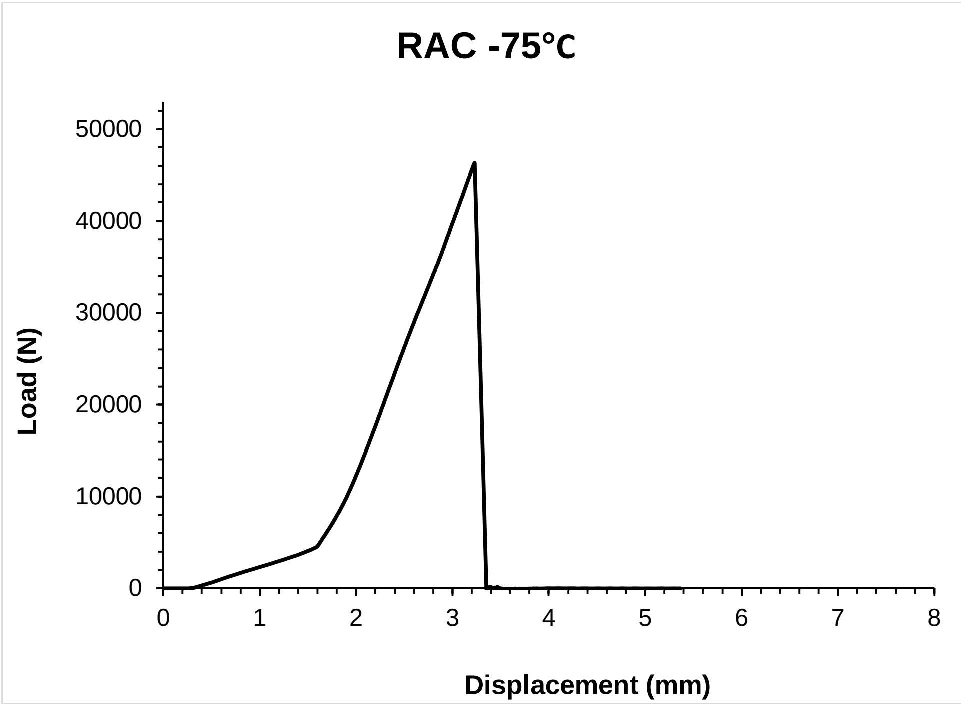


Figure 8. Load vs. extension for RAC sample (RS6) at -75^{o}C.

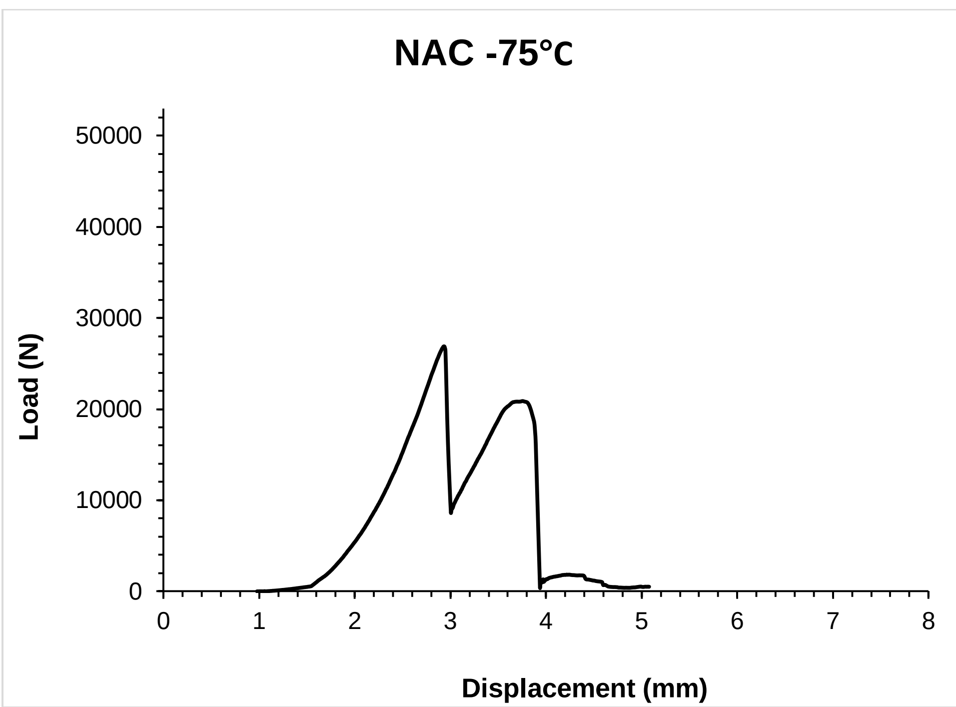
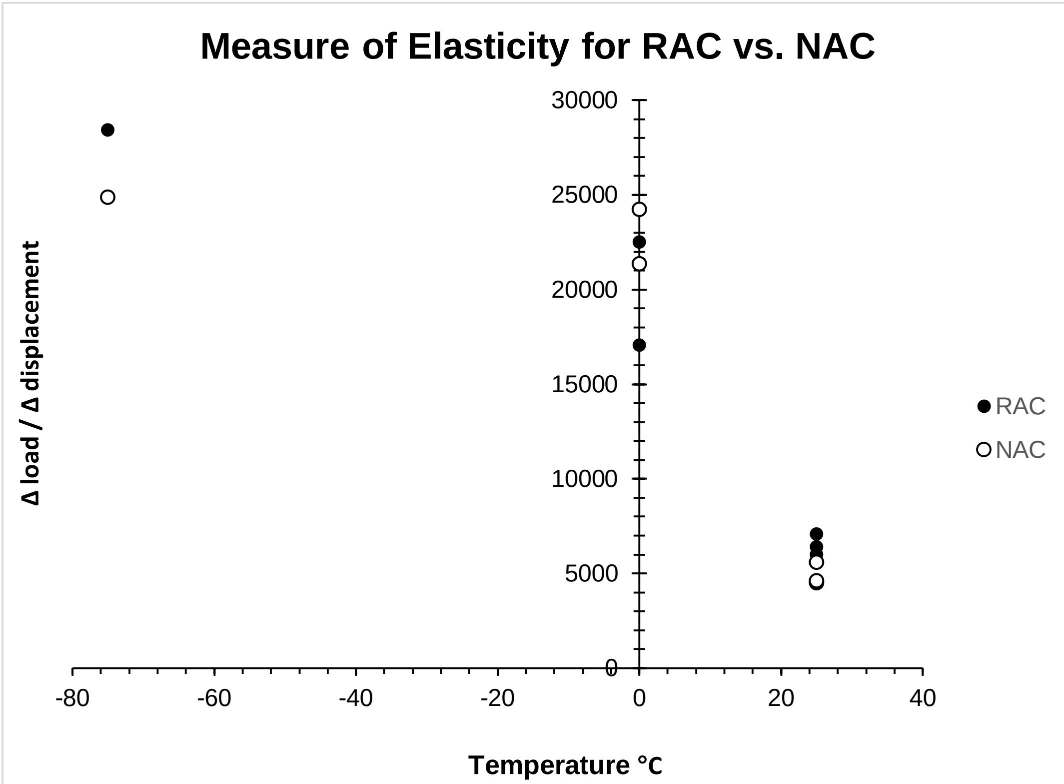


Figure 9. Load vs. extension for normal asphalt concrete sample (NS6) at -75^{o}C.

a.



b.

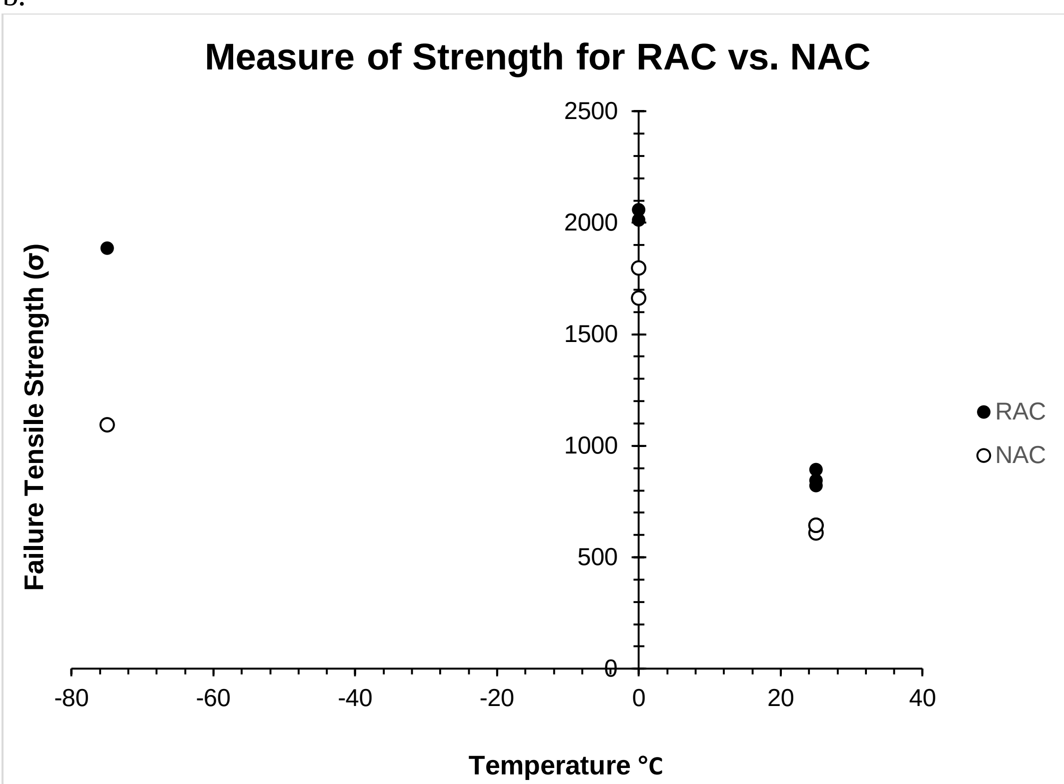


Figure 10. a) Measure of elasticity for RAC and NAC samples for each tested temperature. b) Measure of strength for RAC and NAC samples for each tested temperature.