The effect of nano zinc oxide as an activator on the mechanical and thermal properties of Rubber Composite for Sukhoi Su-25 - Attack Aircraft Tyres

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Abstract : The research main idea is to design rubber composite that can be used in the aircraft (Sukhoi-Su-25) tires. This kind of aircraft tyres is demanded by the Iraqi Ministry of Defense. Were successfully made in IRAQ. One of the goals of the research is to improve its qualifications to make it convenient to suit all hard circumstances that the aircraft tyres might expose which is unique to all other types of tyres. also aims to preserve the environment through reducing pollution resulted from the use of great amounts of zinc oxide, which it use an activator in rubber composite, by Substitution conventional Zinc Oxide by nano zinc oxide when producing of tyres . pollution also takes place when we try to dispose the tyres of. Zinc oxide (ZnO) nanoparticles are synthesized by sol–gel method and tested by: X-Ray Diffraction Analysis (XRD), Atomic Force Microscopy (AFM),Scanning Electron Microscopy (SEM),Energy Dispersive **X-**Ray Spectroscopy (EDS)**,** Fourier Transform Infrared Spectroscopy (FTIR).The cure characteristics, mechanical properties and thermal behaviour of natural rubber (NR and RSS1) systems containing nanoZnO are investigated and compared to those of (NR and RSS1) with micro-sized (conventional) ZnO. The RSS1 vulcanizate from aircraft tyre tread composite with 0.9 phr (parts per hundred parts of rubber) sol–gel derived nanoZnO shows improvement in the curing and mechanical properties in comparison to the RSS1 vulcanizate with 5 phr conventional ZnO. the ageing test and fatigue resistance test in 100℃ reveals that nanoZnO impose better thermal stability than conventional ZnO in the RSS1 vulcanizates. Thus, nanoZnO not only acts as a curing activator but also nano filler to improve the resulting properties of the RSS1 vulcanizates. nanoZnO leads to the reduction of ZnO level in the RSS1 composites. Therefore, sol–gel derived nanoZnO diminishes the pollution of aquatic environment due to higher amount of conventional ZnO in rubber composites.
Keywords : Sol–gel method, Nanostructured zinc oxide, Cure activator, Mechanical properties, Thermal stability.

Introduction

In modern civilization, rubber plays a leading role. The property by rubber composites essentially depends on the vulcanization process. Vulcanization is a process by which highly soluble plastic composites is converted into insoluble elastic state with improved mechanical properties and increased resistance to temperature variations and solvent action etc. by forming crosslinks between the rubber chines .In the vulcanization process many other ingredients are also added to rubber composites to improve some of its properties, to facilitate the manufacturing processing or to reduce the cost . In sulfur vulcanization of natural rubber (RSS1) the basic ingredients are ZnO, stearic acid, accelerators and sulfur. The ZnO is used as an activator in rubber vulcanization and increases the efficiency of the vulcanizing or crosslinking system. Stearic

acid accelerates the activity of ZnO which further accelerates the action of accelerator and sulfur in the vulcanization process. For industrial use, ZnO is produced at levels of 10^5 tons per year and about 50–60 % ZnO is used in rubber industry[1]. In the vulcanization of rubber the conventional amount of ZnO is 5 phr (parts per hundred parts of rubber). Now the reduction of ZnO level in rubber industry is very important from environmental point of view because the fact that the excess ZnO is released into the lithosphere during degradation of rubber   as at the end of the products life[1]. Zinc oxide is also released in the environment through leaching in land-fill sites and by friction during service. Soluble zinc compounds have toxic effect on aquatic organism[2]. To solve this environmental problem attempts have been made to reduce the ZnO level in rubber vulcanization[3-5]. In presence of accelerators, ZnO produces zinc – accelerator complex[6]which is highly soluble in the rubber phase and leads to Crosslinking reaction. However, the ZnO is not completely reacting with the accelerator and there is some unreacted ZnO. Because of the low specific surface area for the conventional ZnO, a small amount reacts with accelerators and large amount stays excess in the rubber vulcanizates and leaching in aquatic environment and can be harmful for aquatic organisms. Another problem is the low affinity of zinc oxide towards most elastomers, so it is very difficult to incorporate it efficiently into rubber matrix. Third problem is mould fouling, that during vulcanization, a layer of zinc sulphide is deposited onthe wall of the mould and builds up gradually with each subsequent production cycle[5,6].   But, because of the high specific surface area of nano sized ZnO, a small amount of ZnO almost completely react with the accelerator and a very little amount remains excess which is tightly bound to the rubber network. For this reason, it is expected that very negligible amount of unreacted nanoZnO will leach out and hence will have negligibly small toxic effect for aquatic organism. Sol–gel method is important for the preparation of nanoparticles mainly due to its easy mechanism, small cost and low fabricating temperature[7]. Several works[8-12] has been done to synthesize nanoparticles using sol–gel technique.

In this work nano sized ZnO is prepared in laboratory by sol – gel reaction and this nanoZnO is used as cure activator in the vulcanization of NR. There are many studies exist in literature [13-17] containing the effects of nanoZnO on various types of rubber. The aim of the present study is to investigate the effect of sol–gel derived nanoZnO as cure activator in the vulcanization of NR and also to reduce the quantity of ZnO in rubber compounding. In this way sol– gel technique will provide improved and Innovative ways for the reduction of harmful environmental pollution produced and reduced the other problems Byrubber composites, especially conventional ZnO. Thus, the present work is an attempt to develop rubber technology with the help of sol–gel science and technology.

2- Experimental part

2.1Materials and physical measurements:

- Natural rubber (standard Vietnamese rubber SVR) and (ribbed smoked sheet RSS1), zinc oxide , stearic acid , sulfur, DCBS Accelerator,TBBS Accelerator , Carbon black N_{326} ,Carbon black N_{11o} ,Renacit , Struktol 40 ms,Wax ,IPPD, Resorcinol melt ,Resorcinol melt , PVI , HMT from the state company for tyres and rubber industries in Iraq –Diwaniya.
- Toluene.
- To increase the ignition resistance of the Tyres, has been addition of Borax (Sodium Borate Partially Hydrate) with the chemical formula (Na2B4O7.5H2O) to the tread rubber composites.
  The test is carried out according to ASTM E 285-80   by using a thermal torch at (2000) °C[26]. The sample dimension is 4 mm in thick and 40mm diameter. The Blue Conical Shape fire is applied on the sample with a distance of (1.87 cm) .the required time for the fire to burn or penetrating the rubber sample is determined. The thermal erosion rate is determined by the equation: Erosion rate =d/b, where: d is the thickness in mm, b is the time to burn or penetrating the rubber sample.
- Nano zinc oxide ZnO is synthesized using sol-gel method nano zinc oxide is tested by : Field emission scanning electron microscopy (FESEM) images are obtained on instrument (XRD-6000, Shimadzu, Japan), with a wavelength of 1.54060 °A , Scanning Electron Microscopy (SEM), Energy Dispersive X-Ray Spectroscopy (EDS), Fourier Transform Infrared Spectroscopy (FTIR) using 8400S –FTIR-Perkin-Elmer spectrophotometer. The cure characteristics of the different stocks are obtained using the Monsanto Rheometer at 3_ arc for 140 _C. The stocks are cured under pressure at 135 _C for optimum cure time (t90), keeping vulcanizates for 24 h. at ambient temperature before measuring the tensile strength according to ASTM D 412-51 T using micro computer controlled electronic universal testing machine) (WDW-5E)

at a crosshead speed of 500 mm/min. by dumbbell shaped test pieces'. Hardness(shore A) of the vulcanizates is measured by ASTM D1415 for measuring rubber international hardness. extension fatigue cracking tested according to ASTM D 430 – 7 using Wallace-Dematta Flexing Machine ,thermal ageing test is carried out by Ageing O7E Multi-Cell Ageing Oven,This cell method of ageing exposes a test sample to elevated air temperatures, allowing its physical properties, such as tensile strength, to be measured and compared with those of an un-aged sample. Unlike conventional ovens, in the Wallace O7E individual samples are aged in separate cells preventing any contamination from adjacent samples through the migration of volatile products which can be found in many rubber composites.

2.2 Synthesis of ZnO nanoparticles

An 11 g of the zinc acetate dehydrate, oxalic acid 12.6 g, and 500ml ethanol its purity of 99.90% was used in the following steps[27]:

1. Dissolve: Dissolves zinc acetate dehydratesalt($Zn(CH3COO)2 \cdot 2H2O$) in 300 ml of ethanol at a temperature of 60 C° for 30 minutes and in another bowl, dissolve oxalic acid (HOOCCOOH.2H2O) with 200 ml of ethanol at a temperature of 50 C°.2 .Mixing: Adding warm acetate solution to the oxalic acid solution which remains under constant mixing for 24 hours, where the white thick liquid is noticed. 3. Evaporating and Drying: At this stage, the excess humidity is removed by evaporation on a hot plate at 80 C° for 20 hours, then drying in an oven at temperature 600 C° for 3 hours. After evaporation, the material was weighed. The weight of the resulting ZnO nanoparticles prepared by this procedure was 7 g[27]. Then, the resulting ZnOnano particles were modified to get perfect homogeneity of nanoZnO by the introduction of reactive groups to the filler surface. The modification process was achieved by using Oleic acid for the surface modification of ZnO nanoparticles. (9 ml) was dissolved in 300 ml o-xylene to form an oleic acid solution. Then, the prepared ZnOnano-particles (6 g) were added to the above solution and allowed the reaction to perform at 50 °C under stirring for 1 h. Finally, the particles were separated by centrifuge at 15000 rpm for 15 minutes and washed three times with toluene, to remove the un-reacted coupling agents and then dried. The flask was covered by para film and standing for 1 days. Then the modified ZnO nanoparticles become ready to use

2-3 Preparation of the rubber composite

In this work , initially, a standard natural rubber (NR) composites is prepared according to (ASTM D 3184) in order to obtained the cure characteristics of a natural rubber composites activated with nano zinc oxide instead of conventional zinc oxide and compared the obtained cure parameters with its standard parameters which it supported in specification according to ASTM , then, the same procedure is applied to produce a composites of tread of aircraft tyres with RSS1 natural rubber , in order to test the cure characteristic of it . the rubber is masticated in a two-roll mixing mill, and then conventional ZnO and stearic acid are added and again masticated. After that accelerator and sulfur are incorporated to the rubber matrix and the mixing is done near about for 10 min. according to ASTM   D3182[4]. The same procedure is repeated to prepare NR nanocomposites containing different amount of nanoZnO (0.2, 0.5, 0.9, 1.5 phr). Mixing composition of different ingredients is presented in Table 1. For the different mixes NR indicates natural rubber SVR , RSS1 indicates ribbed smoked sheet natural rubber , number indicates amount in phr, N indicates nano particle, C indicates conventional particle, as for example mix NR/0.5 NZnO represent NR vulcanizate containing 0.5 phrnanoZnO.

3- Results and Discussion:

3-1 X-Ray Diffraction Analysis (XRD):

From the X-ray test of unmodified nanoZnO (UMN ZnO) powder at a diffracted angle (30°to 70 °), a crystalline peak appeared which indicates the crystalline structure ($2\theta = 36°$) as a figure (3-1a). Also, a peak for MN ZnO at ($2\theta = 36.569$). This indicates that crystalline material is prepared which agrees with the results of[29]. In the case of modified nanoZnO with a coupling agent it was noted that crystalline peak has the same crystal structure with little shifting of crystalline planes due to the presence of coupling agent. This indicates that the modification does not affect the structure of the particle as shown in figure (3-1b) which is reported by[30]. Crystallite size is calculated using Scherer equation (CS = 0.9λ β cos θ) Where, **CS** is the crystallite size, Where λ is the wavelength of X rays used (1.54060 Å), β is the full width at half maximum (FWHM) and θ is the angle

of diffraction. The Observed diffraction peaks of ZnO at 2θ = 31.72°, 34.38 °, and 36.26 are related to (100), (002), and (101) which is agreed with the International Centre for Diffraction Data[31]. The crystallite size of prepared nano powder is found to be around 27 nm for modified and 29 nm for unmodified, which is in the order of nano size that is close to that obtained from[32].

Table (2-1) The formulation of studied vulcanizates in parts per hundred parts of rubber (phr) according to ASTM   D3182 [4]

Formulation	composites designation				
	NR/0.2 NZnO	**NR/0.5 NZnO**	**NR/0.9 NZnO**	**NR/1.5 NZnO**	**NR/5 CZnO**
NR	100	100	100	100	100
Conventional ZnO	-	-	-	-	5
Nano ZnO	0.2	0.5	0.9	1.5	-
Stearic acid	2	2	2	2	2
Carbon black(ISAF)	46	46	46	46	46
Aromatic oil	4	4	4	4	4
Accelerator OBTS					
Sulfur	2.5	2.5	2.5	2.5	2.5

3-2 Scanning Electron Microscopy (SEM):

Figure (3-3) shows two magnification of ZnO unmodified nanoparticles (UMN) and modified nanoparticles (MN). The results of this analysis showed that highly agglomeration are observed by this examination in figure (3-3 A, B) because ZnO nanoparticles has a high surface energy that tends to clump together in large particles which is disappearing in figure (3-3 C, D) that is the modification case. It was found that the surface of modified ZnO nanoparticles by coupling agent has reduced the agglomeration by reducing the energy of the surface, that is reflected the homogeneous dispersion after modification. This corresponding to the results of[28].

3.3 Cure characteristics of NR vulcanizates:

Cure parameters of NR vulcanizates in presence of nano and conventional ZnO are calculated at 135 _C first for NR and the results are presented in Table 3-2. It is clear From the result that optimum cure time (t90) of NR vulcanizate containing 0.5 phrnanoZnO is lower than NR vulcanizate with 5 phr conventional ZnO . This data indicates that nanoZnO act as an effective crosslinking agent and better cure activator for the vulcanization of NR compare to conventional ZnO. The crosslinking efficiency of nanoZnO is assured by the value of cure rate index (CRI) of different NR vulcanizates. The value of CRI is 59.57%greater for NR vulcanizate containing 0.5 phrnanoZnO (NR/0.5 NZnO) compare to NR vulcanizate having 5 phr conventional ZnO (NR/5 CZnO).while in RSS1 natural rubber composites, The optimum cure time (t90) for 0.9phrnanoZnOis lower than its value with 5 phr conventional ZnO (RSS1/5 CZnO) by 18.2%. And its scorch time is higher than its value with(RSS1/5 CZnO)[37] by27.5% and cure rate index (CRI) is higher thanits value with (RSS1/5 CZnO) by 32.56%. The specific surface area of nanoZnOis larger than conventional ZnO. So, the reaction between nanoZnO and stearic acid becomes very easy because of the increase of interfacial area for reaction when nanoZnO is used as cure activator. This causes formation of large amount of zinc stearate molecules. Thus, the value of CRI increases to greater extent by the incorporation of 0.9 phrnanoZnO with RSS1 rubber composites with respect to that value of RSS1 vulcanizate containing 5 phr conventional ZnO. the crucial step of vulcanization process is the formation of Zinc accelerator complex[9,10], nanoZnO reacts very quickly with stearic acid and accelerator and therefore quickens the formation of Zinc accelerator complex ,Because of the greater specific surface area of nanoZnO compare to conventional ZnO,. This resulting complex then reacts with sulfur to produce active sulfurating agent [3]. In the next step large numbers of crosslink precursors are produced by the reaction between active sulfurating agent and allylic sites of rubber chain[3]. The crosslink precursors then react with another polymer chain to form many number of crosslinks. Thus, the larger surface area of nanoZnO compare to conventional ZnO accelerates the rate of formation of Zinc accelerator complex via the
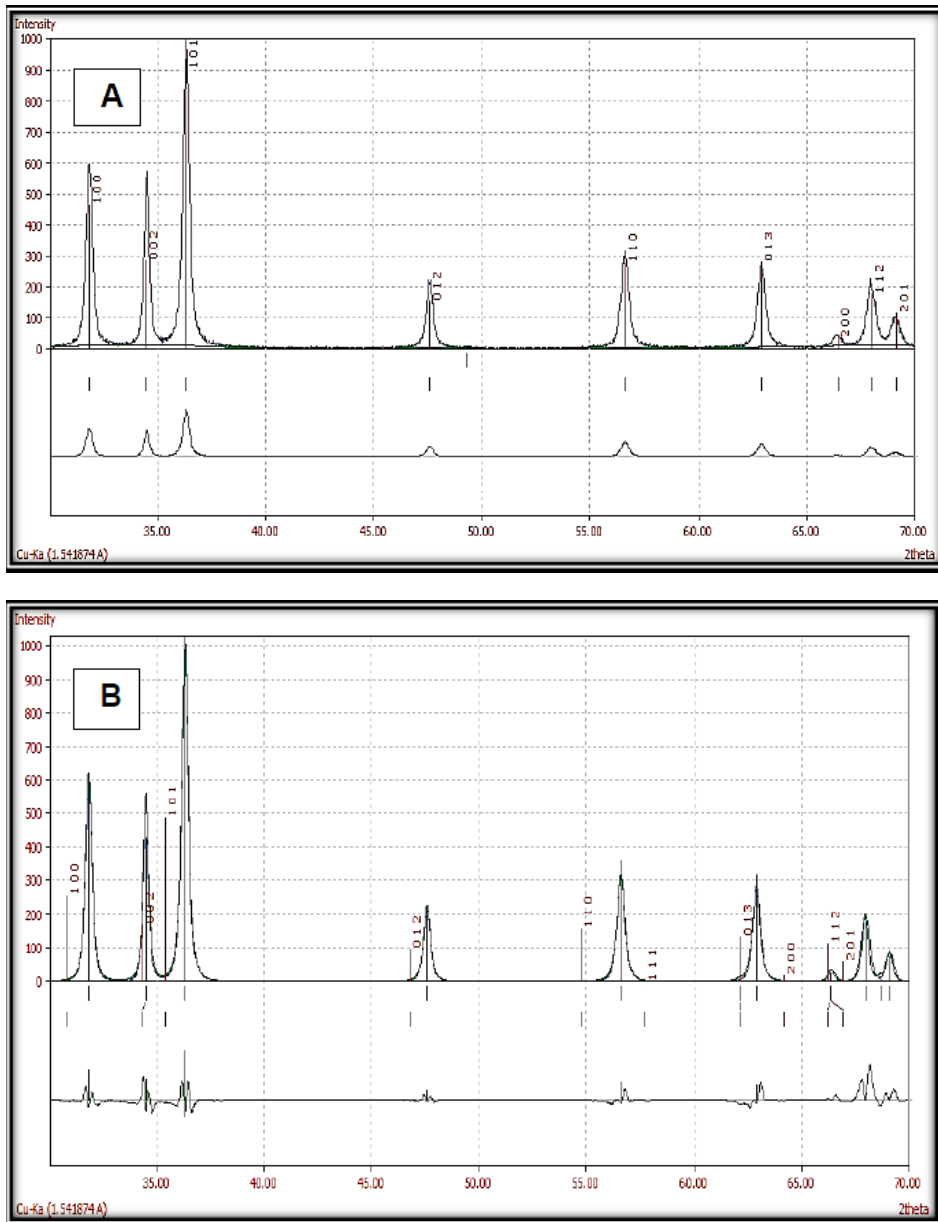
Figure (3-1) X-Ray diffraction analysis of A. un modified nanoZnO, and B. X-Ray diffraction analysis of modified nanoZnO.

Reaction of nanoZnO with stearic acid and accelerator. The large specific surface area of nanoZnO is the most important factor in lowering the optimum cure time and increasing the cure rate index of NR vulcanizates containing nanoZnO. And, the small cure time and high cure rate index of NR vulcanizates in presence of nanoZnO confirms that nanoZnO is an effective vulcanizing agent and cure activator for natural rubber.

3.4 Mechanical properties of NR vulcanizates:

It is observed that the tensile strength for tested samples from the standard composites from ASTM increased by using nano zinc oxide in compare with the sample (NR/5CZnO) as shown in figure (3-3). (NR/0.5NZnO) is increased by 10% while (NR/1.5NZnO) increased by 21%. In the tyre tread composites with RSS1 natural rubber, the sample (RSS1/0.5 NZnO) is increased in tensile strength by 10% and for (RSS1/0.9 NZnO) by 16% and for the sample (RSS1/1.5 NZnO) by 21%. Figure   (3-4) .the increase of the specific surface area of the nano zinc oxide in compare with the conventional zinc oxide causes an increase in the crosslink
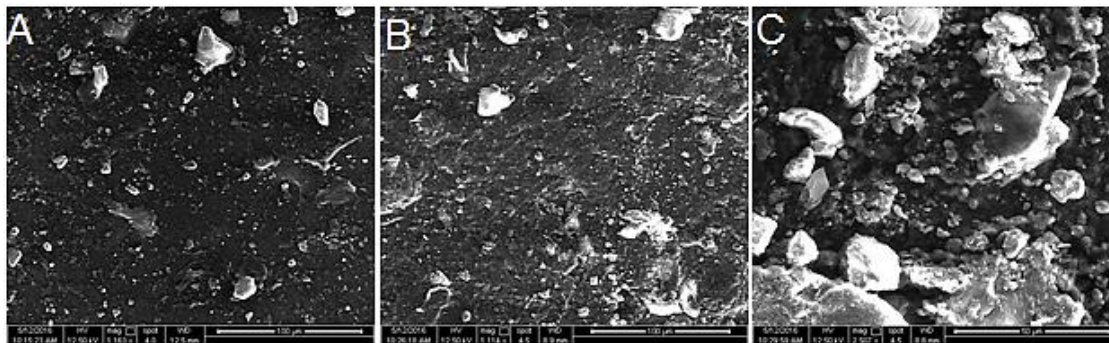
Figure (3-2) The SEM images clearly show homogeneities for nano size particle of ZnO , SEM images A for modified nano size particle of zinc oxide in (RSS1/0.9 NZnO) sample,B for modified nano size particle of zinc oxide in (RSS1/1.5 NZnO) sample .C for unmodified nano size particle of zinc oxide in (RSS1/1.5 NZnO).

Density. as a result , the activity and speed of the reaction is increased . And also because the perfect and uniform distribution of the nano particles in the rubber matrix instead of the micro size particles. This increase in tensile strength because it causes an obstruction of related movement of the rubber chains and decreased the free volume inside it.

Table (3-2) cure characteristic of RSS1,SVR natural rubber composites in presence of nano and conventional ZnO.

Composites designation	Scorch time, $t2$ (min)	Optimum cure time, $t90$ (min)	Cure rate Index CRI = 100/ $(t90 - t2)$ (min^{-1})
NR / CZnO	1.2 -1.30	2.15 -2.45	80 -117.6
NR/ 0.5 NZnO	2.23	2.7	127.66
NR/ 0.9 NZnO	2.05	2.7	90.91
NR/ 1.5 NZnO	1.87	3.1	67.42
RSS1/ CZnO	2-2.6	4.5-5.3	52.63 30.30 -
RSS1/ 0.5 NZnO	2.73	3.92	68.18
RSS1/ 0.9 NZnO	2.55	3.68	69.77
RSS1/ 1.5 NZnO	2.07	3.77	48.39

 noted that the increase in tensile strength in the composites with (RSS1/0.9NZnO) in compare with (RSS1/5CZnO) because of the high specific surface area and uniform distribution means that the nanoZnO particles play a role of nano filler in natural rubber composites[14].

(3.5)Crosslink Density Test:

Crosslink density test carried out by vulcanizate samples were accurately weighed (w) and immersed in about 25 ml of toluene in closed bottle. The samples were taken out after 7 days. The surfaces were dried with filter paper. They were quickly weighed by using the electronic balance. The specimens were weighed after 6 days at the laboratory temperature[26] .The volume swelling ratio (rυ) obtain by equation:

$$rυ = 1 + (ρp /ρ1)(w'/w-1)$$

Where , ρp is mass density of sample, and ρ1 is mass density of solvent, w is the initial weight of the sample before swelling and w' is the weight of the sample after swelling .The volume fraction of polymer (elastomer) was calculated by equation

$$υ2g = 1/ rυ$$

$v2g$ is the volume fraction of polymer in the swollen gel. From the value of $v2g$, thus obtained Mc , was then calculated using relation:

- [ln(1- $v2g$) + $v2g$ + X $v2g$ 2] = (Vsρρ / Mc) ($v2g$ 1/3 - $v2g$/2)

Crosslink density V (mole / cm^3) was calculated using relation:

V=1/2Mc

where X is a parameter characteristic of interaction between the rubber network and the swelling agent. For NR toluene system the value of X could be taken as 0.393, Vs is the molar volume of toluene (106.4 cm3/mol) .27 Crosslink Density of samples are tested ,the sample (RSS1/0.9NZnO) is Outperform the sample (RSS1/ CZnO) by 67.228%, the Crosslink density is decreased by a little ratio when the ratio of NZnO is increased because of the agglomeration which is happening in the nano particles and causes decrease in specific surface area for these nano particles[14],figure (3- 4). The increase of crosslink ratio when using nano zinc oxide is takes place due to the increase in specific surface area and the uniform distribution within rubber matrix in the composites in comparing with the conventional ZnO. So, the ratio of zinc ion (Zn++) on the nano particles is more than its ratio in conventional ZnO. The role of (Zn++) is very important in formation of short crosslinks and create a new precursors .High activity of nano-zinc oxide because of increasing the availability of Zn++ ions at the surface of particles compared to the conventional zinc oxide, and high dispersion of nano-particles due to surface area of particles causes the homogeneous distribution inside the composites[15, 16, 18]. According to Manick and Banerjee[19], Shelton and McDonel[20], Morita and Young[21], the presence of zinc oxide in sulphenamide-sulphur forms crosslinks which are mixed radical and ionic pathways .But ionic pathway is more probable with nano-zinc oxide and number of short crosslinks with nano-zinc oxide are more than with conventional zinc oxide due to the surface area of particles of nano-zinc oxide is greater than the surface area of particles of conventional zinc oxide and the number of zinc ion (Zn++) on the surfaces of particles of nano-zinc oxide is greater than the number of zinc ion (Zn++) on the surfaces of particles of conventional zinc oxide.

3-6 Elastic Gibbs free energy ΔG:

Elastic Gibbs free energy ΔG is determined from (Flory–Huggins equation)[22]:

ΔG=RT[ln(1- *v2g*) + *v2g* + X *v2g* ^{2}]

Where R is the universal gas constant, T is the absolute temperature; $v2g$ is the volume fraction of swollen rubber, X is the rubber solvent interaction parameter .The volume fraction of a rubber network in the swollen phase $v2g$ is calculated before. The value of ΔG indicates that (RSS1/0.9 NZnO) has greater elastic behavior about 41.279% compare to (RSS1/5 CZnO) figure (3-3) as ΔG is closely related to the elastic behavior of the material. The better elastic behavior of (RSS1/0.9 ZnO) is explained by considering better compatibility between rubber matrix and nanoZnO[11,23].
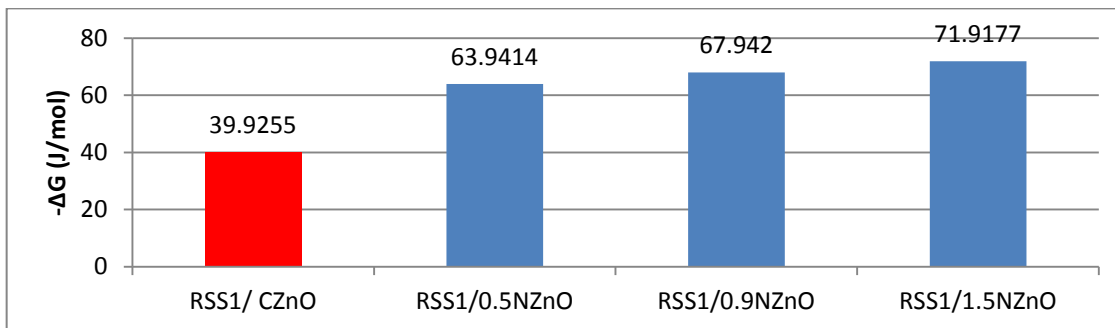

Figure (3-3) effect of NZnO in rubber composite onelastic behavior

3-7 Thermal Ageing test:

From the Ageing test results , its observed that the deterioration of the tensile resistance of the sample (RSS1/0.9NZnO) is less than its value   in all other samples , that the deterioration in tensile resistance due to

thermal ageing is 10.5% while its value in the sample(RSS1/5CZnO) is 73.19 % ,figure (3-4) . The uniform distribution for nano zinc oxide not only impedes the thermal motion of the rubber chains but also causes homogeneous heat thermal stability of NR nanocomposite due to incorporation of modified nanoZnO into the rubber matrix [24, 25, 36]
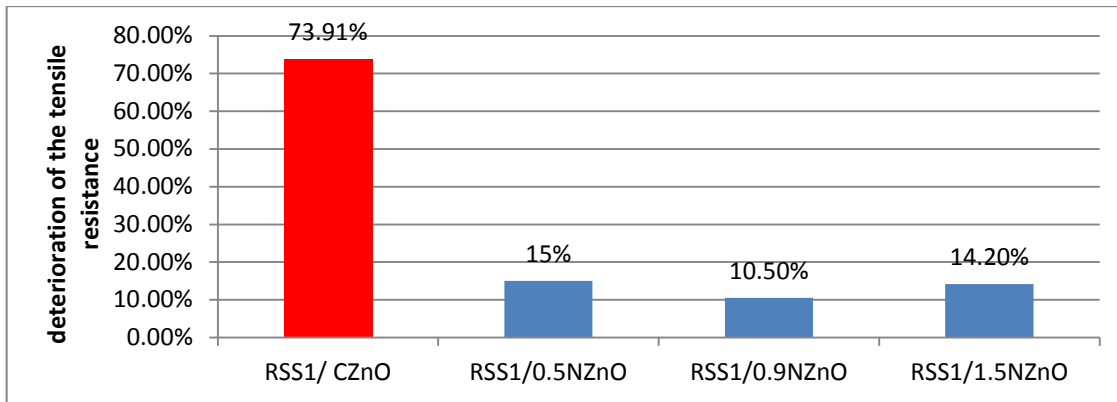

Figure (3-4) shows the effect of the nano zinc oxide ratio on the decrease of tensile resistance due to thermal ageing in the rubber composites of aircraft tyre tread from RSS1 rubber.

Both the facts account for the enhanced the distribution throughout the matrix to avoid heat concentration.

3-8 Dynamic fatigue test by FlexingDe- Mattia:

In the high elastic rubber products, the energy loss is small and heat generation during the dynamic stresses islittle. The flex testing device Demattia is considered an important measure of the resistance to bending (flex resistance), especially for tyres applications.

In Extension Fatigue Cracking Test, the number of cycles which is necessary for cracks growing are high (where more than 100,000 cycle) for the sample (0.9PHR NZnO) form (3-5), compared with the 10536 cycle for the sample (5PHR CZnO) while we find in test of bending to the crack growth (bend flexing) the success of the samples matched conventional sample In The rate of crack growth to high cycles of fatigue bending figure (3-6). The best resistance to periodic bending and stretching is due to strongest entanglements between rubber chains as a result of increased vulcanization rate because of the increased surface area of zinc oxide nanoparticles and thus increase the ratio of the existence of ion zinc (Zn ++) and increase the production of short crosslinks and new crosslink precursors as well as the role of nanoscale zinc oxide as an effective nano filler and homogeneity spread of it whiten rubber matrix in the rubber nano composite (due to the small size of the particle compared with conventional zinc oxide).the homogeneity spread of nano zinc oxide whiten the rubber matrix has another role in addition of its role of Impedes the motion of rubber chains , it's also decrease heat concentration by uniform distribution in all over the rubber matrix which is contribute to the thermal stability for rubber , this explains the results of thermal dynamic fatigue which it carried out at 100°C[35].The better flex crack resistance may be due to the stronger cross links between the rubber chains[35-38].
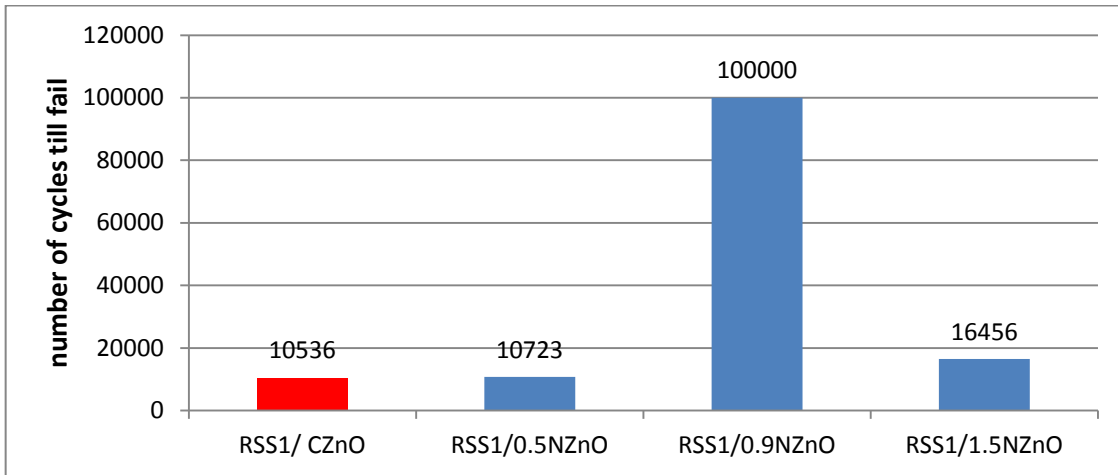
Figure (3-5) shows the effect of nano zinc oxide ratio on the number of cycles till failure in the aircraft tread tyre composites s made from RSS1 natural lrubber.

3-9 Flame resistance test by using Thermal Erosion rate equipment (mm/sec):

Test is carried out according to ASTM E 285-80, by using thermal torch which of temperature (2000°C)[34], the best result is for the sample with 30 phr without affecting on
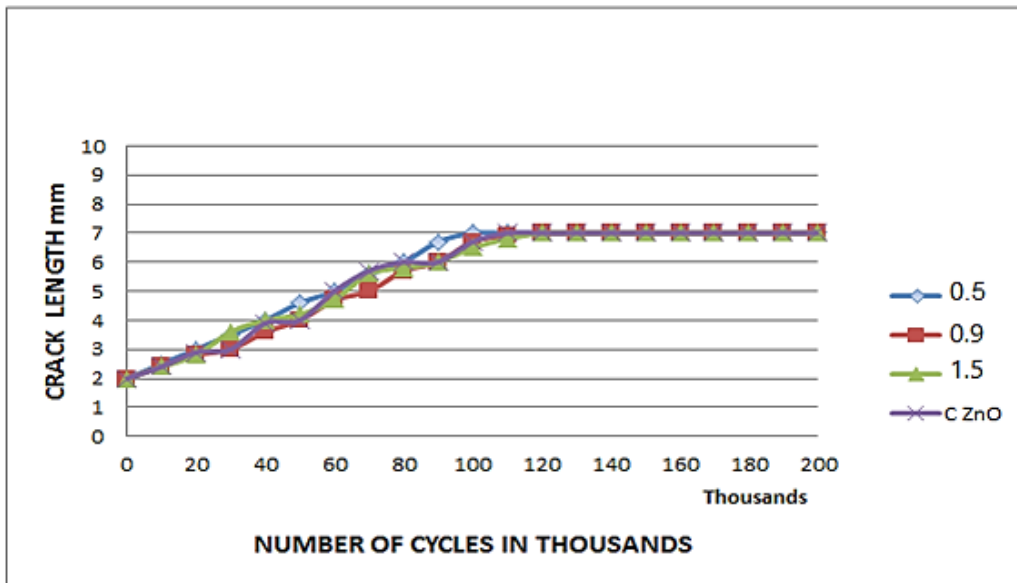

Figure (3-6) shows the effect of nano zinc oxide ratio on crack growth in the aircraft tread tyre composites s made from RSS1 natural lrubber.

Mechanical properties in compare with the composites without adding Borax (Sodium Borate Partially Hydrate) figure (3-7).
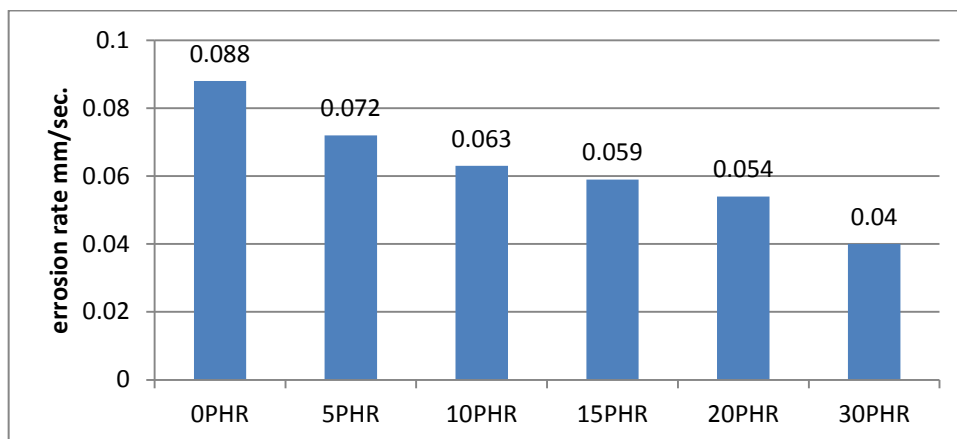
Figure (3-7) shows the effect of nano zinc oxide ratio on flame resistance in the aircraft tread tyrecomposites s made from RSS1 naturall rubber by using Thermal Erosion rate equipment (mm/sec) .

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