Title of thesis Safety Concrete Median Barrier with Impact Load Energy

I Calibio Paulino Nhavene____

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Safety Concrete Median Barrier with Impact Load Energy Absorber

By

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14168

Dissertation submitted in partial fulfilment of

The requirements for the

Bachelor of Engineering (Hons)

Civil

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CERTIFICATION OF APPROVAL

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(AP. Dr. Bashar S. Mohammed)

UNIVERSITI TEKNOLOGI PETRONAS

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own expect as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Calibio Paulino Nhavene

Abstract

The degree of safety delivered by Concrete Median Barriers is to be improved by introducing an impact load energy absorber, the crumb rubber. The performance of this new design is investigated using lab tests. Therefore**,** this research study focus on the performance of concrete median barriers under impact loads. In order to increase the absorption capabilities of the concrete, crumb rubber was used to increasingly replace fine aggregates until an optimum crumb rubber content was achieved. Impact load test, thermal conductivity test, and compressive test were performed as a mean to access the behavior of rubberized concrete under impact load. However, due to low strength of a rubberized concrete, Nano-silica and fly ash were added in the concrete mixture in order to reverse the negative effect of crumb rubber on the compressive strength of the concrete. Results depict an increment on the amount of the energy absorbed by the concrete when CR is increased. Crumb rubber has also demonstrated to be usefully in decreasing the thermal conductivity of the concrete materials.

ACKNOWLEDGEMENT

Various agents and personality were behind the success of this project entitled “Safety Concrete Median Barrier with Impact Load Energy Absorber”. Hence, although there is no way I can reattribute them for their efforts, my plan is to show my wordy appreciation for their endless support.

My first thanks goes to the Almighty God for His powerfully word that has been lightning my path through the whole project and life in general. Secondly, I would like to thank my supervisor AP. Dr. Bashar S. Mohammed for not only giving me a step-by-step guidance that I needed in order to complete my project, but also for giving me a moral support during my setback times.

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Chapter 1: Introduction

1.1 Background

Safety on the road have always been one of the major concerns in engineering, therefore, many new cars and roads designs have always aimed to address this issue. From the time where the number of out-of-control vehicles leaving their lanes to invade opposite traffic streams began to be a problem, new ideas of safety barriers came into consideration in road designs.

Concrete median barriers (CMB) are unbending barriers which do not change in shape considerably under extreme accident conditions. Scientists have assessed their impact performance utilizing crash tests, computer simulation, and in-administration execution assessment. On the other hand, the majority of this exploration concentrated on assessing impact performance with traveler autos or light trucks, as these barriers were not initially intended for effects including vast trucks or other substantial vehicles *(Elham et all, 2008)*

Taking into account that the collision theory teaches that excess shock energy in a collision between two objects is the main cause of the deformations or damages of the objects involved in the collision, it becomes unavoidable to attempt to reduce the severity of the vehicle-CMB crash outcomes by changing its properties so that it can absorb more energy. With this in mind and taking in to account that crumb rubber is the cheapest available material in the market that can absorb great amount of impact energy, it is reasonable to consider crumb rubber as a partial substitute of fine aggregates in a concrete mixture so as the concrete can have high impact energy values. Conversely, the CMB made of rubberized concrete will offer much more safety than the conventional concrete.

1.2 Problem Statement

Even though Concrete Median Barriers are an outright method for keeping drivers from intersecting street medians and impacting vehicles moving in the inverse traffic stream, they usually cause extra crashes on the vehicles colliding with the concrete median barrier. This intricate security impact of concrete median barriers has not been researched well.

Theoretically, the excess of impact load energy is the cause of the damage on the vehicles after colliding with the concrete median barriers. Therefore, the aim of this project is to lessen the severity of the crash outcomes on the vehicles by introducing a shock energy absorber material (crumb rubber) in concrete median barriers.

1.3 Objectives and Scope of Study

The objectives of this project are:

1. Conduct experimental studies on the rubberized concrete in order to obtain optimum proportions of crumb rubber to be introduced in a concrete mixture so as to optimize the absorption capabilities of the resulting concrete.

2. Investigate the degree at which the use of an energy absorber in concrete median barriers can reduce the severity of the crash outcomes on the vehicles.

3. Outline the principles to be used in the new concrete median barriers with energy absorber. Therefore, the main focus will be on the rubberized concrete.

Chapter 2: Literature Review

Median barriers physically separate restricting activity streams and help stop vehicles going into contradicting movement paths. They are regularly based on the focal point of wide urban multipath streets where they can be utilized to stop people on foot crossing the street at perilous spots Andrew et al. (2008).

Median barrier can likewise be utilized to utmost turning alternatives for vehicles, and movement these developments to more secure areas.

Median barriers utilized as 'safety barriers' (intended to securely stop or redirect vehicles that hit them) are generally stronger than average boundaries utilized predominantly to regulate movement streams or demoralize walkers from intersection *Rosendahl et al.(2006).*

Choices about what sort of median barriers ought to be utilized ought to be focused around a few elements including activity volume, movement speed, vehicle blend, average width, the quantity of paths, street arrangement, crash history, and establishment and upkeep costs.

Median Barrier is utilized to avoid cross-median crashes on separated expressways. Despite the fact that it is generally reported that crash frequencies increment in the wake of introducing median barrier, little is thought about median barrier crash seriousness conclusions, *Andrew et al. (2008).*

The estimation results demonstrate that crashes with a cable median barrier build the likelihood of less-serious accident conclusions in respect to impacts with a concrete median barrier. Expanding the median barrier counterbalance was connected with a lower likelihood of serious accident results.

From the researches made in the United States, every year more than 40,000 drivers are murdered and an alternate 3 million are harmed in accidents on the expressway and road *arrange (NHTSA, 2001).* Despite the fact that turnpikes are composed utilizing the largest amount of geometric configuration criteria, *Neuman et al. (2008)* shows that there is one cross-average accident casualty every year for each 200 expressway miles; roughly 250 fatalities happen yearly on expressways as an aftereffect of CMC occasions; and, that average related accidents are more than three times serious as other accident sorts on roads. The creators additionally show that more or less 44% of

CMC occasions happen on country expressways, and that about two-thirds of deadly CMC accidents include guys. Also, more than half of deadly CMC occasions happen around evening time.

2.1 Effects of Nano-Silica on concrete

2.1.1 Compressive Strength and Modulus of Elasticity

There is an inverse proportionality between the amount of voids present in a concrete and the compressive strength of the concrete. Additionally, when Nano-silica (NS) is added, it fills the voids in the concrete including those on interface between aggregate and the cement paste. Consequently, the concrete becomes more compactly dense and homogenous. In addition to the void filling effect, NS pozzolanic reaction results in the consumption of $Ca(OH)_2$ and formation of C-S-H gel which is known by its high bounding capacity. As an outcome, the compressive strength of the concrete increases. *(Mukharjee & Barai, 2014).*

Additionally, the increased packing density of the bound between aggregates and cement paste results in less mobility of the particles and consequently the modulus of elasticity of the concrete is increased.

2.1.2 Hydration

There is a greater number of contact surfaces present in a Nano-particle made substances than those of other types. Therefore, when Nano-silica is added in a concrete mixture, there is an increase of the reaction sites in the cement paste *(Zhang, et al, 2012).* Thus, the total heat increases.

2.1.3 Permeability and water sorptivity

The void filling effect coupled with formation of C-S-H gel in the NS pozzolanic reaction results in an increase of packing density of the microstructure of the paste. Therefore, there is a noticeable decrease of the permeability of the concrete. In addition to that, the compaction of the interfacial transition zone between the cement paste and the aggregate reduces the water sorptivity *(Puentes,& Palomar 2015).*

2.1.4 Chloride penetration and diffusion

The chloride penetration and diffusion rate in a concrete material is directly proportional to the concentration of Ca^{2+} and OH^{-} ions *(Zhang & Li., 2011).* Additionally, in order to have a favorable movement of particles in a substance, there have to be free spaces to allow the motion

2.2 Effects of Crumb Rubber on Concrete

2.2.1 Compressive strength

When crumb rubber is used to increasingly replace fine aggregates in a concrete mixture, it becomes relevant to take note on the fact that crumb rubber is known by its high poisson ratio, low elasticity, high porosity as well as weak bounding *capacity (Onuaguluchi & Panesar, 2014).* Therefore, weak bounding between crumb rubber particles and cement paste is expected. Furthermore, the resulting concrete will have a high susceptibility to cracking. Thus, the concrete will have relatively low compressive strength compared to the one of a normal concrete.

2.2.2 Modulus of elasticity

The modulus of elasticity of each component used in a concrete mixture as well as the air entrained in the mixture are some of the factors to be weighed up in order to understand the influence of crumb rubber on the elasticity of the concrete *(Onuaguluchi & Panesar, 2014).* Recalling the fact that crumb rubber particles have low elasticity and high air entertainment, it becomes clear that the addition of crumb rubber will reduce the elasticity of the concrete.

2.2.3 Impact load energy and thermal conductivity

There is an inverse proportionality between the elastic modulus of a material and the capacity of that material to absorb energy from an impact load. Additionally, a rubberized concrete has low modulus elasticity, thus, it is clear that a rubberized concrete has a tendency of absorbing more energy from impact load than a normal concrete.

Comparatively, crumb rubber particles have lower thermal conductivity than rock aggregates and sand *(Limbachiya, M., 2009).* Therefore, when they are used to partially replace fine aggregates present in a concrete mixture, the will lower the thermal conductivity and diffusivity of the resulting concrete due to an increase of entrapped air in the concrete and relatively low thermal conductivity of the crumb rubber *(Hall, et al, 2012).*

2.3 Fly Ash

Fly ash is derived from combustion of the powered or ground coal. Fuel gases are responsible by for transporting the fly ash through firebox. According to the nature of the coal that produces, fly ash can be divided into two categories: class C and class F fly ash.

Class C is a product of combustion of lignite or subbituminous coal. This type of coal is the most recommended in the green building guide, therefore is mostly used in for residential applications. Class F on the other hand, comes from Anthracite and bituminous when they burned out.

The addition of fly ash in a concrete mixture, it improves its plastic properties by enhancing its workability, lowering the water need as well as the segregation and bleeding. The heat of hydration is also slightly lowered by the use of fly. Due to the low permeability, the resulting concrete will tend to have an increased sulphate resistance. In general, when fly ash is added in a concrete mixture, it tends to fill in the voids and therefore, the resulting concrete will have an improved compressive strength and reduced permeability

2.4 Impact Load Lab tests

Toughness is a measure of the measure of vitality a material can ingest before cracking. It is the fate of designing significance when the capacity of a material to withstand an effect load without breaking is considered.

Two government sanctioned tests, the Charpy and Izod, are generally used to measure Impact Energy.

2.4.3 Charpy test

- The specimen is supported as a simple beam with the load applied at the center.
- The position of latching tube is set to 140°
- The specimen is supported horizontally from two sides

2.4.4 The Izod test

- The specimen is supported as a cantilever beam.
- The position of latching tube is set to 90°
- The specimen is supported Vertically from one side

Both Charpy and Izod impact testing use a swinging pendulum to apply the load. The difference in the Charpy and the Izod techniques is in the way that the specimens are supported in the apparatus machine. Using notched specimens the specimen is fractured at the notch.

2.4.5 Apparatus

Impact testing machine from the UTP Lab at 17-00-05 is depicted bellow

Figure 1: Impact test machine (from ASTM E23)

2.4.6 Specimen

The standard specimen is 1x1x5.5cm according to (ASTM E23)

Figure 2: charpy specimen (from ASTM E23)

2.4.7 Test procedures

The following procedures are outlined according to ASTM E23 standards

2.4.7.1 Operations

1. Select the test (Charpy/Izod)
2. Select and fit the respective striker in the hammer, first tighten the screws of the wedge and then of strikers
3. Fix the latching tube to corresponding position (for Charpy 140° position and for Izod 90° position)
4. Place a specimen on the support of the block
5. Bring the striker (hammer) closely to specimen and tough it lightly with the specimen
6. Pointer when touched to its carrier should read 300 J line for Charpy and 170 J for Izod. Otherwise correct it by losing and tighten the screw of the pointer carrier
7. Remove the specimen. Latch the hammer. Place the pointer as 300 J for Charpy and 170 j for Izod
8. Release the hammer. Hold back the releasing lever
9. The pointer will show the frictional losses. This reading should be less than 1.5 joules for Charpy and 0.8 for Izod
10. Thus the machine is ready for the test

2.4.7.2 Conducting the test

1) Place the specimen onto the support with notch facing backside of the striking direction
2) Using the setting gauge. Center the notch in between the anvils
3) Place the pointer to read 300 J. latch the hammer

b) Release the hammer. The pointer will indicate the amount of energy consumed by the specimen.

c) **Izod test**

1) Place the specimen onto the support with notch facing forwards the direction of striker of the striking direction.
2) Using the setting gauge, center the notch to the reference level
3) Face the pointer to read 170 J. latch the hammer
4) Release the hammer. The pointer will indicate the amount of energy consumed by the specimen for its rupture.

2.4.7.3 Calculations

1. The load is applied as an impact from a hammer that is released from position h_1.

2. The pendulum with a knife edge strikes and fractures the specimen at the notch.

3. The pendulum continues its swing, rising to a maximum height h_2', which is lower than h_1.

4. The energy is calculated from the difference in initial and final heights of the swinging pendulum. Impact energy (toughness) from the test is related to the area under the total stress-strain curve.

2.5 Rubber material

Rubber materials can be characterized as "materials which show the property of long-range reversible flexibility" *(Blackley 1983).* Long-extend reversible flexibility can be considered the capacity of a material to support vast strain under a connected burden without calculable harm and come back to its unique shape once the heap is evacuated. Utilizing this definition, the terms elastic and elastomer can be utilized reciprocally.

Elastic can be comprehensively separated into two classes, common and engineered. The subatomic recipe for common elastic is (C5H8)20.000. The structural equation for regular elastic monomer is (CH8).

According to the research paper by Paul et al, material properties attractive in an elastomeric vitality retaining compound are abridged as takes after.

1. Flexible Modulus: Rubber materials by and large disperse little vitality for every unit weight and, hence, competitor mixes ought to have greatest conceivable firmness.
2. Temperature Sensitivity: Rubber vitality safeguards materials ought to display as meager temperature affectability as would be prudent. Particularly, elastic mixes utilized as a part of vitality safeguards should stay adaptable at the lower temperature great, and the aggregate change in versatile modulus ought to be short of what half over the whole temperature extend that the material must perform well.
3. Damping: Energy scattering by competitor materials ought to increment with the speed of packing, and safeguards ought to return negligible measures of put away vitality to the framework. Along these lines, material damping and consistency ought to be high.

4. Durability: Energy safeguards are regularly subjected to profoundly destructive situations and extreme effect conditions. Consequently, vitality engrossing elastic mixes must be naturally dormant and have high tear safety.

Determination of a material prescribed to be utilized as a part of a vitality retaining structure is focused around its temperature reaction and vitality dissemination at room temperature. Round geometry is prescribed because of its suitability for gathering.

Roundabout chambers fall consecutively by-line way without transmitting substantial powers to the supporting structure and are less influenced by effect edge than square barrels. Square chambers exclusively require more vitality to crumple than roundabout ones both statically and progressively when tried in their ideal introduction. In any case, vitality scattering of an individual square chamber is significantly diminished when tried with other effect edges. Bunches of square chambers show an insecure conduct *(Paul et al,2010)*

2.6 Rubberized Concrete

Siringi(2012) conducted research to study the effect of substituting fine aggregates by crump rubber materials and the results from this experiment indicates that while replacement of mineral aggregates with crump rubber results in reduction in compressive strength, this may be mitigated by addition of silica fume or using a smaller size of crump rubber to obtain the desired strength.

The greatest benefit of using crump rubber is in the development of a higher ductile product with lower density while utilizing recycled crump rubber. From the results, it is observed that 7-10% of weight of mineral aggregates can be replaced by an equal volume of crump rubber to produce concrete with compressive strength of up to 4000 psi (27.5 MPa). Rubberized concrete would have higher ductility and toughness with better damage tolerance but the Elastic Modulus would be reduced.

2.7 Location

Rosendahl (2006) states that on controlled access interstates, concrete barriers will by and large be given in medians of 30 ft or less. On non-controlled access parkways, solid boundaries may be utilized on medians of 30 ft or less; then again, mind ought to be practiced in their utilization with a specific end goal to stay away from the making of a deterrent or limitation in sight separation at median openings or on level bends. By and large, the utilization of concrete barriers on non-controlled access offices ought to be limited to regions with potential safety concerns, for example, railroad partitions or through zones where median narrowing happens. Concrete barriers may be considered in medians more extensive than 30 ft focused around an operational investigation.

Chapter 3: Methodology

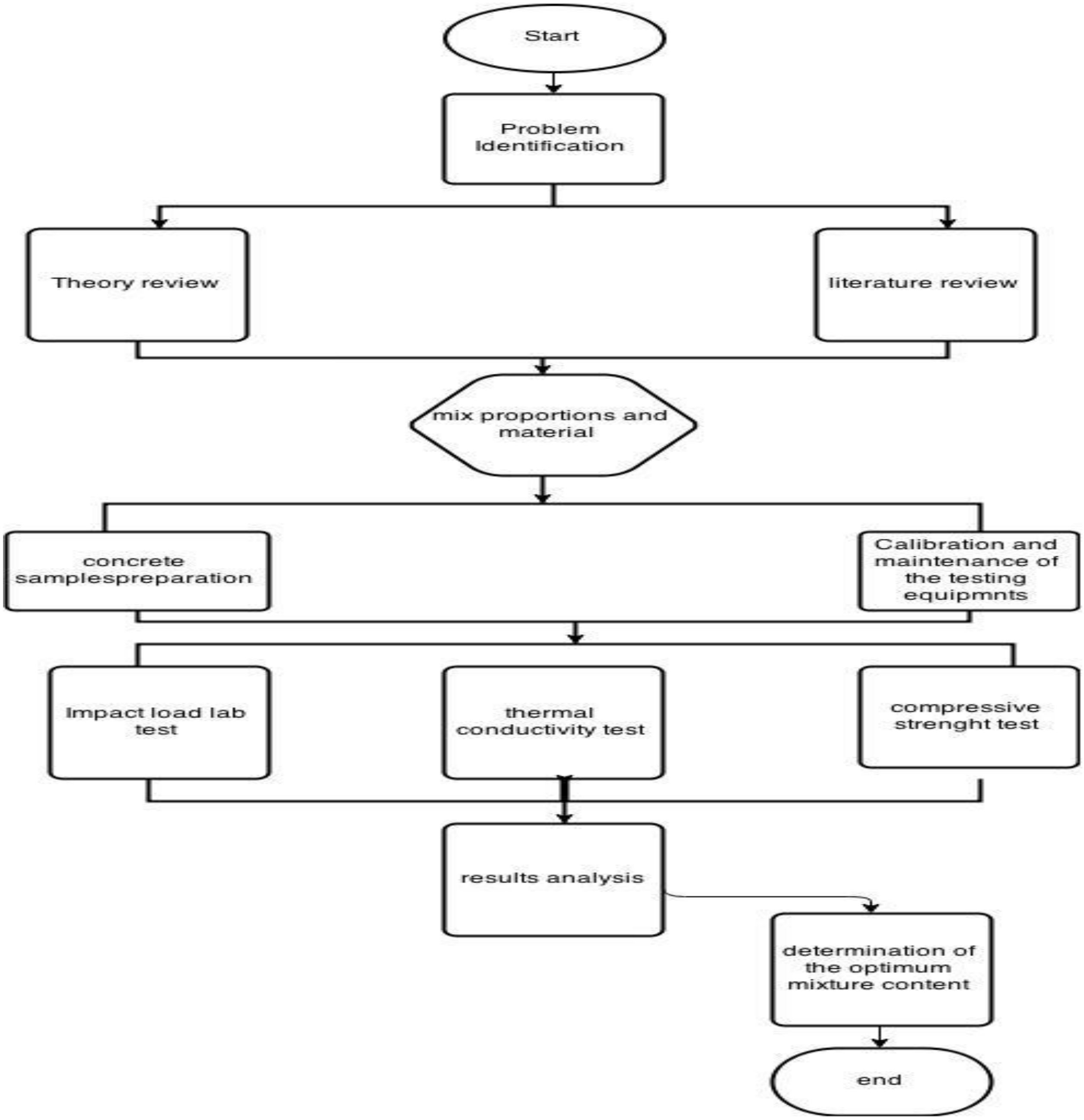


Figure 3: methodology

The figure above depicts the methodology to be used for this project. Basically the figure is composed of elements as described in the following sub-sections

3.2 Data Gathering

The data to be used in this project is composed by:

1. Physical properties of the concrete constituents namely: coarse aggregates, fine aggregates, crumb rubber, Nano silica and water.
2. Attempt proportions of the concrete mixtures
3. Results from the previous studies

3.3 Design of experiments

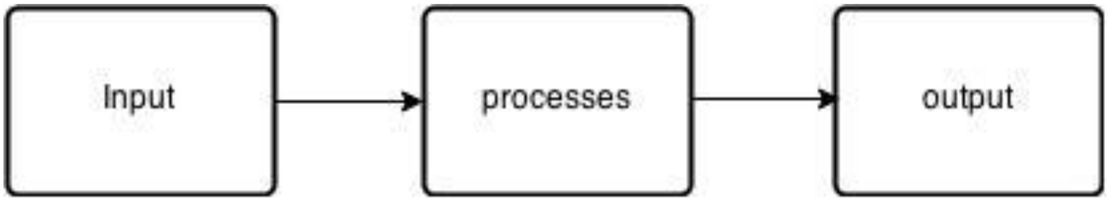


Figure 4: design of experiments

The experiments in this project are to follow the flow depicted in the above figure, the description is as follows:

3.3.1 Input Variables

The input variables on this project in line with the objectives of the project. Therefore, concrete mixture components and testing equipment constitute the input variables.

3.3.2 Settings

Settings refer to the weight of each variable to be used in the experiments. Therefore for this research the following are the settings:

1. Proportions of the concrete constituents.
2. Ambient and room temperature at which the experiments will take place
3. Size of the samples
4. Calibration of the equipment to be used

3.3.3 Output

The target end result of this project is to find the optimum mixture content to be used so as to maximize the absorption capabilities of the concrete median barriers. In addition, the degree at which the use of an energy absorber in concrete median barrier can reduce the severity of the crash outcomes on the vehicles will be outlined here.

2.2.4 Material used

Material properties

Table 1: chemical composition of the material used

wt.%	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O
Fly ash	62.00	18.89	4.90	5.98	1.99	2.41	1.14
Cement	21.40	4.59	2.99	62.85	1.70	0.98	1.68

Besides the crumb rubber, the materials used in the preparation of the samples were sand, coarse aggregate, fine aggregate, fly ash and water.

The Portland cement used was in accordance with ASTM Type 1, the fly ash (FA) and aggregates were provided in the UTP concrete lab.

Table 2: Physical properties of the materials used in sample preparation.

Properties	Fly ash	Cement	Properties	Coarse aggregate	Fine aggregate
Specific gravity	2.3	3.15	Specific gravity	2.67	2.65
Loss on ignition (%)	1.87	2.02	Absorption (%)	1.10	2.10

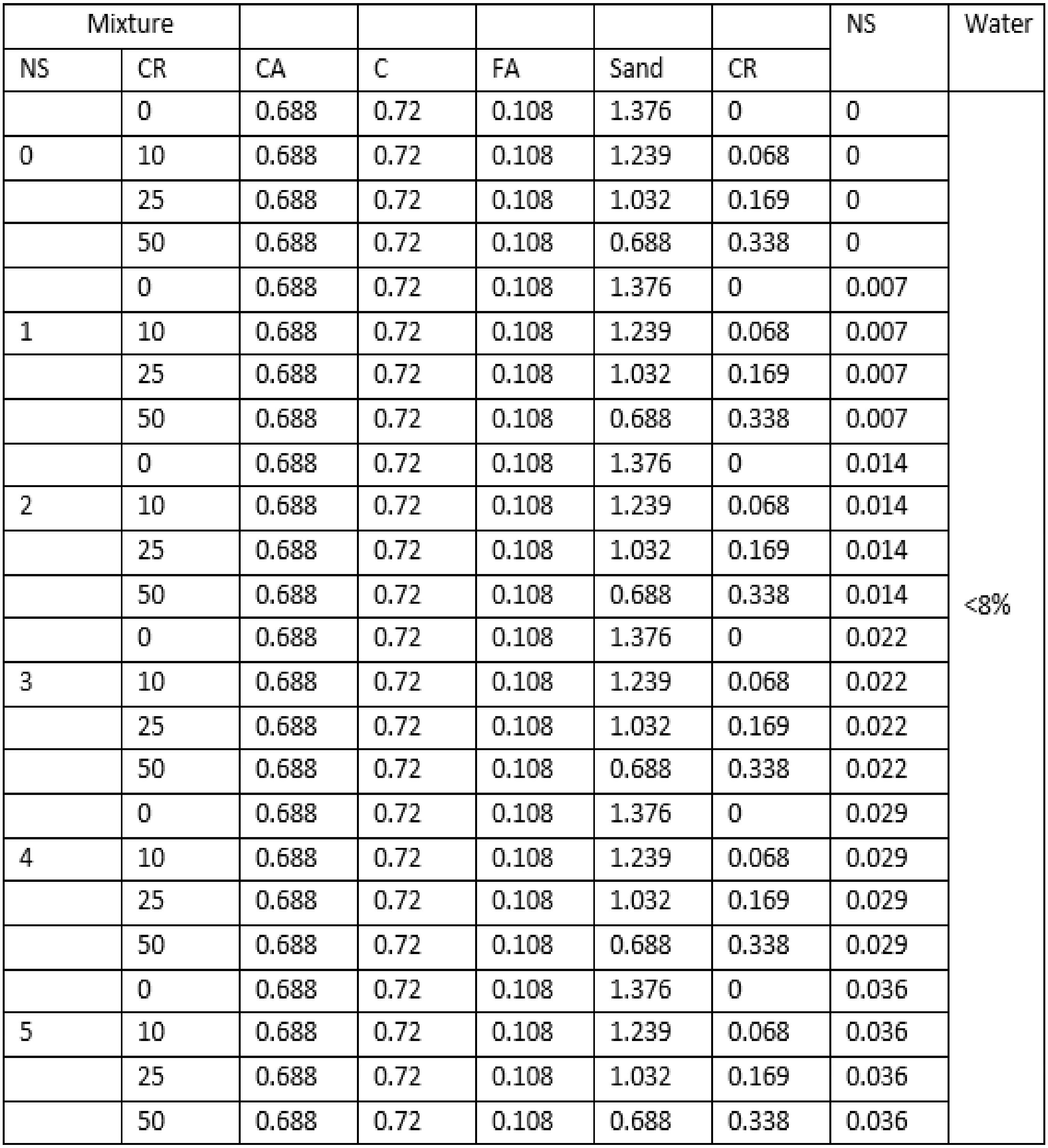
Mixing proportions and sample preparation

The mixing proportions are listed in the table below. Each mix contains 0.688kg of coarse aggregates, 0.72 of cement, and 0.108 of fly ash. The content of crumb rubber was 0%, 10%, 25% and 50% of the total volume of the mixture. As the amount of the crumb rubber was being increased, the amount of the sand in the mixture was being reduced. The first set of mixture had 0% NS. Then the subsequent mixtures had 1,2,3,4 and 5% of NS.

The mixture were designed to by dry, therefore, the water content of the mixture was fixed to 8% of the total volume of the concrete mixture.

The molder used was a 50mmx50mmx50mm. In order to account for human error during the mix, 3 samples were prepared for each mix so that the average value can be taken during the conduction of the tests. Furthermore, given the fact that one of the sources of human error in the concrete mixing for dry mixture is the consistence of the blows during the filling of the concrete molder with the concrete mixture, 15 blows for each sample was fixed.

Table 3: mixing proportions



Mixture							NS	Water
NS	CR	CA	C	FA	Sand	CR		
	0	0.688	0.72	0.108	1.376	0	0	<8%
0	10	0.688	0.72	0.108	1.239	0.068	0	
	25	0.688	0.72	0.108	1.032	0.169	0	
	50	0.688	0.72	0.108	0.688	0.338	0	
	0	0.688	0.72	0.108	1.376	0	0.007	
1	10	0.688	0.72	0.108	1.239	0.068	0.007	
	25	0.688	0.72	0.108	1.032	0.169	0.007	
	50	0.688	0.72	0.108	0.688	0.338	0.007	
	0	0.688	0.72	0.108	1.376	0	0.014	
2	10	0.688	0.72	0.108	1.239	0.068	0.014	
	25	0.688	0.72	0.108	1.032	0.169	0.014	
	50	0.688	0.72	0.108	0.688	0.338	0.014	
	0	0.688	0.72	0.108	1.376	0	0.022	
3	10	0.688	0.72	0.108	1.239	0.068	0.022	
	25	0.688	0.72	0.108	1.032	0.169	0.022	
	50	0.688	0.72	0.108	0.688	0.338	0.022	
	0	0.688	0.72	0.108	1.376	0	0.029	
4	10	0.688	0.72	0.108	1.239	0.068	0.029	
	25	0.688	0.72	0.108	1.032	0.169	0.029	
	50	0.688	0.72	0.108	0.688	0.338	0.029	
	0	0.688	0.72	0.108	1.376	0	0.036	
5	10	0.688	0.72	0.108	1.239	0.068	0.036	
	25	0.688	0.72	0.108	1.032	0.169	0.036	
	50	0.688	0.72	0.108	0.688	0.338	0.036	

4. Chapter 4: Results and Discussion

After cnducting the the tests on the 72 samples, the results that were found are summerized on this chapter.

4.1 Impact test results

The impact test was conducted on the impact testing machine Amsler RKP 450 in the UTP facilities. Results depict different effects of inclusion of Crumb Rubber and non-silica as described below.

4.1.1 Crumb Rubber

From figure 5, it is observed that when crumb rubber is used to increasingly replace fine aggregates in the concrete mixture there is high increase on the impact load absorption capabilities of the concrete. These finding are still in parallel with the findings from the previous researches and existing theories revised in this paper. The direct proportionality tendency between the amount of crumb rubber present in the concrete mixture and the impact load energy of the resulting concrete can be explain by considering two facts: First is the fact that there is an inverse proportionality between the elastic modulus of a material and the capacity of that material to absorb energy from an impact load. And the second fact is that a rubberized concrete has low modulus elasticity. Thus, it is clear that a rubberized concrete has a tendency of absorbing more energy from impact load than a normal concrete mixture.

Now if a closed attention is paid to the figure 6 and figure 7, it can be seen that rate of thermal conductivity decrease due to increment of the amount of crumb rubber in the concrete mixture is not constant. For instance, while the highest rate of decrement is observed when crumb rubber is increase from 0-10%, from 25% crumb rubber there is no significant further decrease of thermal conductivity. Therefore, the conjecture in here is consider 25% of crumb rubber as the optimum amount to be used in order to achieve optimum thermal conductivity

This pattern can be taken as a true conjecture if a carefully consideration of the fact at the beginning of the replacement of fine aggregates by crumb rubber the number of voids increases drastically but as the crumb rubber is kept increasing, there will be a saturation of the number of voids in the concrete and therefore there will be no further decrease of the thermal conductivity.

4.1.2 Nano Silica

No too much analysis need to be made to observe that the figure 7 is suggesting an decrease of the absorbed energy when the amount of NS present in the concrete increases. These finfings are due to he fact that there is an inverse proportionality between the amount of voids present in a concrete and the compressive strength of the concrete. Additionally, when Nano-silica (NS) is added, it fills the voids in the concrete including those on interface between aggregate and the cement paste. Consequently, the concrete becomes more compactly dense and homogenous. In addition to the void filling effect, NS pozzolanic reaction results in the consumption of $Ca(OH)_2$ and formation of C-S-H gel which is known by its high bounding capacity. As an outcome the modulus of elasticity increases and the absorbed energy from an impact load decreases.

However, unlike in crumb rubber, the continue increase of Nano-silica do not seem to reach an asymptotical point, that is, there is a non-stop decrease of the amount of absorbed impact energy when the amount of NS is increase. Therefore, an optimum amount of NS to be added in a concrete mixture in order to reach an optimum absorption capabilities will be decided in accordance with compression tests as it will be discussed later in this paper.

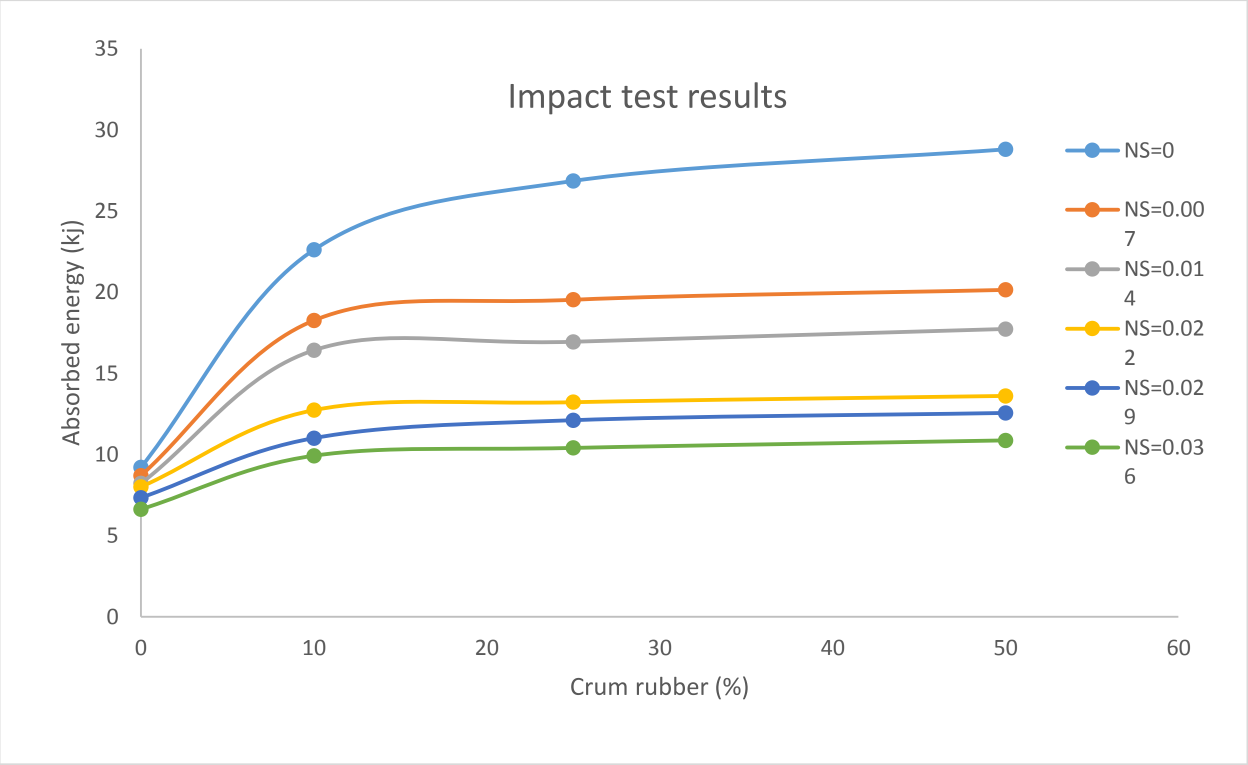


Figure 5: Impact tests results

CR (%)	Nano-Silica					
	0.036	0.029	0.022	0.014	0.007	0
0	6.632	7.346	8.01	8.221	8.71	9.217
10	9.932	11.017	12.74	16.431	18.267	22.617
25	10.412	12.12	13.2282	16.953	19.541	26.863
50	10.875	12.568	13.616	17.742	20.149	28.807

Table: Impact tests results

Table 4: Impact tests results

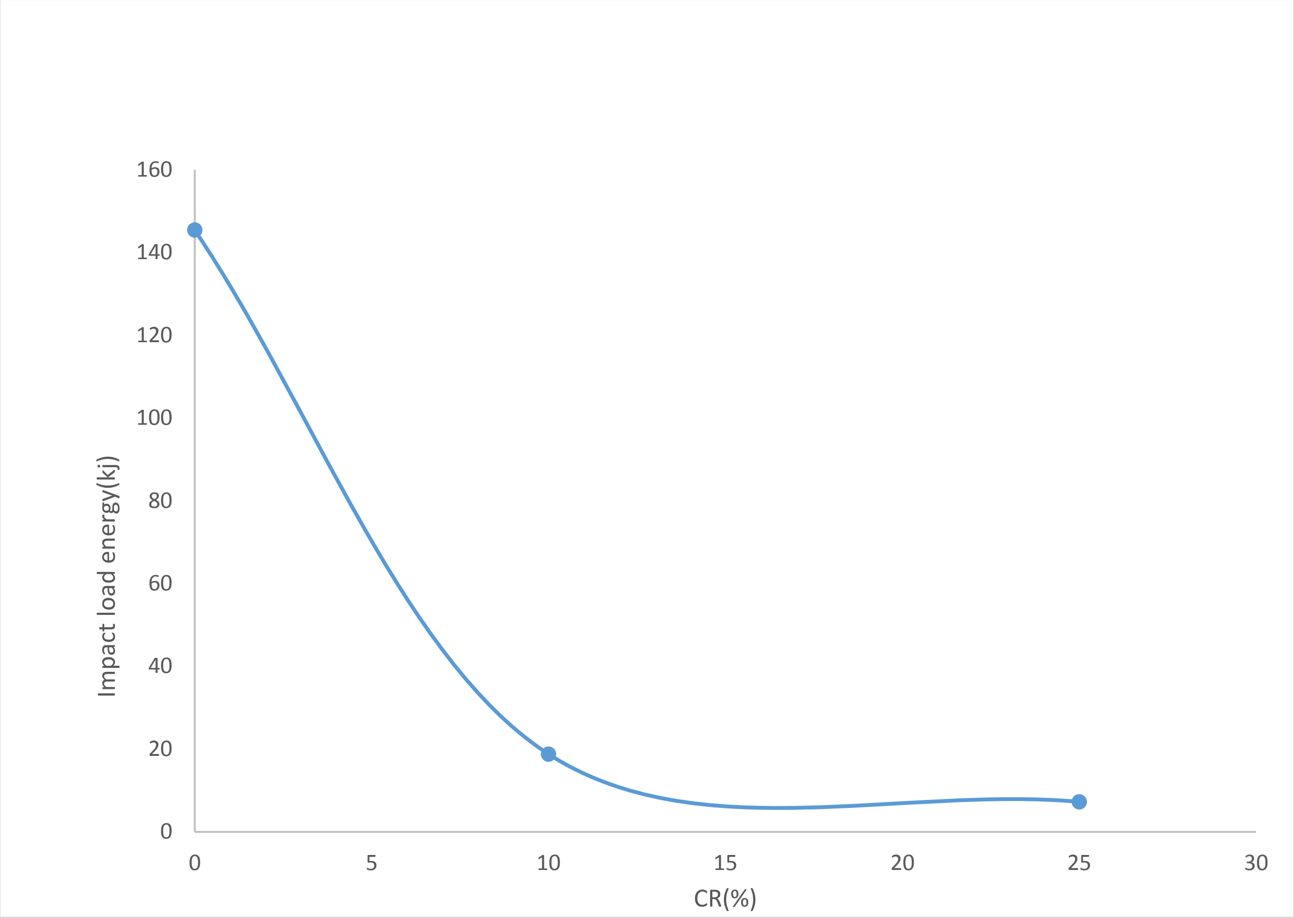


Figure 6: decrement of the absorbed energy as the CR is increase

Table 5: Impact tests results

CR(%)	NS	kj	Increment(kj)
0		9.217	
10	0	22.617	145.3835
25		26.863	18.77349
50		28.807	7.23672

0		8.71	
10	0.007	18.267	109.7245
25		19.541	6.974325
50		20.149	3.111407
0		8.221	
10	0.014	16.431	99.8662
25		16.953	3.176922
50		17.742	4.654044
0		8.01	
10	0.022	12.74	59.05119
25		13.2282	3.832025
50		13.616	2.931616
0		7.346	
10	0.029	11.017	49.97277
25		12.12	10.0118
50		12.568	3.69637
0		6.632	
10	0.036	9.932	49.75875
25		10.412	4.832863
50		10.875	4.446792

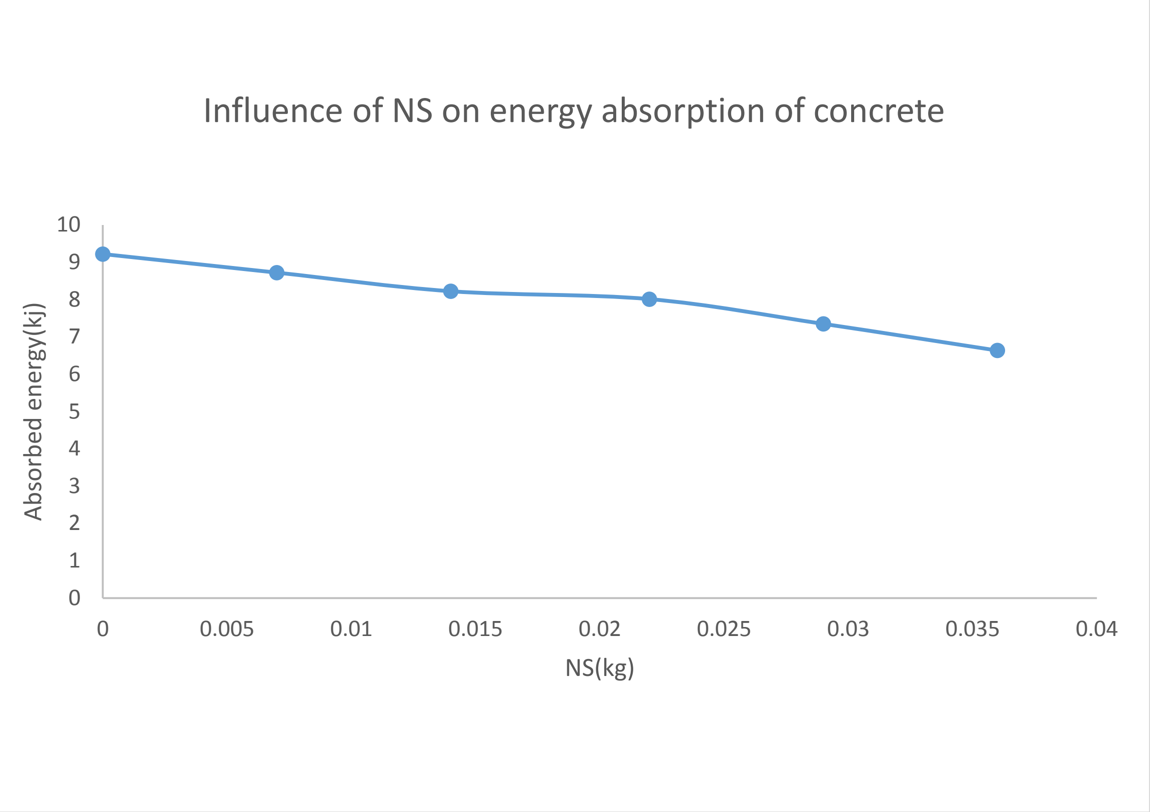


Figure 7: Influence of NS on energy absorption of concrete

4.2 Thermal Conductivity Results

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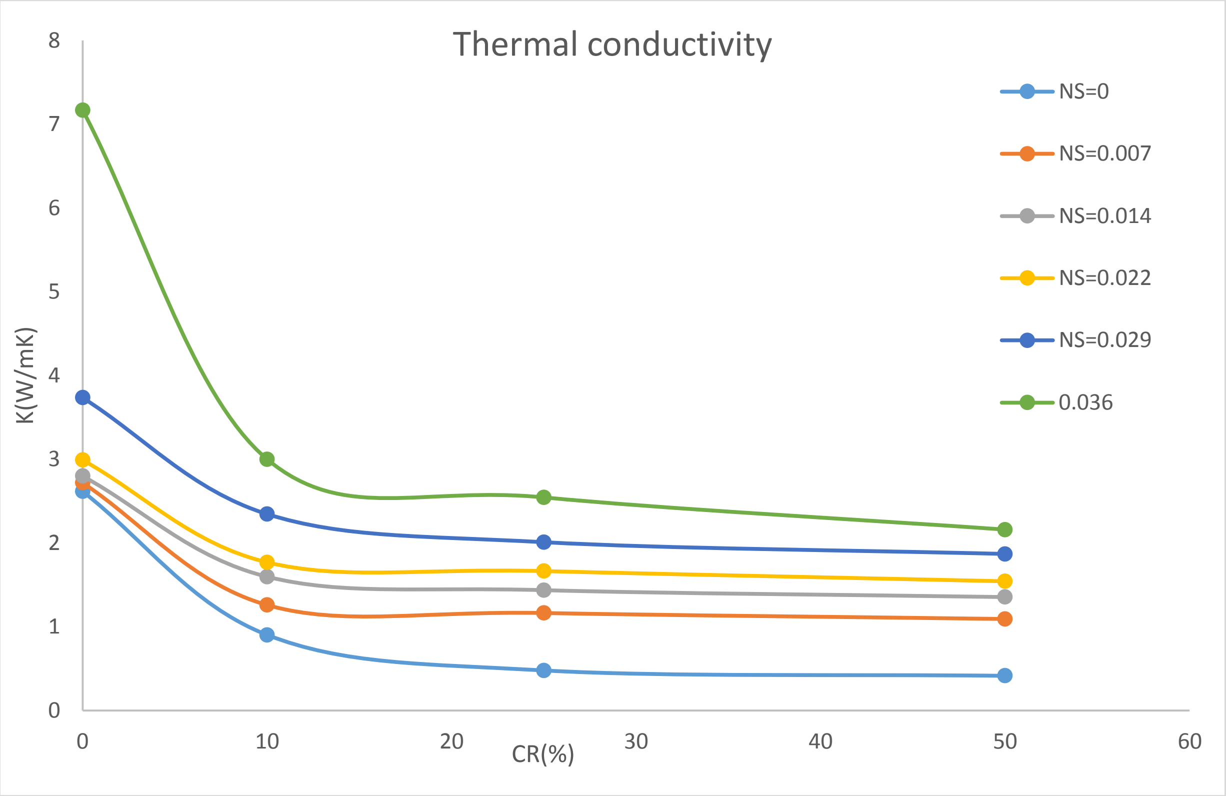

Figure 8: thermal conductivity results

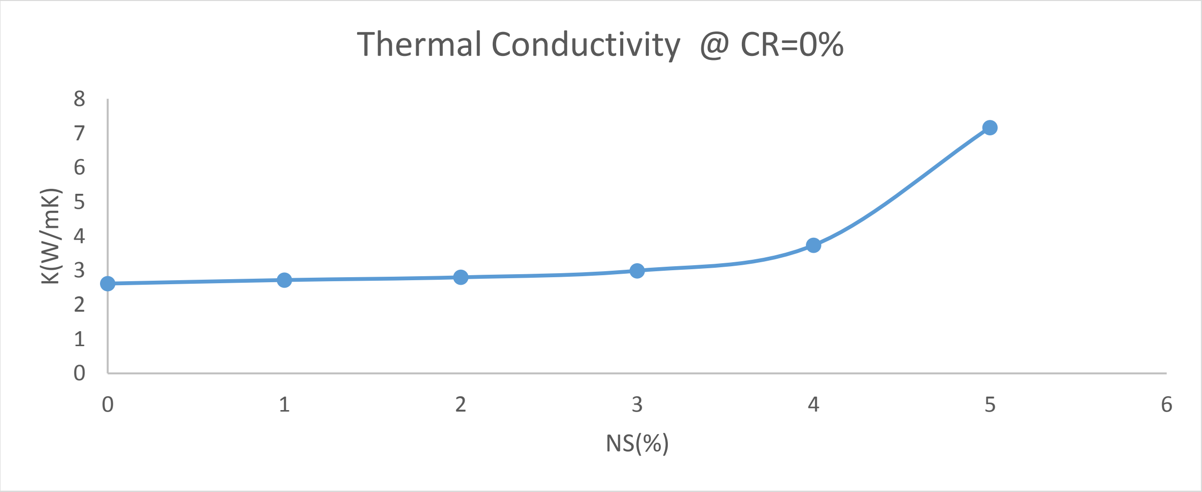

Figure 9: Thermal Conductivity @ CR=0%

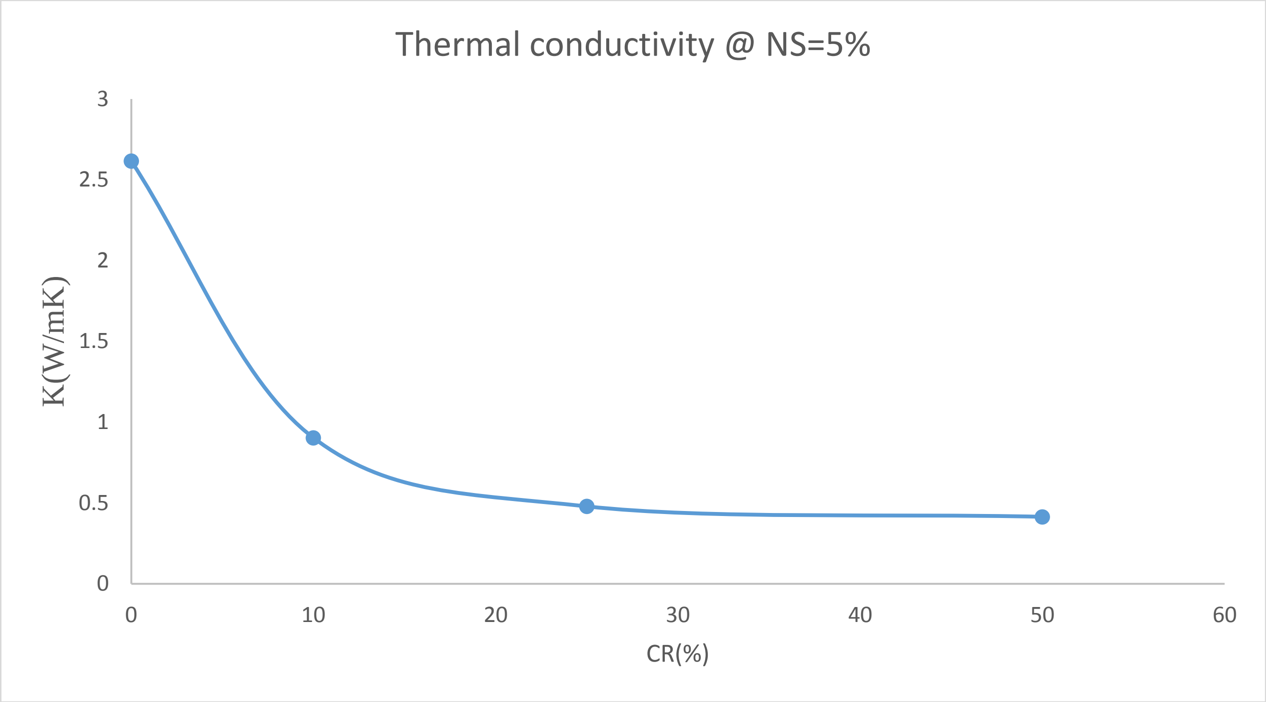

Figure 10: CR vs Thermal conductivity @ NS=5%

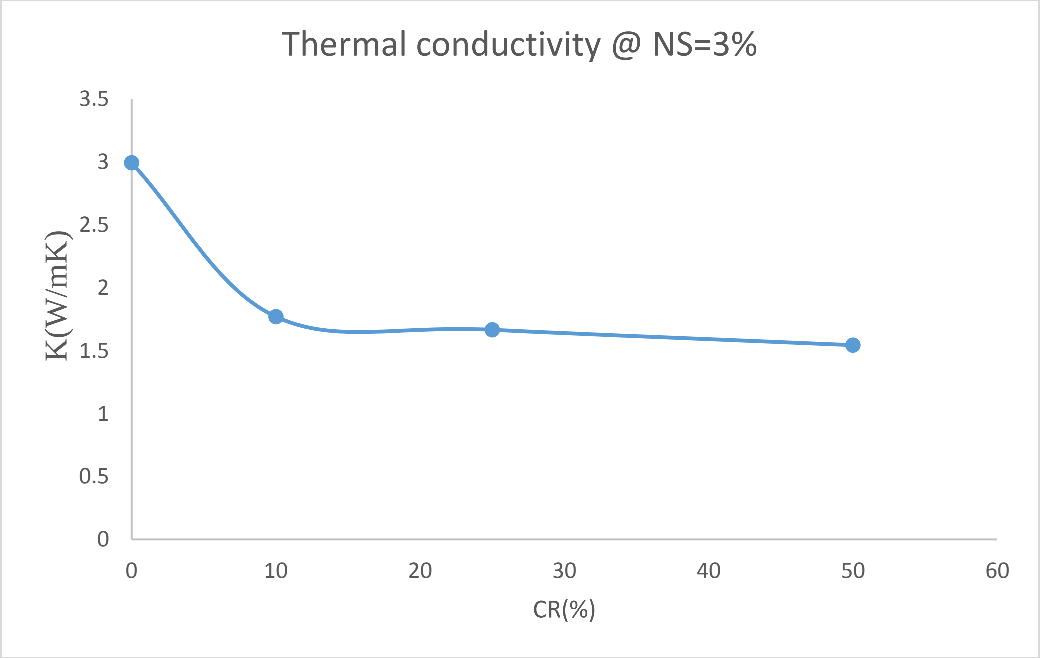

Figure 11: CR vs Thermal conductivity @ NS=3%

Table 6: thermal conductivity tests results

CR (%)	NS(kg)	k (W/mK)
0		2.6168
10	0	0.903386
25		0.478886
50		0.414559
0		2.71965
10	0.007	1.25989
25		1.16435
50		1.09307
0		2.79949
10	0.014	1.59792
25		1.43714
50		1.35467
0		2.99129
10	0.022	1.76977
25		1.66509
50		1.54346
0		3.73507
10	0.029	2.34577
25		2.01011
50		1.86969
0		7.16994
10	0.036	3.000825
25		2.54513
50		2.16068

Table 7: thermal conductivity tests results

	NS(kg)					
CR (%)	0.036	0.029	0.022	0.014	0.007	0
0	7.16994	3.73507	2.99129	2.79949	2.71965	2.6168
10	3.000825	2.34577	1.76977	1.59792	1.25989	0.903386
25	2.54513	2.01011	1.66509	1.43714	1.16435	0.478886
50	2.16068	1.86969	1.54346	1.35467	1.09307	0.414559

4.2.1 Crumb Rubber

Seventy two samples we used to conduct the thermal conductivity test using the TCI equipment. From figure 8, it is observed that when crumb rubber is used to increasingly replace fine aggregates in the concrete mixture there is high decrease on the thermal conductivity of the concrete. These finding are still in parallel with the findings from the previous researches and existing theories revised in this paper. The inverse proportionality tendency between the amount of crumb rubber present in the concrete mixture and the thermal conductivity of the resulting concrete can be explain by looking on the fact that crumb rubber particles have lower thermal conductivity than rock aggregates and sand. Therefore, when they are used to partially replace fine aggregates present in a concrete mixture, the will lower the thermal conductivity and diffusivity of the resulting concrete. The fact that when crumb rubber is used to replace fine aggregates increases the amount of entrapped air due to increased number of voids and the air have a relatively low thermal conductivity, this air present in the concrete will lower the thermal conductivity of the concrete provided that there is no heat transfer by induction.

Now if a closed attention is paid to the figure 8 and figure 9, it can be seen that rate of thermal conductivity decrease due to increment of the amount of crumb rubber in the concrete mixture is not constant. For instance, while the highest rate of decrement is observed when crumb rubber is increase from 0-10%, from 25% crumb rubber there is no significant further decrease of thermal conductivity. Therefore, the conjecture in here is consider 25% of crumb rubber as the optimum amount to be used in order to achieve optimum thermal conductivity.

This pattern can be taken as a true conjecture if a carefully consideration of the fact at the beginning of the replacement of fine aggregates by crumb rubber the number of voids increases drastically but as the crumb rubber is kept increasing, there will be a saturation of the number of voids in the concrete and therefore there will be no further decrease of the thermal conductivity

4.2.2 Nano-silica

From the figure 9, it can be induced that when Nano-silica is increased, there is an increase of the thermal conductivity of the concrete. This can be explained by observing that when Nano-silica is added, it fills the voids in the concrete including those on interface between aggregate and the cement paste. Consequently, the concrete becomes more compactly dense and homogenous. The void filling effect coupled with formation of C-S-H gel in the NS pozzolanic reaction results in an increase of packing density of the microstructure of the paste. Therefore, there is a noticeable decrease of the number of voids in the concrete. Therefore, the entrapped air is reduced and consequently the thermal conductivity of the resulting concrete will increase.

4.3 Compression test results

The general results of the compression tests conducted by *(Wong.S, 2012)* are depicted in the table 8 and figure 9.

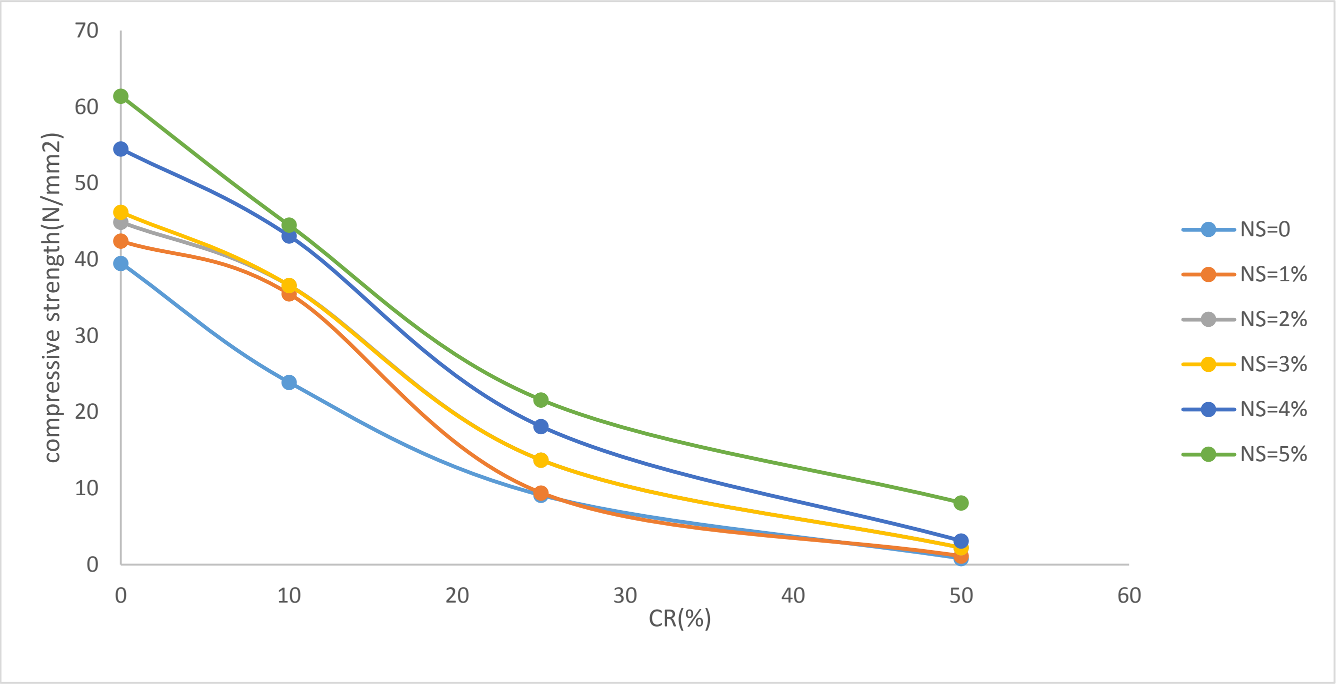

Figure 12:compressive strength test results

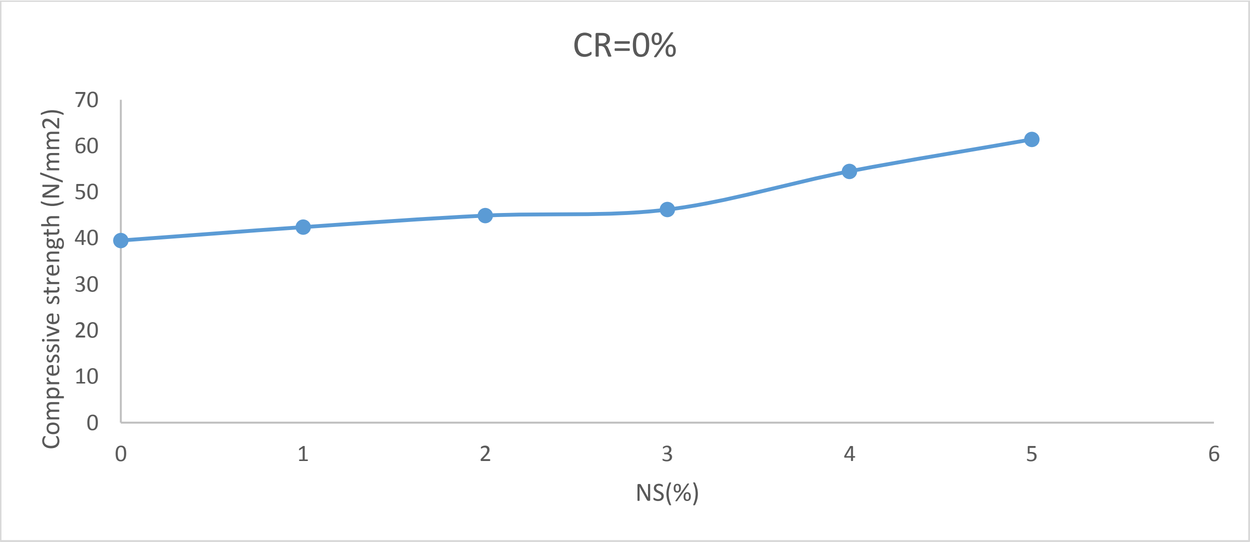

Figure 13:compressive strength test results at CR=0%

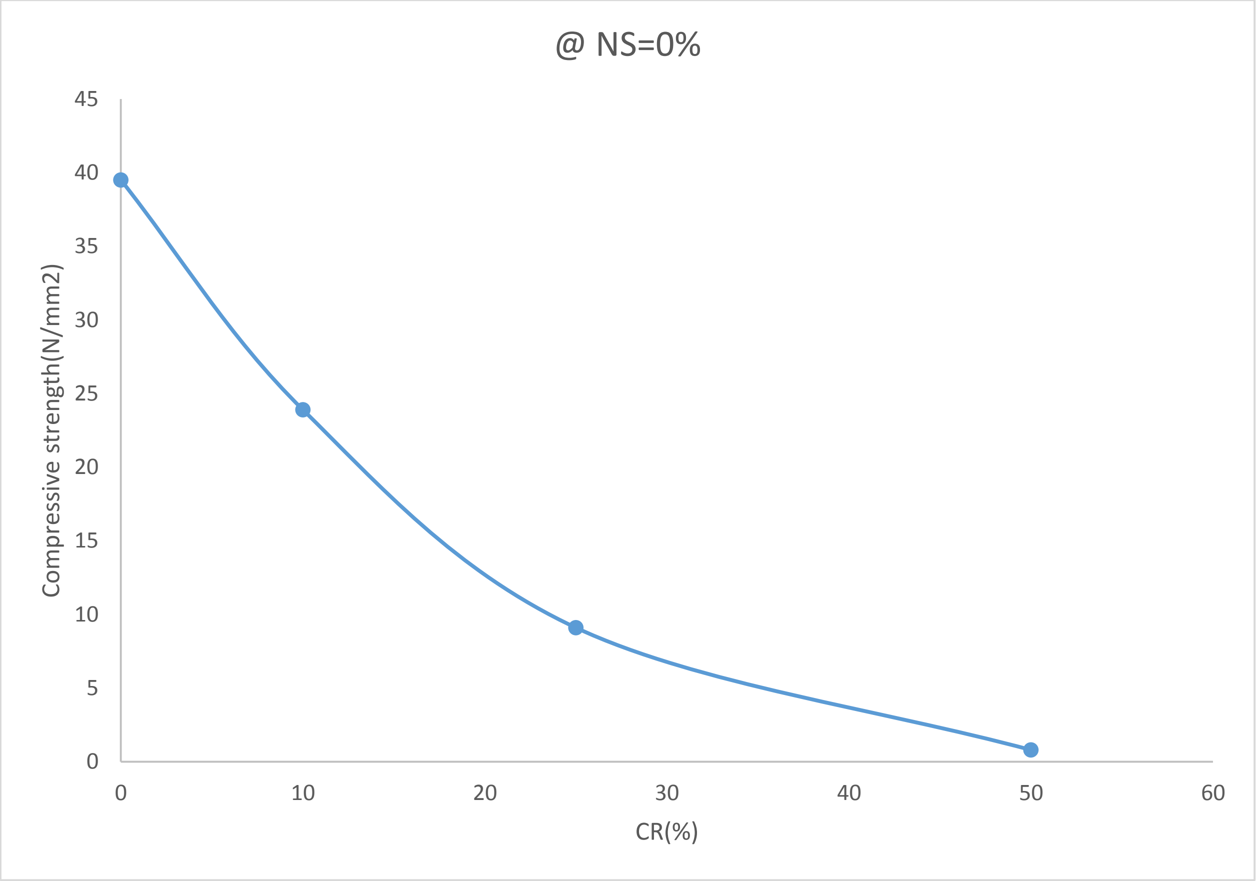

Figure 14:compressive strength test results at NS=0%

Table 8: compressive strength results

CR(%)	NS(%)					
	0	1	2	3	4	5
0	39.5	42.4	44.9	46.2	54.5	61.4
10	23.9	35.5	36.6	36.6	43.1	44.5
25	9.1	9.4	13.7	13.7	18.1	21.6
50	0.8	1.1	2.2	2.2	3.1	8.1

Table 9: compressive strength results

CR (%)	NS (%)	Compression(N/mm)	Decrement (%)
0		39.5	
10	0	23.9	39.49367089
25		9.1	61.92468619
50		0.8	91.20879121
0		42.4	
10	1	35.5	16.27358491
25		9.4	73.52112676
50		1.1	88.29787234
0		44.9	
10	2	36.6	18.48552339
25		13.7	62.56830601
50		2.2	83.94160584
0		46.2	
10	3	36.6	20.77922078
25		13.7	62.56830601
50		2.2	83.94160584
0		54.5	
10	4	43.1	20.91743119
25		18.1	58.00464037
50		3.1	82.87292818
0		61.4	
10	5	44.5	27.52442997
25		21.6	51.46067416
50		8.1	62.5

4.3.1 Crumb Rubber

From the graphs on the figure 12, it can be seen that as we replace fine aggregates by crumb rubber, there is a significant depletion of the compressive strength of the resulting concrete. This result can be explained by the fact that when crumb rubber is used to increasingly replace fine aggregates in a concrete mixture, it becomes relevant to take note on the fact that crumb rubber is known by its high Poisson ratio, low elasticity, high porosity as well as weak bounding capacity. Therefore, weak bounding between crumb rubber particles and cement paste is expected. Furthermore, the resulting concrete will have a high susceptibility to cracking. Thus, the concrete will have relatively low compressive strength compared to the one of a normal concrete.

4.3.2 Nano-silica

A zoom in on the figure 12 gives an insight of how NS quantitatively qualitatively affects concrete compressive strength. At first glance it can be spotted that as the amount of NS in the concrete mixture is increase, the compressive strength of the concrete also increases. These finds do not contradict with the findings outlined from the previous researches. This is due to the fact that there is an inverse proportionality between the amount of voids present in a concrete and the compressive strength of the concrete. Additionally, when Nano-silica (NS) is added, it fills the voids in the concrete including those on interface between aggregate and the cement paste.

Consequently, the concrete becomes more compactly dense and homogenous. In addition to the void filling effect, NS pozzolanic reaction results in the consumption of $Ca(OH)_2$ and formation of C-S-H gel which is known by its high bounding capacity. As an outcome, the compressive strength of the concrete increases.

However the rate of increase is not equally distributed, for along the graph it can be seen that there is a slow increase of the compressive strength when the addition of the NS is below 3%. But as we keep increasing the amount of NS present in the concrete mixture, the compressive strength drastically increases. This phenomenon can be explained by the fact that at NS>3% the whole concrete mixture experience a drastic heat of hydration and reduction of pores of the concrete.

Therefore, an optimum NS for optimum compressive strength must be greater than 3%.

Chapter 5: Conclusions and Recommendations

The experiments conducted on this project highlight the intricacy of crumb rubber in improving the performance of safety concrete median barrier by increasing its impact load energy absorption capabilities. Furthermore, due to the fact that crumb rubber comes from wasted tires that might present a big threat to the environment if not carefully recycled, the technology of rubberized concrete comes as a solution to this problem since it uses crumb rubber as a fine aggregate replacer.

From experimental results, the following can be conjectured:

1. The optimum rubber content to be used in concrete mixture in order to maximize it impact energy absorption is 25%. If crumb rubber is increased to more than 25%, there is no significant change in the impact energy absorption capability of the resulting concrete.
2. The optimum amount of Nano-silica to be introduced in a concrete mixture, is determined accounting its thermal conductivity requirements. Therefore, from the experimental results of this research, there is a suggestion that NS must be in lower than 3%. This is because for lower an amount of NS greater than 3%, the thermal conductivity starts to increase drastically.
3. There is direct proportionality between the amount of the crumb rubber present in a concrete mixture and the impact load energy absorbed by the resulting concrete.
4. As the amount of crumb rubber in a concrete mixture is increased, the amount of voids increases and therefore, the compressive strength of the concrete reduces.
5. For future studies, a wet mixture concrete is advised in order to reduce the error that comes from the lack of consistency in filling in the concrete molder.

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