Comparison of Enhanced Flexural Strength of Concrete Slabs through Various Techniques

Project Advisor:

Maj. Dr. Rizwan

Submitted By:

Wahaj Farooq

ACKNOWLEDGEMENT

First, I want to thank Allah Almighty Who gave me the opportunity and ability to complete my master degree. I also want to thank my Parents and family, without their prayers it would not have been possible and they were always there to support me through the hardships that I have been facing in my way.

I am really grateful to my thesis supervisor; Dr. Major Muhammad Rizwan for his continues support and guidance for paving my way to complete my thesis work. He was always there taking out his precious time for my guidance. I also want to sincerely thank Mr. Najam-ul-Hassan, Director of Ultra Chemicals (Pvt), and Mr. Tariq Ali, lab incharge, Ultra Chemicals (Pvt) for all their guidance. And Mr. Zafir Riaz, Lab Engineer, Structures lab for his support.

This research work is dedicated to

OUR FAMILIES AND INSTRUCTORS

who gave us encouragement and moral support along our journey

Table of Contents

Abstract

Masonry and reinforced concrete structures in active seismic zones are highly prone to dynamic forces. These forces cause serious damage to the structures. In the past, a lot of research has been done on various techniques (like confinement) to enhance the strength and serviceability of the structures in active seismic zones. Concrete shows brittle behavior, which is not admissible in structures. Potential use of concrete in structure demands it to be ductile, in contrast to its brittle behavior. New methods and materials had been also introduced to increase the ductility and strength of concrete structures. Poly-urea has been used since a long time in mining and tunneling sector. After successful application of poly-urea in mining sector, now it is being used in structures to increase the strength and ductility. It is applied with the help of special plural-component spray. It also requires highly skilled labor and other resources. Here it arises the need of another material, which can deliver same performance and also has easy application. This experimental and analytical research, aims at comparing the effect of two different TSL's on two-way concrete-slabs. Results of poly-urea coated slabs from a recent research are compared here with the new TSL, Tough Coat 150. It is applied with the simple brush technique just like ordinary paint, rather than spray technique. TSL is applied by varying the thickness on the tension surface of the slab. The slabs are of uniform dimensions, but varying in strength and varying with respect to absence/presence of reinforcement. The slab's response, in terms of strength and ductility is examined. A test assembly is configured to apply uniformly distributed load on slabs until failure in flexure. Load-displacement graphs obtained from the tests are processed to arrive at predetermined parameters of peak-load, yield-load, ductility, yield secant stiffness and energy-dissipation.The comparison shows an increase in strength in terms of peak-load, greater energy dissipation capacity and high yielding point for the slabs coated with Tough-Coat 150.

Chapter 1

Introduction

1.1 General

Concrete is the most preferred material in the construction industry due to its capability to attain any shape or size. Many other properties of concrete, like its strength and hardness, makes it suitable for structural applications. Concrete shows brittle behavior, which is not admissible in structures. Potential use of concrete in structure demands it to be ductile, in contrast to its brittle behavior.

Steel reinforcement is extensively used to overcome the brittle nature of concrete. Concrete is good in compression, whereas steel in tension. These both materials are used together in Reinforced Cement Concrete(RCC) in composite form.(oladapo, 1964). Moreover, RCC construction entails several logistic limitations such as procurement, transportation, cutting, storing and laying out of steel which are both time-consuming and resource-intensive processes.

Now-a-days synthetic polymer-based compounds and epoxies are getting famous in tunneling and mining sectors, where they are being used as roof-supporting system. They can be applied with ease, shows elastic behavior, and develops a bonding-layer over loose rock surface. (H. Yılmaz, 2003). TSL's not only with-stand under static loading, they have also proved as efficient supporting-system under the dynamic loading conditions.

Currently, variety of TSL's are available in market, varying upon usage, application methods, tensile strength and adhesion. Poly-urea based coatings are being used on a large scale in the tunneling industry. Recent research carried out on the application of poly-urea on concrete slabs concluded that the strength of slabs has been increased in terms of both yield and ultimate loads.

Polyurea is a type of TSL that is currently being used as both hydro-isolation (Szafran & Matusiak, 2017) and fire-resistant (Arunkumar et. al. 2015) material with high durability and very good chemical resistance (VersaFlex Polyurea FSS 45DC Datasheet). It is also flexible with high tensile strength (VersaFlex Polyurea FSS 45DC Datasheet), which are the characteristics usually associated with structural steel.

1.2 Problem statement

Potential use of concrete in structure demands it to be ductile, in contrast to its brittle behavior. Eventually, reinforcement is used in structural concrete members to make them ductile. Thin Spray-on Liner (TSL) is a forefront material, which can be applied with ease. It is being tremendously used in under-ground support system to increase strength and ductility of rocks. But the current understanding of TSL’s effect on structural members is very less. The intended purpose of this study is to analyze the effects of two different TSL’s on strength and ductility of structural slabs.

1.3 Research Hypothesis

It is evident from past research that poly-urea sufficiently enhances the both flexural strength and ductility of concrete-slabs. But the application of poly-urea requires controlled conditions of high temp and pressure along with special compressed-air propeller spray with highly skilled man-power. So, we reach at a hypothesis;

“Selection of an efficient and economic TSL based on method of application, which will be easy to apply and give optimum results in term of flexural strength and ductility”

Chapter 2
Literature review

2.1 Terminology

In 1993 the term “super-skin” was introduced in the mining industry to explain sprayable material that will set hard and remain stable with a high yield and high performance (Reynolds and Leach, 2002).

The term “Thin Spray-on Liner (TSL)” was proposed to explain a thin layer of surface-support made from polymer, plastic or cement-based compositions. It was first officially defined in Australia at the Perth Workshop that was held during the 1st International Seminar on “Mine Surface Support Liners: Membrane, Shotcrete and Mesh” in August 2001.

The agreed layer thickness for TSL is upto 5mm, which may vary from 2mm to 10mm in field application depending upon requirement(Yilmaz et al. 2003). Mostly TSL’s are in viscous-liquid state, so they are sprayed on the surface using high-pressure air pumps. The “Liner” refers to a protective covering/layer that protects the inside surface. As the TSL is applied on the inside surface of mines & tunnels, so the term liner is used in this context.

Inspite of the fact that shotcrete is also the sprayed-liner, but it does not fulfill the thickness criteria. Shotcrete layer thickness usually ranges from 25mm to 150mm. (Stacey, 2001).

2.2 History & Background

Initially TSL’s were used as sealants in underground excavations to minimize the weathering of rocks. (Spearing *et al*, 2009). But later on Thin Spray-on Liners were introduced in the mining and tunneling industry as a new support-concept about three decades ago. It gained huge attention in very less time due to its notable operational advantages. TSL’s are easy to apply, longer shelf-life and fast curing time. It was introduced as an alternative to rock-bolt, mesh and shotcrete. Because mesh is expensive. And on the other hand, shotcrete requires too much logistics and its also time-consuming. The first tests on TSL were conducted in Canada in mid-1980’s. (Archiblad et al. 1992)

A survey carried out by Tannant in 2001, there were about 55 mines in North America, Australia and South Africa where TSL was being used as surface-support. And this number is increased by now around the world.

2.3 Application of TSL in mining and tunnels

Working in mines and tunnels has always involved the risk of injuries and fatalities due to rock-falls. A case study carried out in 26 under-ground metal mines in Australia has shown that 90% of the injuries have been caused by rock-fall in few meter radius of active faces (Potvin et al 2002). 65% of the fatalities are linked to the rockfall incidents in South African gold mines (Erasmus 2000). The industry demands that the workplace should be free from the risk of any fatal injury. A lot of research and work is being done in order to deal with these risks. Different support systems have been devised to mitigate the risks involved in underground workplaces. It includes installation of steel mesh and shotcrete. Current support systems would probably reduce the risks of rockfall injuries, but it negatively affects the cost and mining operations. Steel mesh increases the operational costs and shotcrete involves several logistics problems.

The thin spray-on liner(TSL) has been introduced to address these issues. It is an alternative to the traditional support-systems like rock-bolts, steel mesh and shotcrete. TSL restricts the movement of un-raveled and loosened rock fragments, thus maintaining the essential integrity of the rock-mass under gravity loads and general loading conditions. It keeps the small key blocks intact and prevents the fallouts of small rock pieces due to gravity pull. As the TSL is less viscous as compare to the shotcrete, it fills up the gaps and penetrates into the fracture-lines. Hence, bonds the rock-mass together and prevents the inter-block movement effectively. (Ferreira et al. 2011)

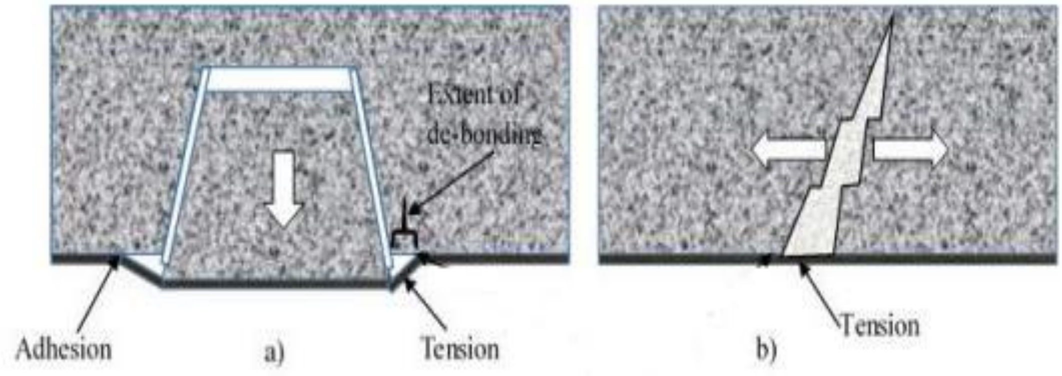


Figure 1: TSL supporting loose mine blocks

When tested with thin coatings of TSL, it was found that tensile strength of rock improved by up to 30% while that of shotcrete by more than 40%. Furthermore, the application added ductility and flexibility to the rock and shotcrete and increased the energy absorption capacity associated with failure. (Mpunzi, Masethe, Rizwan, & Stacey, 2015)

Just after the blasting is done in under-ground mines, it is considered necessary to apply a thin layer of shotcrete to reduce the adverse effects caused by the stresses, induced due to blast. But sometimes it is difficult to apply shotcrete on the surface near the advancing face due to the logistic constraints. As shotcrete requires mixers and large spraying pumps. Smaller quantities of material are brought underground as compare to the other ground-support systems. In order to cover an area of 45m^2 with 25mm of shotcrete, it requires approx. 158 x 25kg bags which is equal to ±4tonnes of weight. In case of a typical TSL having 5mm layer thickness, it only needs 23 x 25kg bags of material, which weighs only a half-ton. (ferriera and pirrodi 2011)

In deep excavation scenario, TSL can be easily applied at the active faces with the help of robotic-arm spray systems. Unlike conventional support-systems, TSL is much easy to apply and logistics is reduced to a smaller extent. TSL is the rapid spraying technique which has the ability to increase the productivity and lessen the operational costs along with minimal inference with the mining operations. TSL's can be regarded as revolutionary surface support-system in the mining industry by improving the productivity, profit margins and safety of work places.

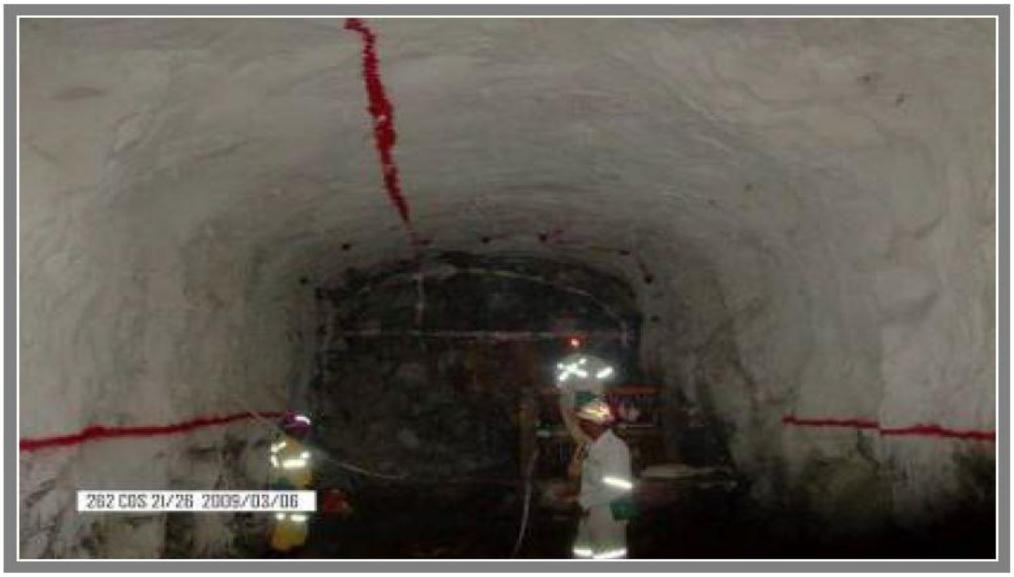


Figure 2: Application of poly-urea in mine

2.4 Application of TSL in Structures

Concrete is the most favorable material in the construction industry. Potential use of concrete in structure demands it to be ductile, in contrast to its brittle behavior. Eventually, reinforcement is used in structural concrete members to make them ductile. Concrete is good in compression, whereas steel in tension. These both materials are used together in Reinforced Cement Concrete(RCC) in composite form.(oladapo, 1964). Moreover, RCC construction entails several logistic limitations such as procurement, transportation, cutting, storing and laying out of steel which are both time-consuming and resource-intensive processes.

Moreover, a structural member came across various changes during its life-span e.g. change in usage, creep, corrosion of steel and exceeding service loads. Many techniques have been introduced to enhance the serviceability of structural-members. These techniques are used for repair and retrofitting of the existing structural members in order to increase the strength of RC-members. Steel plates and carbon-fiber reinforced polymers (CFRP) are one of the existing techniques.

After the successful application of TSL in mining and tunnel industry, now it has been introduced to the structural-members. Poly-urea coating on the structural members is one of the emerging technique in the field of civil engineering to increase the strength and ductility of reinforced concrete members. It involves spraying of a thin layer of poly-urea (TSL) on the outer-surface of structural member. Unlike the traditional strengthening methods, it minimizes the repair-time and effort.

An experimental research was done by a.e marawan et. al. (2015) on shear and flexure behavior of reinforced-concrete beams strengthened with polyurea. **Marawan** compared the shear and flexural strength of beam by varying the thickness of polyurea coating. The ultimate load capacity was increased by 19.4% in flexure and upto 42.5% in shear. It is evident from the test results that the load carrying capacity is directly proportional to the polyurea coating thickness.

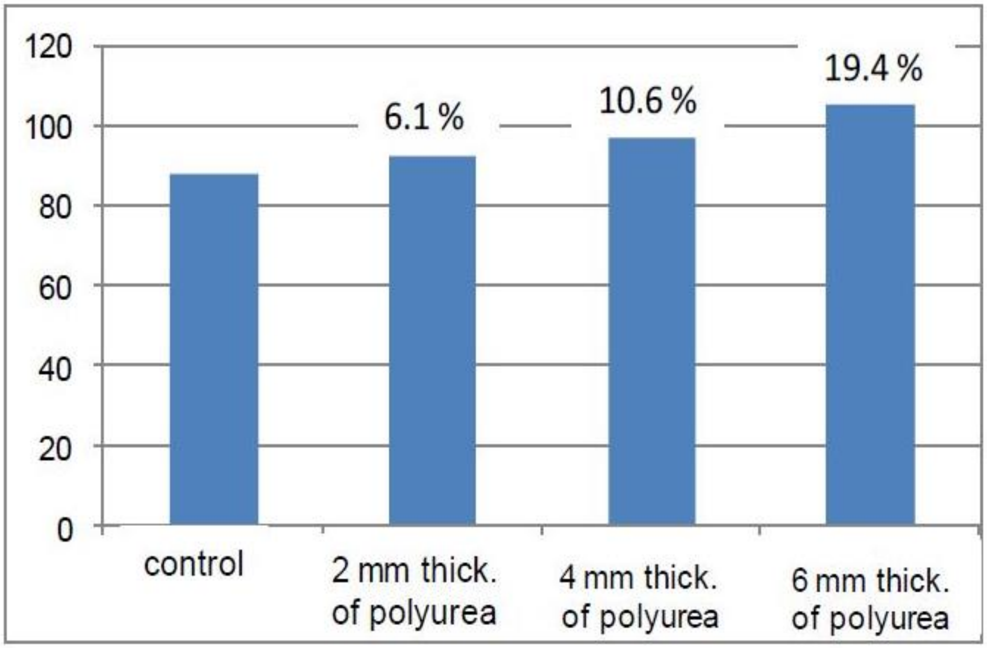


Figure 3: Ultimate Load comparison of Flexure Beams (Marwan et. al. 2015)

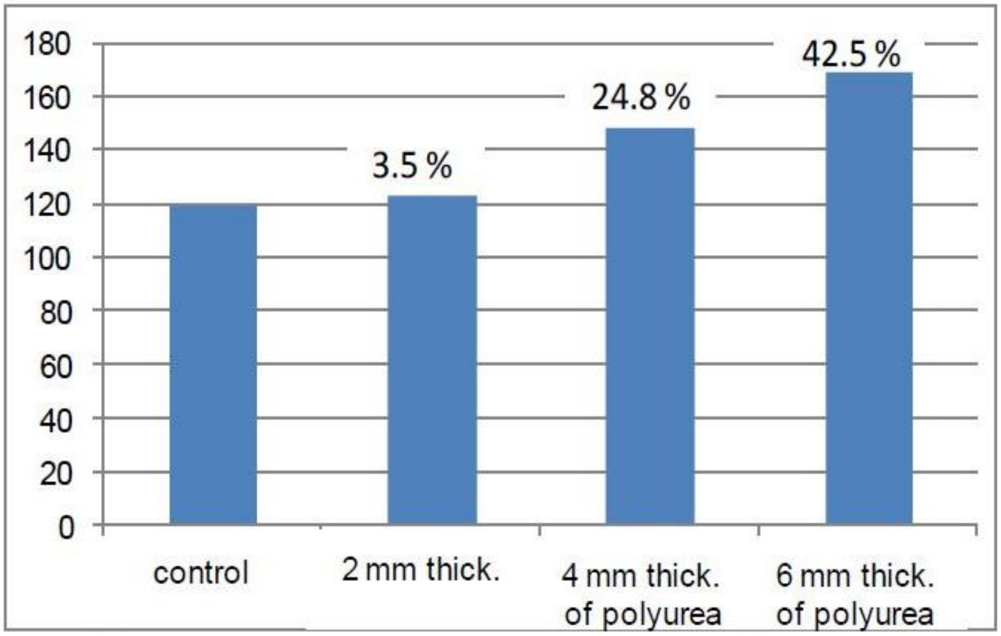


Figure 4: Ultimate Load comparison of Shear Beams (Marwan et. al. 2015)

Polyurea not only enhanced the ultimate load capacity, but it also contributed towards ductility of beam. Beams coated with polyurea showed increased ductility and more deflection before failure.

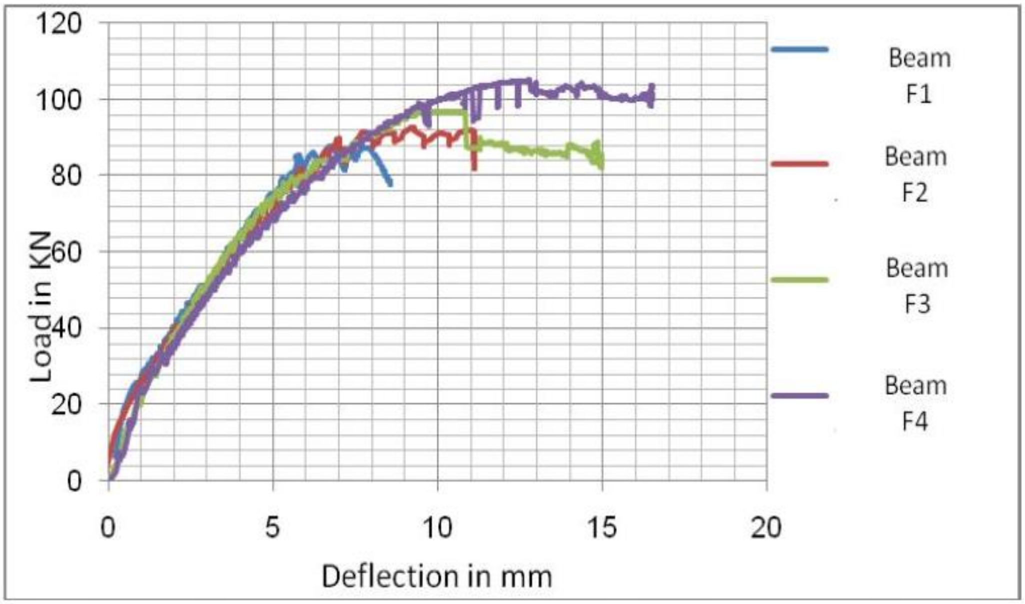


Figure 5: Load-Deflection Comparison of beam (Marwan et. al. 2015)

Polyurea coating also act as confinement material for concrete. It conceals the spalling of concrete at failure.

Figure 6: Confinement of spalling (Marwan et. al. 2015)

Exposing the concrete to fire or high-temperature, decreases the compressive strength, flexure strength and modulus of elasticity. Youssef, El-Fitiany & Elfeki, 2008 tested 11 one-way slabs in flexure after 85-days fire exposure. 5-slabs had TSL applied on compression surface and 6-slabs had TSL on tension surface. The slabs having TSL on compression side doesn't show any effect on flexure behavior of slab (for slabs not exposed to fire) . But they found that the flexure strength of the slab having TSL on tension surface has been increased by 50%. Moreover, by using TSL, the compressive strength of slab will not reduce more than 10%, when exposed to fire.

Recently test was carried out on concrete slabs coated with TSL on tension side, exhibits an increase in the flexure strength. TSL used in this test is polyurea. Test was conducted on two-way slabs. The slabs were of uniform dimensions, but varying in strength and varying with respect to absence/presence of reinforcement. The slab's response, in terms of strength and ductility is examined. It was evident from test results that there is a substantial increase in ultimate load-carrying capacity and ductility of the slabs.

Figure 7: Testing of Poly-urea Coated Slabs

The following nomenclature was used for different slab specimens:

- A = 1: 1.5: 3 Mix Ratio
- B = 1: 2: 4 Mix Ratio
- R = Reinforced slab
- U = Unreinforced slab
- P = Polyurea Coated Slab
- C = Control Slab
- 2,4,6= Thickness of Polyurea Coating

For example, “**ARP 6**” can be identified as “**1:1.5:3 Mix Ratio – Reinforced, Polyurea- coated slab with 6 mm Coating Thickness**” while “BUC” identified **“1:2:4 Mix Ratio – Unreinforced, Control Slab”**

Following graphs show the test results;

Figure 8:Comparison of 1:1.5:3 Mix Ratio, Reinforced Slabs (lines show energy dissipation)

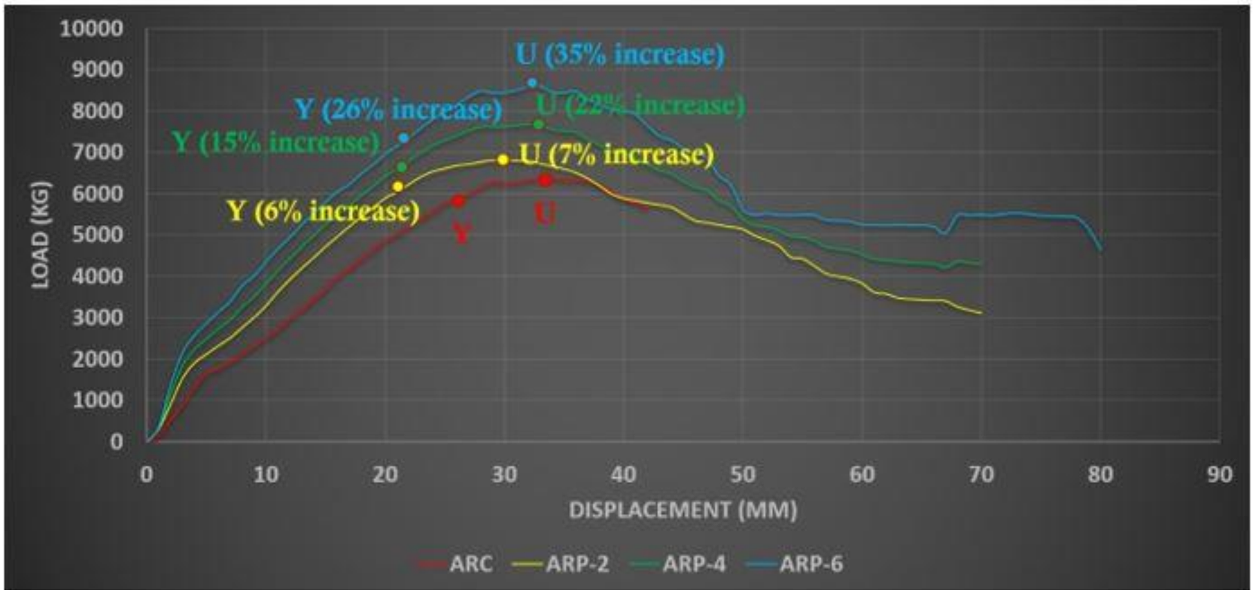


Figure 9: Comparison of 1:1.5:3 Mix Ratio, Reinforced Slabs (Y=yield load, U=ultimate load)

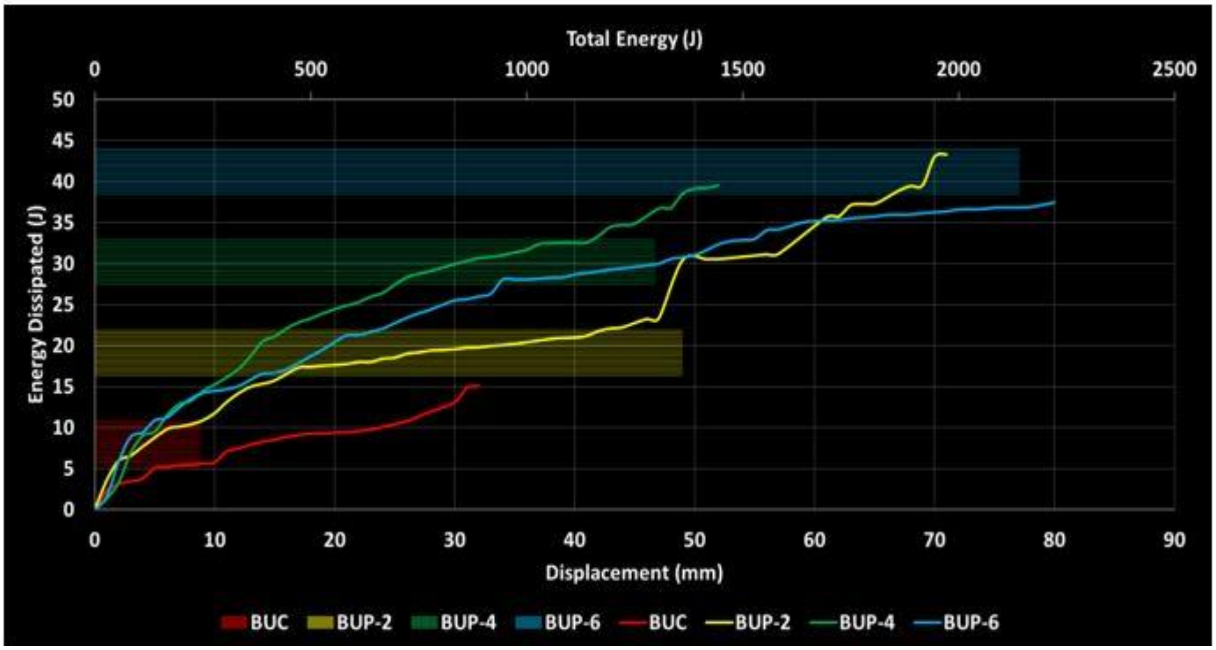


Figure 10:Comparison of 1:2:4 Mix Ratio, Reinforced Slabs (lines show energy dissipation)

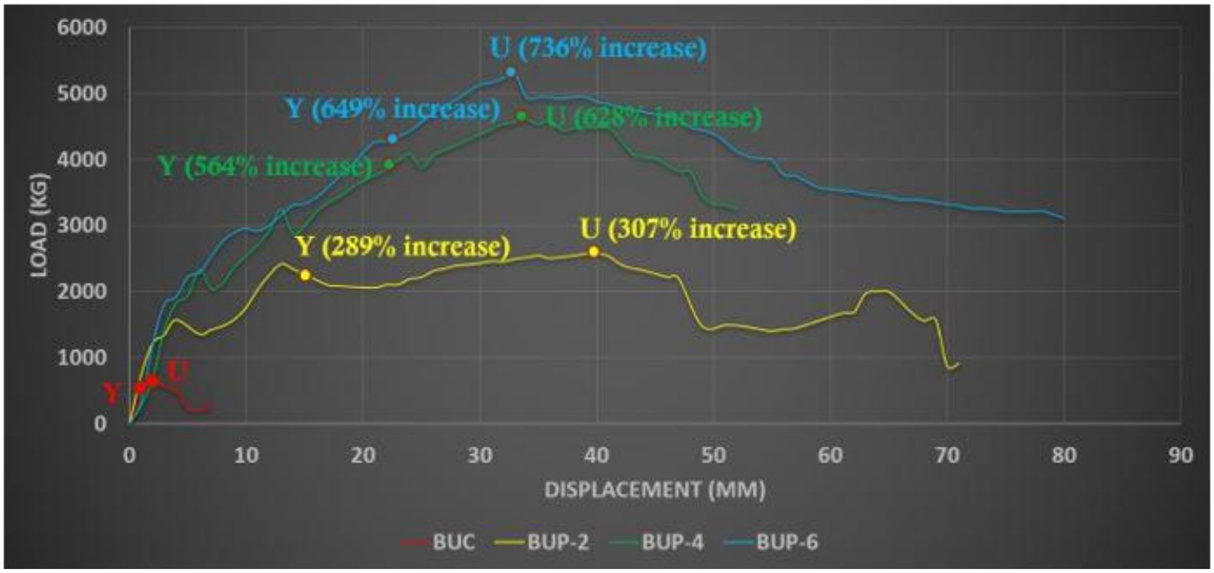


Figure 11: Comparison of 1:2:4 Mix Ratio, Un-reinforced Slabs (Y=yield load, U=ultimate load

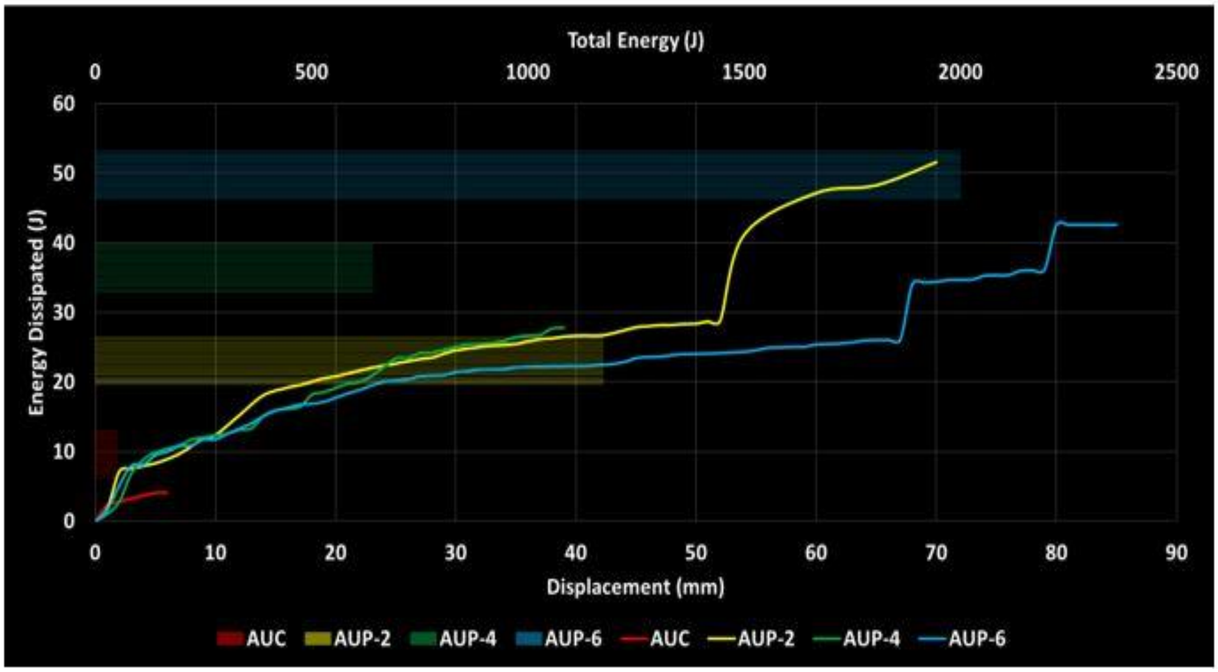


Figure 12: Comparison of 1:1.5:3 Mix Ratio, Unreinforced Slabs (Lines show energy dissipation)

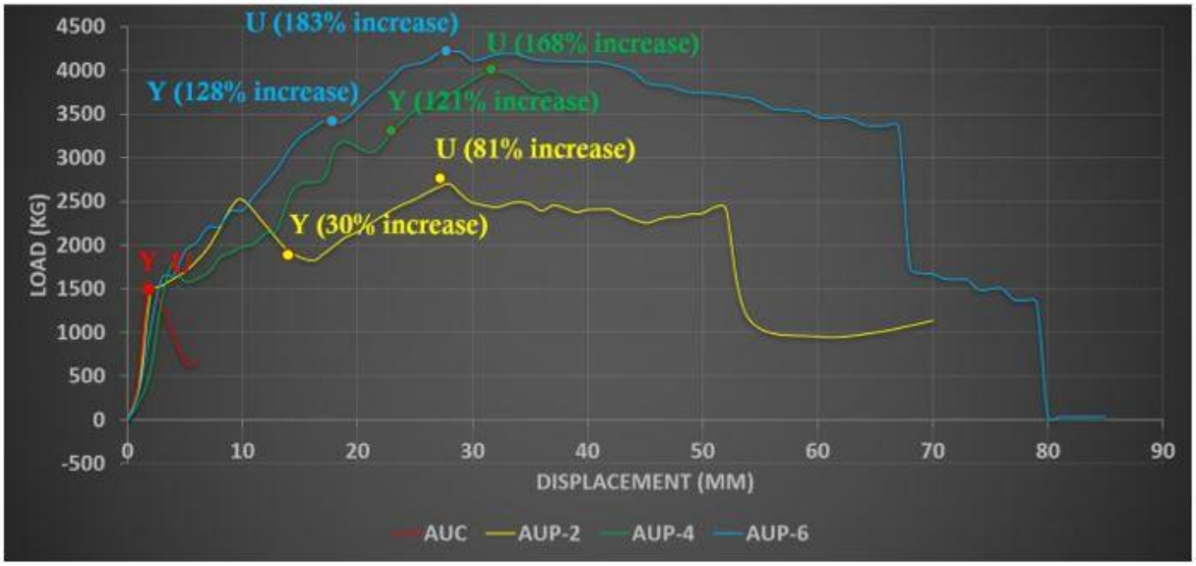


Figure 13: Comparison of 1:1.5:3 Mix Ratio, Unreinforced Slabs (Y=yield load, U=ultimate load

2.5 Failures related to TSL’s

Espley et. Al (1999) recognized three type of failures, associated with thin spray-on liners;

2.5.1 Adhesive Failure

This type of failure occurs when liner loses its bond with the intact surface. Adhesion plays a vital role in distribution and transfer of loads and stresses. Moreover, it prevents the spalling and fragmentation. Adhesive strength of a typical high quality TSL is 0.5MPa.

2.5.2 Tensile Failure

Tensile failure is linked with the adhesion of TSL. Tensile failure happens when adhesion is lost along a crack or joint. In tensile failure, the flexure strength of the member is compromised. Tensile strength of a high quality TSL is from 5MPa to 15 MPa.

2.5.3 Direct Shear Failure

It could happen when adhesive strength of TSL exceeds the shear strength of material. No debonding of liner occurs in this failure. It happens without any prior warning or signs. But direct shear failure is very rare in TSL’s.

2.6 Physical Properties of TSL

Curing time is the most vital aspect in the physical properties of TSL. Because the strength depends upon curing time. Yilmaz H.2010 compare the tensile strength of 20 TSL products by varying the curing time upto 28-days. It was concluded, by increasing the curing time, the tensile strength increases in logarithmic way.

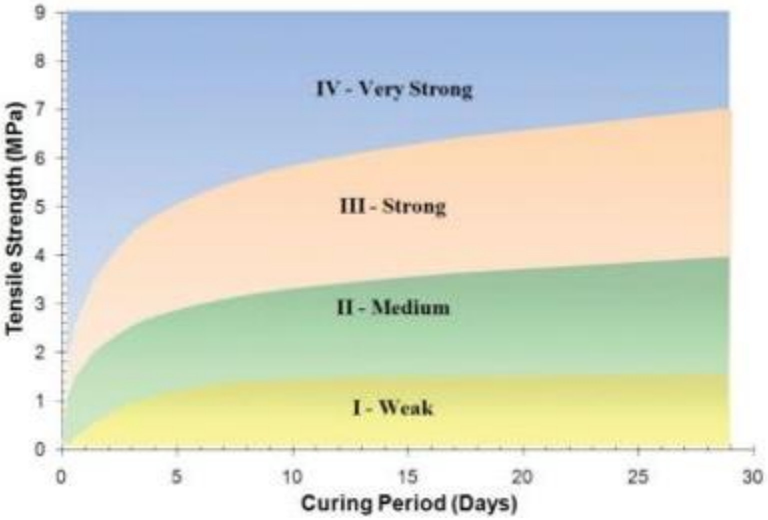


Figure 14: Comparison of TSLs and Effect of curing Period on their Tensile Strengths (Yilmaz H., 2010)

Yilmaz H., 2011 was involved in development of testing methods for comparative assessment of TSL shear and tensile properties. He performed 4000 tests on 32 TSls from 12 companies as well as one brand of plain shotcrete. The main test variable was that of curing time from 1 day to 28 days.

TSL characteristics such as high tensile strength and improved elasticity allow them a unique functionality not available with current support tools. To further the study of TSLs into dynamic loading characteristics, Moreau, 2006 proposed a dynamic loading test methodology and went on to show that TSLs do have a potential support advantage when exposed to dynamic loading making them a suitable ground support system for areas anticipated to be affected by high dynamic loading such as earthquakes. Ozturk & Tennant, 2010 tested for the adhesive strength of TSLs via a pull-off test and concluded that adhesive strength is inversely proportional to the square root of the liner thickness.

An efficient and good quality TSL should also have following properties;

- Sufficient pot-life i-e more than 30mins.
- Consistent performance of factory pre-mixed products.
- Rapid strength development (compressive, tensile and shear).
- Excellent adhesion i-e bond with substrate.
- Visible coatings.

2.7 Flexure Properties of Concrete

When analyzing plain concrete beams, Oladapo, 1964 analyzed the loads and strains at which cracks occur in different concrete mixes. He concluded that cracking is not a sudden but a gradual process. Furthermore, the critical stage that represents the limiting tensile strength of the concrete and is the beginning of failure, occurs at between 70 and 90% of the ultimate load.

Flexural Tensile Strength of normal density concrete at ambient temperature can be calculated as:

$$0.6\sqrt{f'_c}$$

Modulus of Rupture (MR) depends upon mix proportions and type, and size and volume of coarse aggregate. An estimate of the MR can be obtained by:

$$f_r = 7.5\sqrt{f'_c}$$

On the other hand, Secant Elastic Modulus is defined as the slope of the line from origin to the point corresponding to 40% of ultimate strength (Xianhong & Yupu, 2007).

2.8 Polyurea coating system-Spray technique:

New discoveries and developments are important to meet the increasing requirements of engineering and construction industry. Modern state-of-the-art techniques and construction materials are being introduced to cope with the new challenges. Polyurea is the recent advancement in this course. It is now being widely used in construction industry. It posses' notable properties, such as high durability, strength and resistance to chemical & weathering actions.

It is also known as polyurea-elastomer. It is the product of two compounds, namely isocyanate and polyamine. These two compounds are combined under high temperature and pressure in appropriate ratio. The chemical composition can vary depending upon the require quality and application. (POLYUREA COATING SYSTEMS: DEFINITION, RESEARCH, APPLICATIONS---Szafran & matusiak 2016)

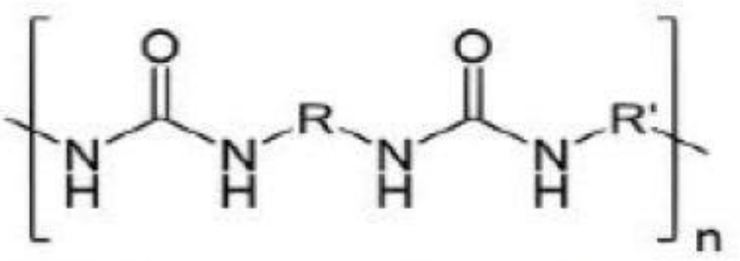


Figure 15: Chain Structure of Poly-Urea

This chain-structure arrangement of molecules makes polyurea highly elastic and durable. Polyurea has also the capability of absorbing energy, resistance against water and humidity action, resistance to UV radiation, high resistance to mechanical damage, very high chemical and biological resistance and high resistance to sudden temperature changes.

The application of Polyurea requires three stages: surface preparation, mixing of the components and application. Surface preparation involves clearing of the surface from any contaminating particles with the use of either blast / sand-blast cleaning or the application of a priming paint to ensure firm adhesion.

Application of polyurea requires special plural-component spray machine. It must be capable of generating high pressure & temperature. It also requires highly-skilled manpower to operate the machine, because of its complex operation.

A typical device used for spraying polyurea is shown below;

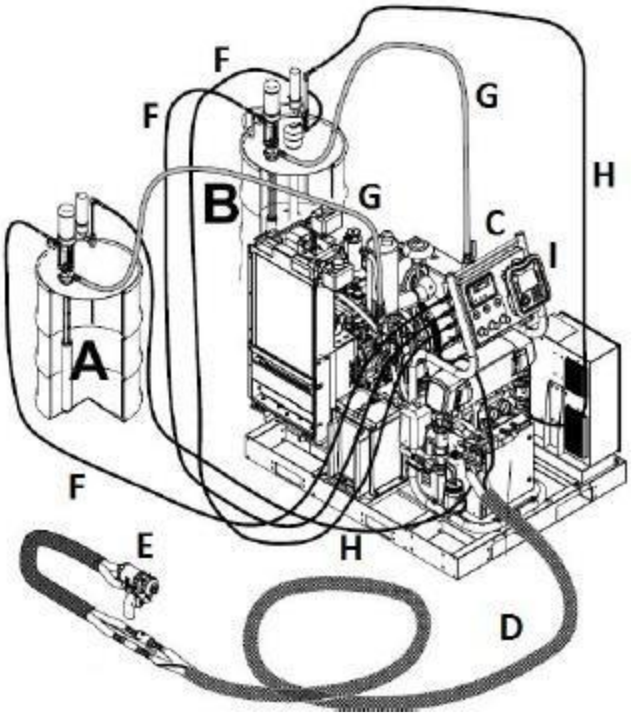
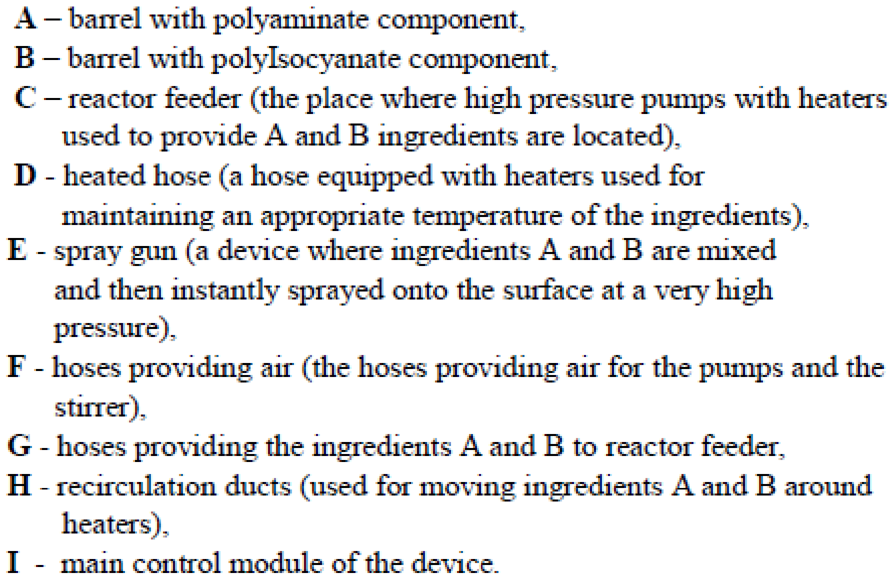


Figure 16: Special Plural-Component Spray



A – barrel with polyaminate component,
B – barrel with polyIsocyanate component,
C – reactor feeder (the place where high pressure pumps with heaters used to provide A and B ingredients are located),
D - heated hose (a hose equipped with heaters used for maintaining an appropriate temperature of the ingredients),
E - spray gun (a device where ingredients A and B are mixed and then instantly sprayed onto the surface at a very high pressure),
F - hoses providing air (the hoses providing air for the pumps and the stirrer),
G - hoses providing the ingredients A and B to reactor feeder,
H - recirculation ducts (used for moving ingredients A and B around heaters),
I - main control module of the device.

Just like any other construction material, polyurea has both some advantages and disadvantages.

Advantages:

- Fast setting and curing time, which helps in attaining material properties in shorter period of time. Espley et al (2001)
- Easily bear the dynamic loads (Hepworth & Lobato ,2002)
- Comparatively less material is used to cover large area. So reduce the logistics. (ferriera and pirrodi 2011)
- Low wastage of material.

Disadvantages:

- A special plural-component spray machine is used to spray polyurea. (POLYUREA COATING SYSTEMS: DEFINITION, RESEARCH, APPLICATIONS---Szafran & matusiak 2016)
- Highly skilled labor is required for application and operation of equipment.
- Very precise motion and speed is required to get the desire thickness.
- Availability of compressed air and water is a must thing. (Henderson & Louw 2001)
- Full body dress and face mask is necessary while application to avoid inhalation and skin-contact with the toxic isocyanates in the air (Lewis 2001)
- Polymerization is exothermic-reaction in nature, temperature can reach upto 150c in closed vicinities. (Archibald 2001)
- Spray equipment needs to be thoroughly cleaned after each operation, to avoid blockage in nozzle and pipes. (Archibald 2001)

2.9 Tough Coat-Brush Technique:

Urge for better and more efficient construction techniques and materials never comes to end. There is also room for improvement. Industry demands the better and economical solutions with optimum results.

Deficiencies and disadvantages of the polyurea coating system, raises the need of some other TSL. Which can be easily applied and give results as that of polyurea. So, a new TSL has been selected for research, that can be applied easily with simple brush technique.

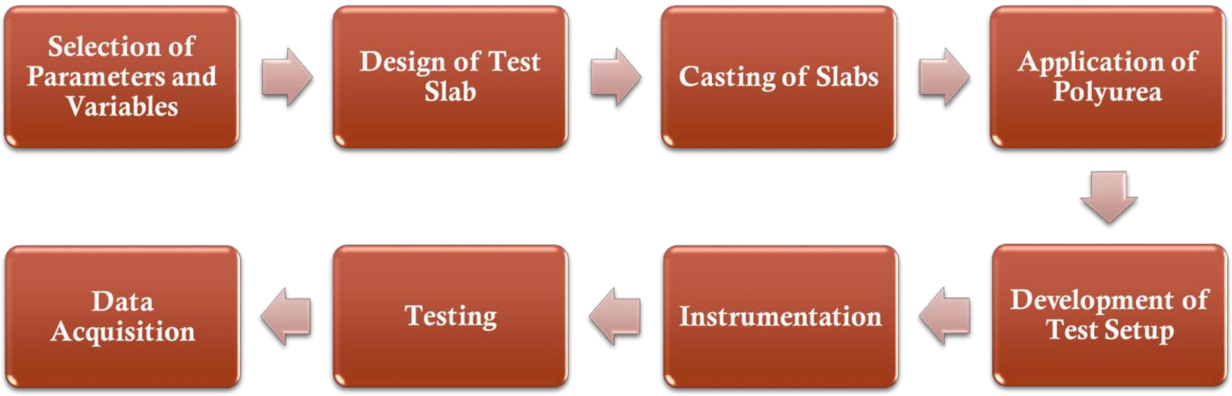
This technique will eradicate the difficulties and complications associated with the spray technique. It will minimize the effort and resource consumption. It can be easily applied, where it is difficult to take spray equipment.

Chapter 3

Methodology and Test Setup

3.1 Methodology

After detail study of literature review, following methodology is adopted for this research;



3.2 Selection of variables and parameters

Following parameters are selected to analyze the ductility and tensile strength of concrete slabs.

- Peak Load: Maximum load a slab can bear.
- Yield Load: Load corresponding to yield point of concrete.
- Ductility Index: Ratio of deformation at peak load to deformation at yield.
- Yield Secant Stiffness: Ratio of strength of concrete to maximum displacement.
- Energy Dissipation: Area under the Load-Displacement curve.

The above parameters are studied via Load-Displacement graphs of the concrete slabs. Furthermore, in order to quantify these parameters, the following variables were chosen to be studied:

- Tough coat thickness (2 mm, 4 mm and 6 mm against no coating for control slabs)
- Concrete Strength (1:1.5:3 and 1:2:4 Mix Ratios)

- Presence / Absence of Light Reinforcement (0.21% reinforcement ratio in case of reinforced slabs)

3.3 Design of Test Slab

3.3.1 Size of slab

Slab dimensions are selected in such a way to maintain the standard throughout the test. The selected dimensions are 3’ x 3’ x 2”. The dimensions were selected so as to ensure two-way action in the slabs as well as to keep flexure the dominant failure mechanism. Another consideration was the ease of handling the slabs throughout the duration of the project. The thickness so selected was kept greater than the specified code minimum.

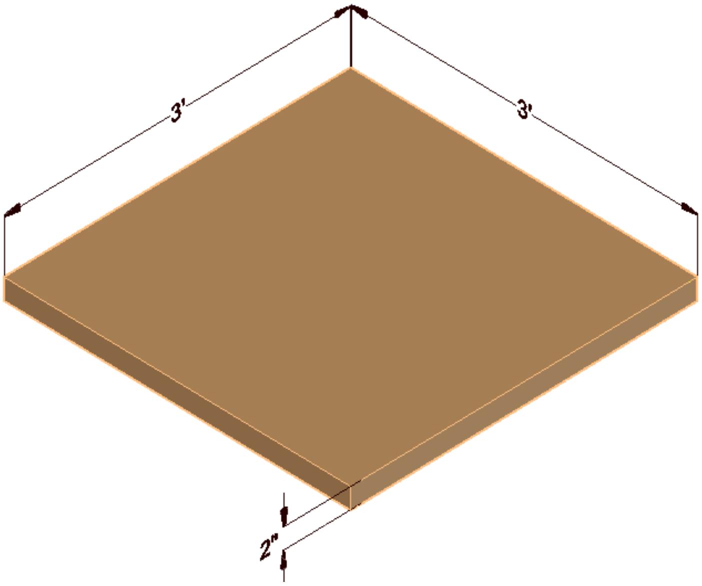


Figure 17: Slab Dimensions

3.3.2 Distribution of test samples

To study the selected variables, total 32 slabs were divided equally into two different mix ratios (i.e. 16 each). These 16 slabs were further divided into reinforced & unreinforced samples (i.e. 8 each). These remaining 8 samples were further categorized into 2samples of each type to take average of results. Types of slab samples are;

- Control slab
- 2mm thickness tough-coat slab
- 4mm thickness tough-coat slab
- 6mm thickness tough-coat slab

3.3.3 Reinforcement details

1 reinforcement bars (5/32 in dia) of Grade 40 steel were provided at maximum allowed spacing of 2h as per ACI-Code (ACI 318-14) with a ½ in clear cover. The reinforcement ratio comes out to be 0.027%, which is greater than the ACI-Code (ACI 318-14) specifications.

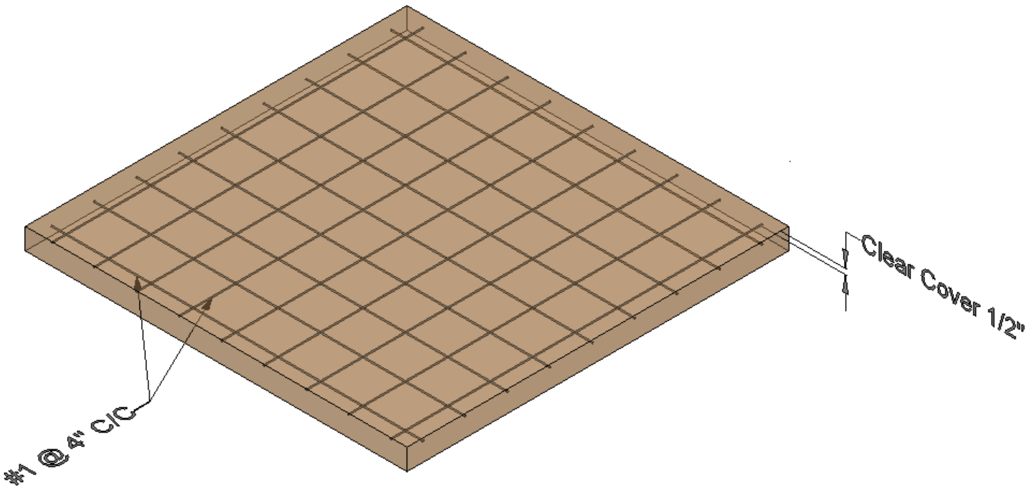


Figure 18: Reinforcement Details

3.3.4 Nomenclature

Following nomenclature was adopted to recognize the different samples;

A	1:1.5:3 Mix Ratio
B	1:2:4 Mix Ratio
R	Reinforced Slab
U	Unreinforced Slab
T	Tough-coat Coated Slab
C	Control Slab
2,4,6	Thickness of Polyurea Coating

For example, “**ART-6**” can be identified as “**1:1.5:3 Mix Ratio – Reinforced, ToughCoat - coated slab with 6 mm Coating Thickness**” and similarly, “BUC” identified “**1:2:4 Mix Ratio – Unreinforced, Control Slab”**

3.3.5 Casting of slabs

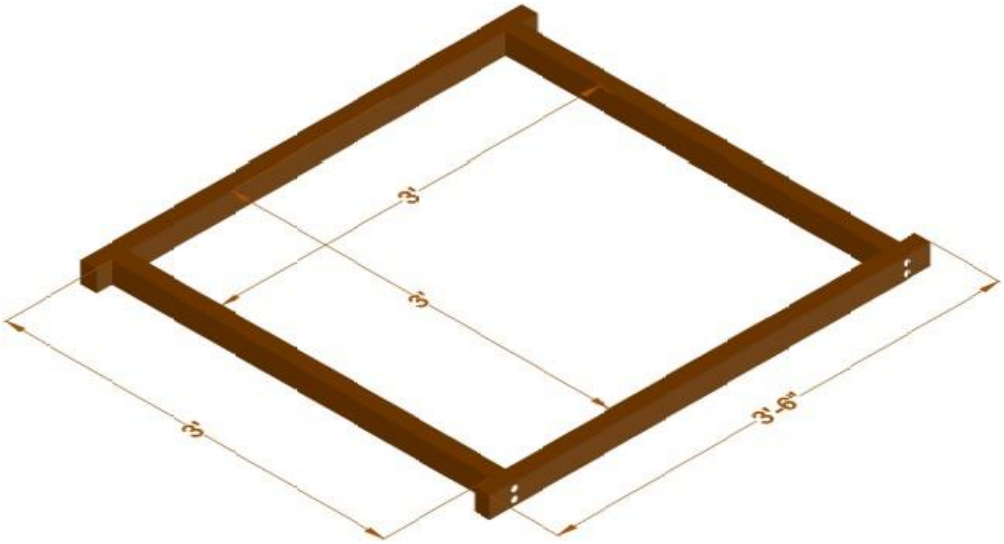


Figure 19: Formwork of Slab

Wooden formworks were made separately for each slab. The inner sides of formwork were lubricated for easy removal. A concrete mixer was used to pour the concrete into formwork. After pouring the concrete upto a depth of 1.5”, steel mesh was placed. After complete pouring, the slabs were left for 28days curing.

Figure 20: Pouring of concrete

3.3.6 Application of ToughCoat

ToughCoat was applied at UltraChemicals (Pvt) Ltd. Factory, Lahore. Before applying ToughCoat, slab surface was cleaned to facilitate the proper bonding between TSL and surface. TSL was applied with simple brush, just like ordinary paint. TSL was applied in layers of 2mm. After each layer of 2mm, TSL was left to set. After complete application of TSL, it was left for 28days curing under shade.

3.3.7 Test Setup

Tests were carried out at MCE Structural Lab. Hydraulic jack was fixed with the Reaction Frame to apply load on concrete slabs. A masonry wall was built to provide two-way support system to the slab. 3-in of the slab from each side, rests on masonry wall providing a total clear-span of 30-inches in both ways. A steel plate (14” x 14”) was used to distribute the load on slab. A load-cell is placed right beneath the hydraulic-jack to measure the load. A Linear Displacement Sensor (LDS) was placed at mid-point under the slab to measure the deflection in slab. A wire mesh was placed on top of the Linear Displacement Sensor to protect it from collapsed slab specimens. All the data was saved with data-logger (System8000).

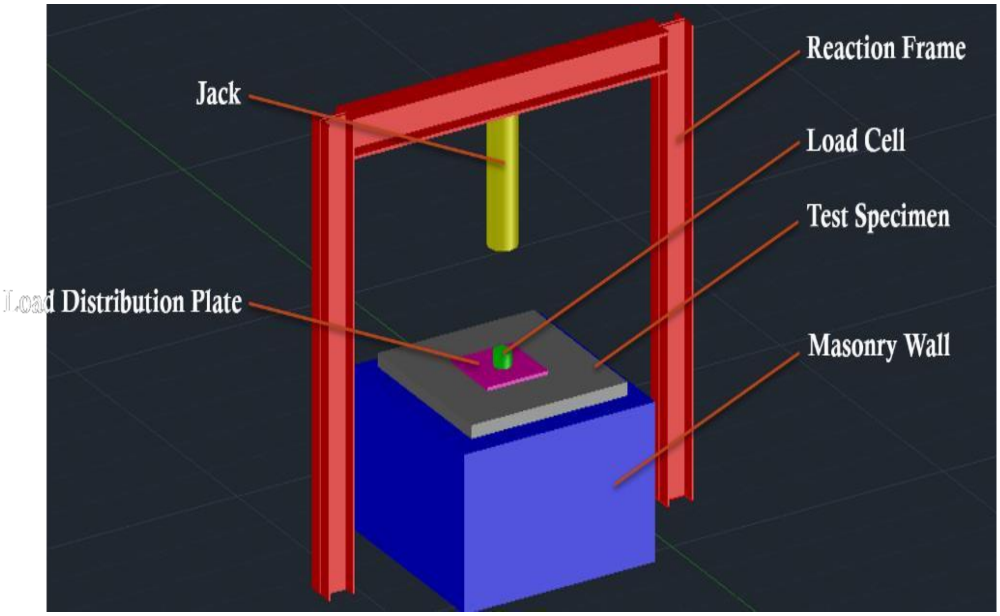


Figure 21: Test Setup

3.3.7.1 Instrumentation

Following equipment has been used in testing;

- Hydraulic Jack and 10,000 psi Hydraulic Pump.
- 100 mm Linear Displacement Sensor.
- Data Logger.
- 50 Ton Load Cell.
- 14” x 14” Steel Distribution Plate.
- Wire mesh.
- Compatible Laptop Computer.
- Reaction Frame.

Figure 22: Linear Displacement Sensor

Figure 23: Data Logger (System8000)

Figure 24: Hydraulic Jack

Figure 25: Reaction frame

Figure 26: Wire Mesh

Figure 27: Specimen ready for testing

3.3.7.2 Test Procedure

Slabs were loaded until failure or until they reached maximum measurable displacement (LDS used measured to a maximum of 100 mm).

After putting the test setup in place, testing was started. Complete test process of one specimen from the start to the data acquisition involved the following steps:

- Slab specimen was placed on the welded steel pipe which acted as a two way support.
- Slab was centered and leveled with respect to the Linear Displacement Sensor (LDS) using a common bubble level.
- The 14" x 14" steel plate was placed in the center of the slab specimen using a measuring tape.
- In the center of the steel plate, the Load Cell was placed.
- The load cell was adjusted such that it was in the center of the steel plate and also that the jack was directly on top of it. This meant that the assembly below the jack was in center with respect to the slab and slab was in turn in center with respect to the LDS.
- After aligning the whole assembly, the pump was attached with the jack.
- LDS was attached to the data logger.
- Load cell was attached to the data logger.
- Data logger was attached to the computer.
- In the software application on computer the instruments were calibrated and real time readings were extracted of the displacement being recorded by the LDS and the value of load being applied by the Jack on the Load Cell.
- One individual was tasked with the gradual application of load manually using the pump that was attached to the jack.
- Two individuals were tasked with the placement and removal of slabs (weighing 102 kg each)
- Increasing load was applied and the readings were constantly monitored. Load was applied until the slab fractured or the LDS recorded its maximum reading.

Figure 28: Cracking Pattern of Reinforced slab

Figure 29 Cracking Pattern of Unreinforced Slab

Figure 30: Crack Pattern on Tension Side

Chapter 4
Results and Analysis

4.1 Results

After acquiring the test results, the data is shaped into graphs by using MS-excel for further detailed analysis. These were then compared by keeping a variable constant and then making a comparison between other variables.

Important points within every graph includes Load at Yield and Ultimate Load. Energy Dissipation was also calculated for each Specimen type by taking the areas under the graphs. Moreover ductility index, stiffness at peak load and stiffness at yield load is also calculated and compared.

4.1.1 Comparison between Tough-Coat Thicknesses

4.1.1.1 Load Displacement Curves

Tough-Coat is applied by varying the thickness. Results for each thickness is shown below. It is clear from the graphs that there is remarkable increase in yielding and ultimate peak load.

Load displacement curves are obtained and energy dissipation is calculated from area under the curve.

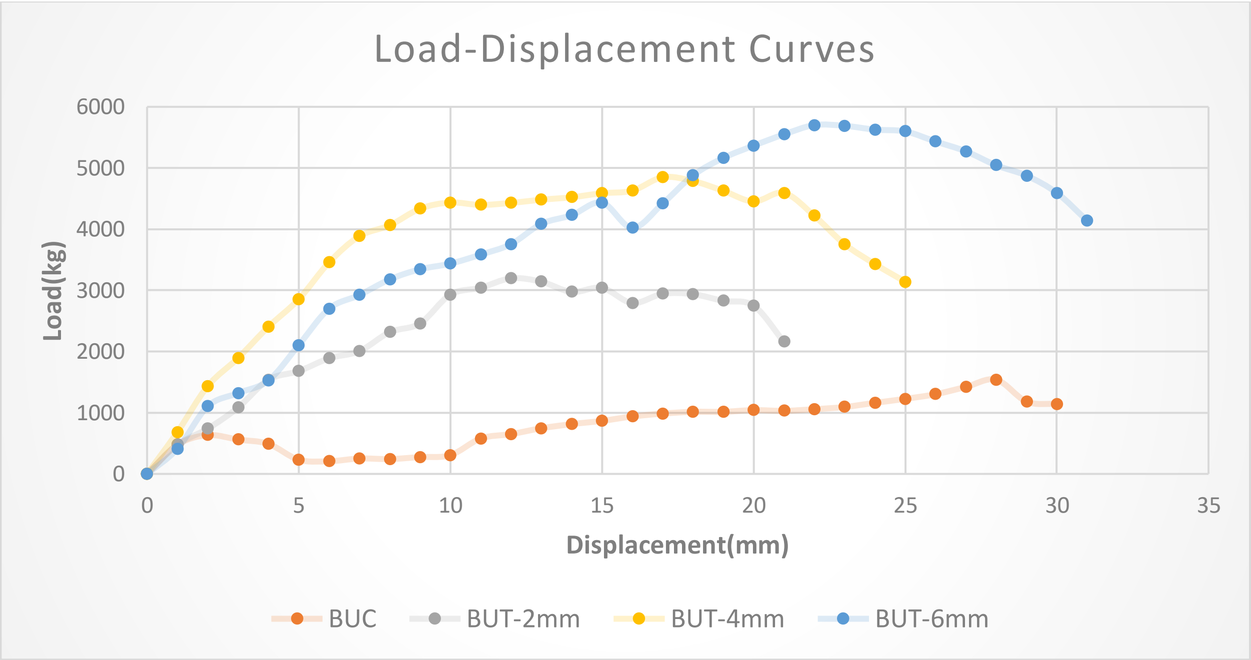


Figure 31: Load Displacement Curves of 1:2:4 Mix Ratio, Unreinforced Slabs.

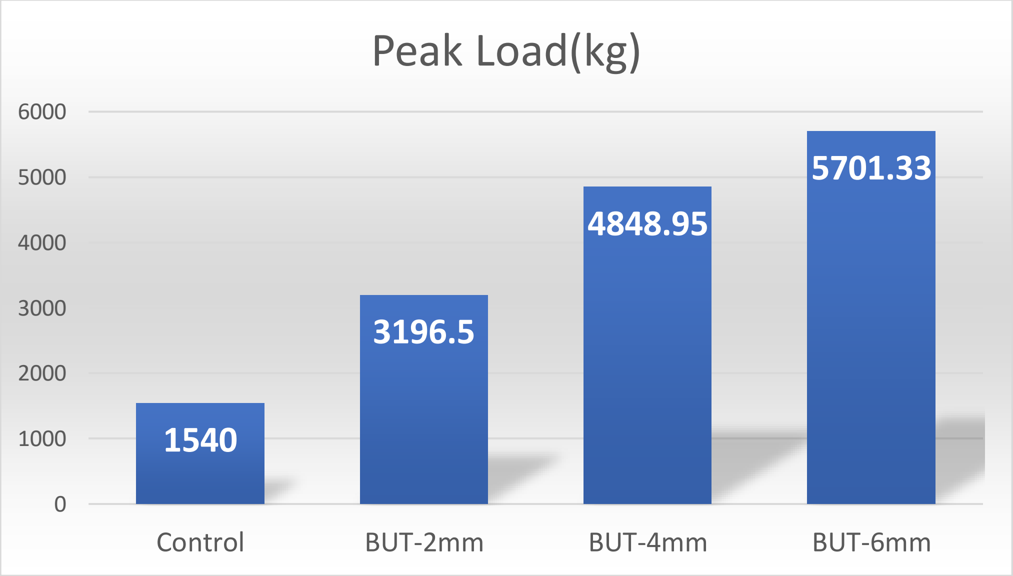


Figure 32: Comparison of 1:2:4 Mix Ratio, Unreinforced Slabs Peak load

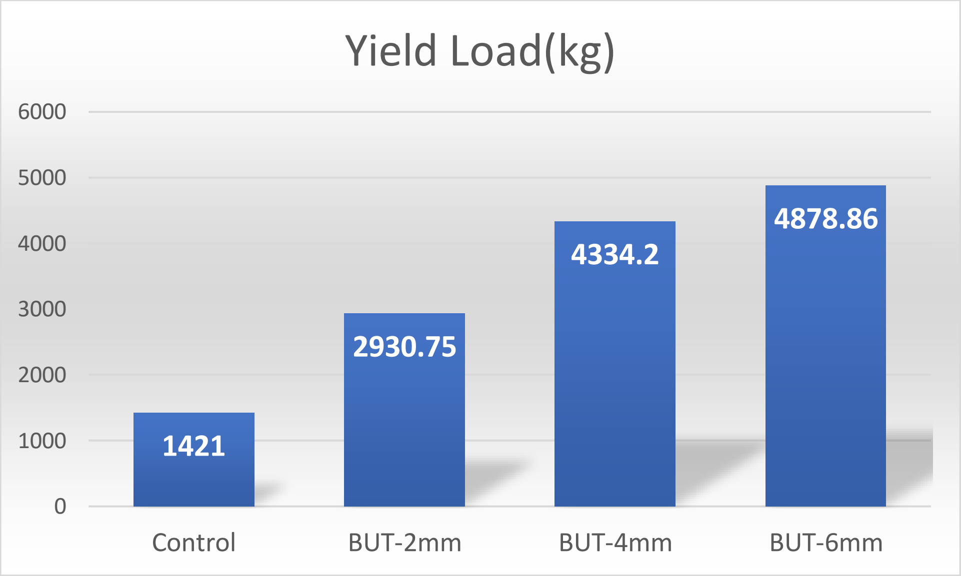


Figure 33: Comparison of 1:2:4 Mix Ratio, Unreinforced Slabs Yield load

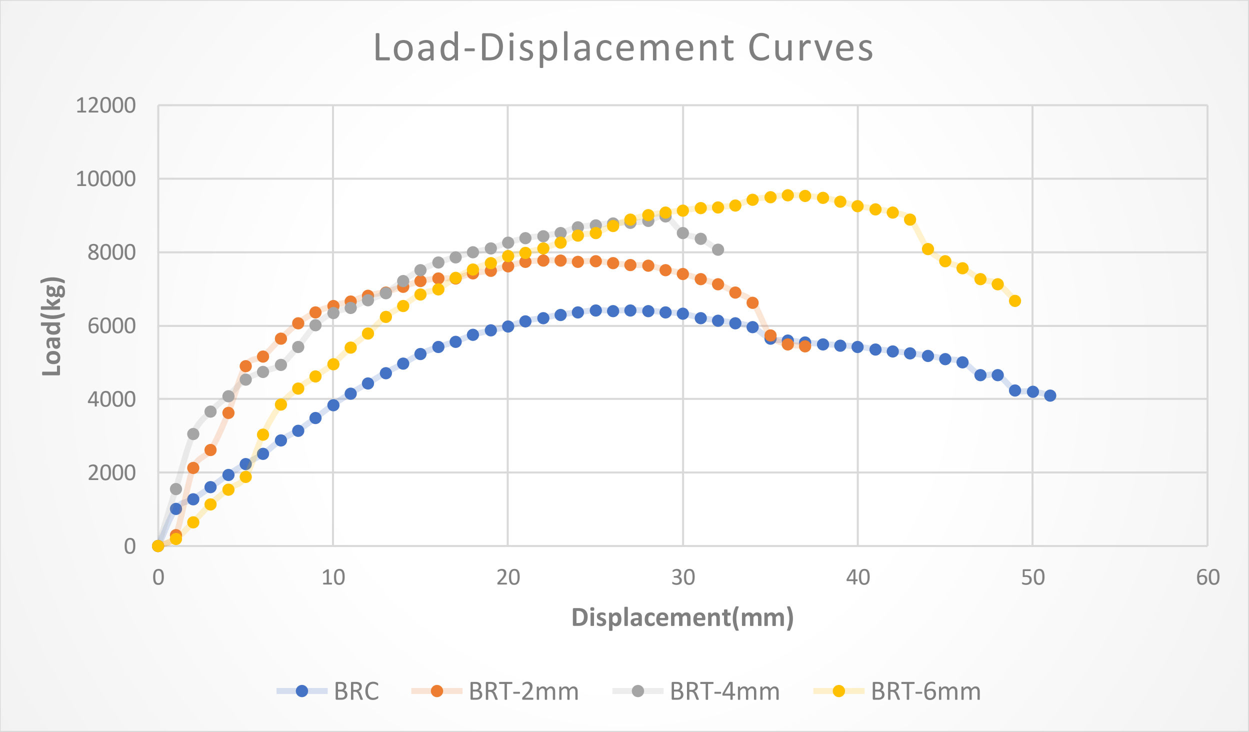


Figure 34: Load Displacement Curves of 1:2:4 Mix Ratio, Reinforced Slabs.

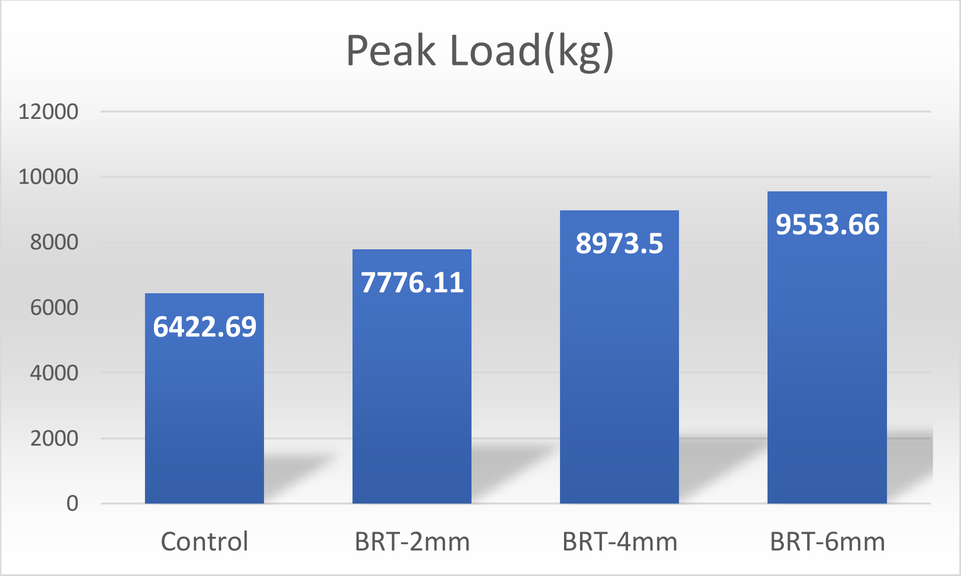


Figure 35: Comparison of 1:2:4 Mix Ratio, Reinforced Slabs Peak load

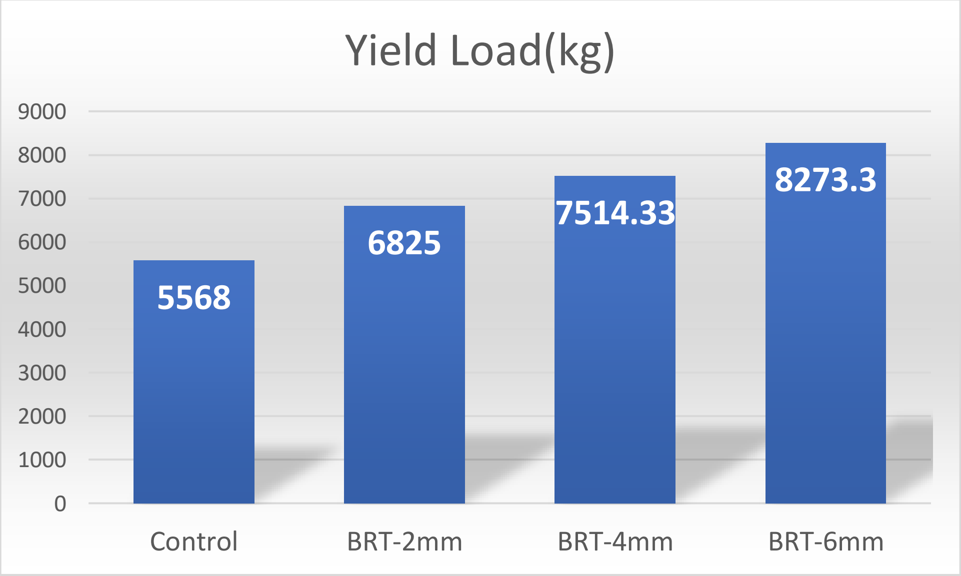


Figure 36: Comparison of 1:2:4 Mix Ratio, Reinforced Slabs Yield load

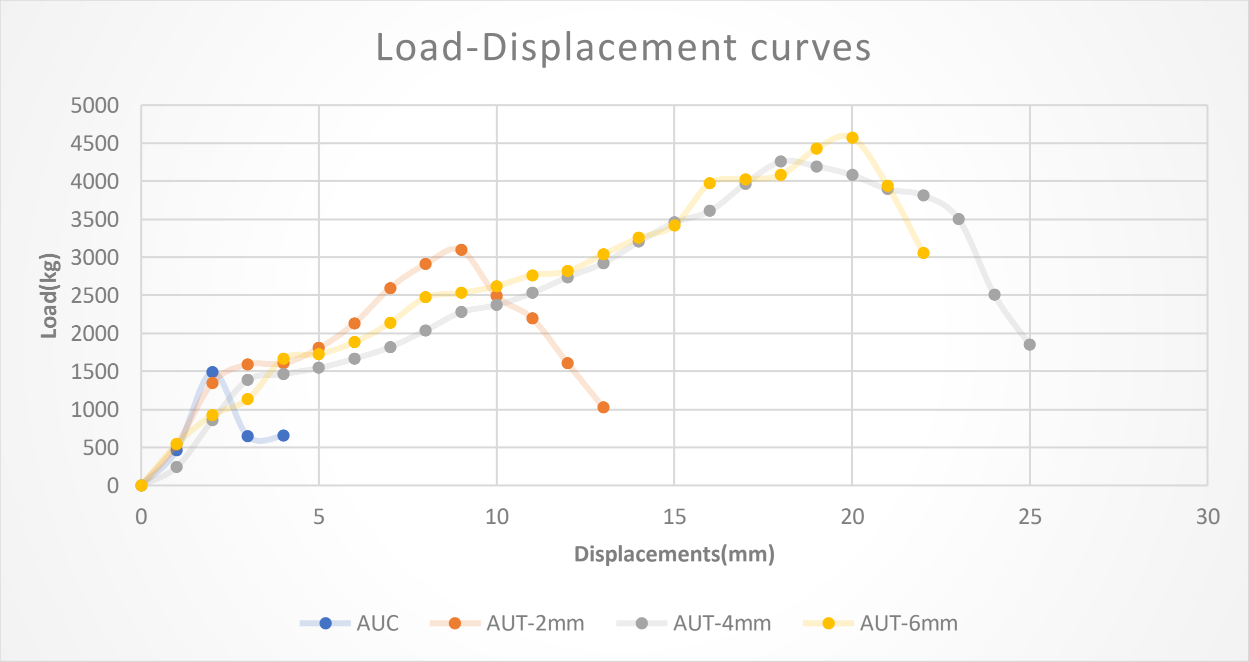


Figure 37: Load Displacement Curves of 1:1.5:3 Mix Ratio, Unreinforced Slabs.

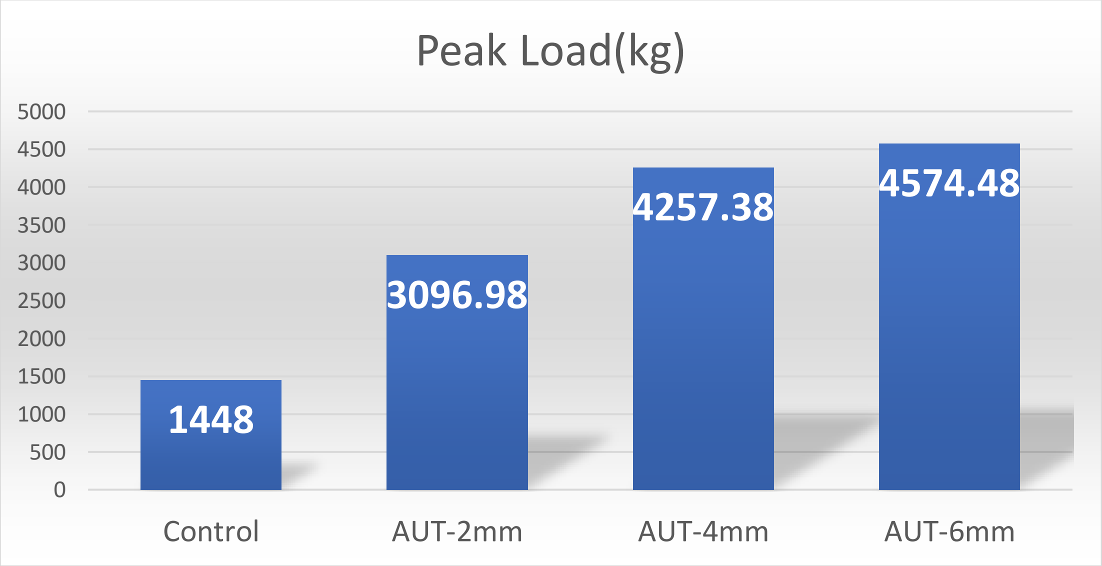


Figure 38: Comparison of 1:1.5:3 Mix Ratio, Unreinforced Slabs Peak load

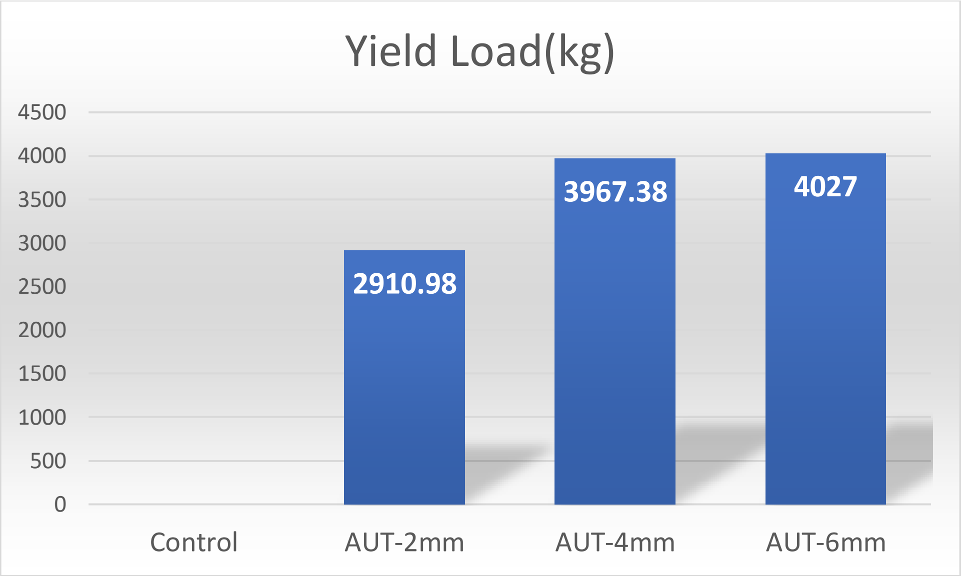


Figure 39: Comparison of 1:1.5:3 Mix Ratio, Unreinforced Slabs Yield load

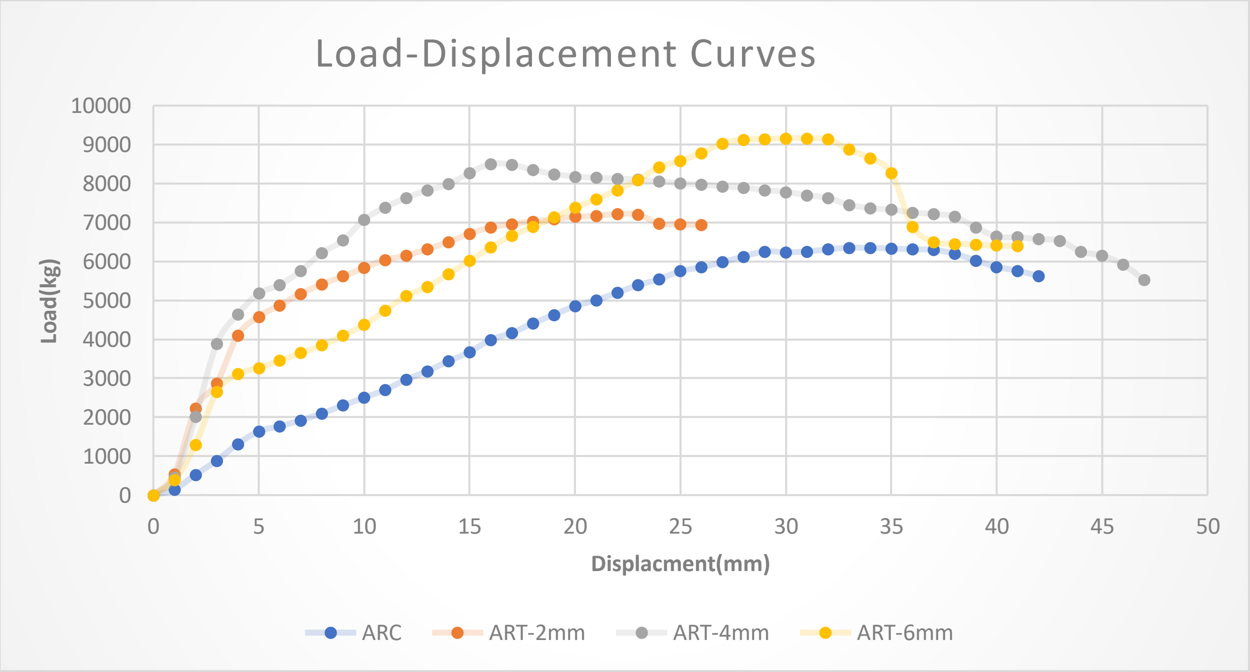


Figure 40: Load Displacement Curves of 1:1.5:3 Mix Ratio, Reinforced Slabs.

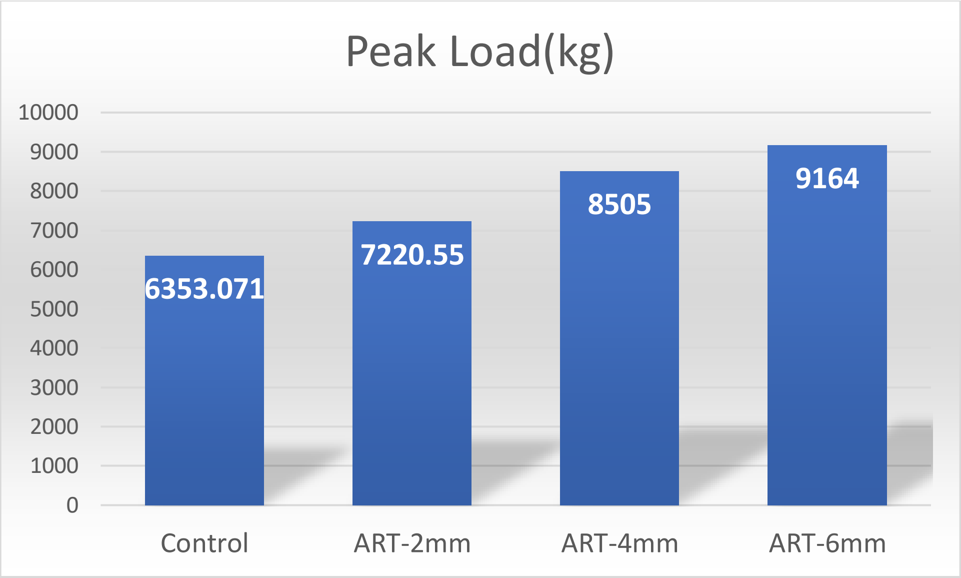


Figure 41: Comparison of 1:1.5:3 Mix Ratio, Reinforced Slabs Peak load

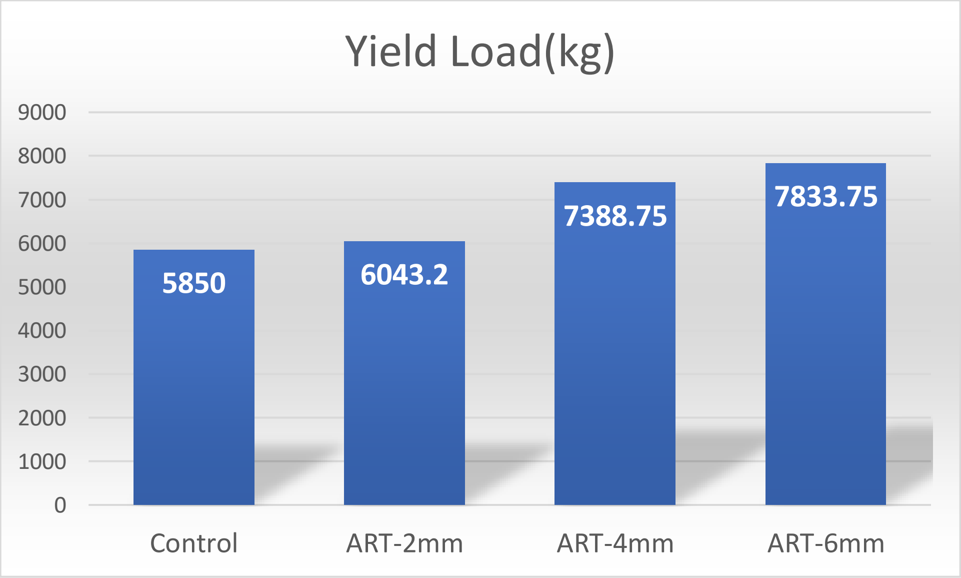


Figure 42: Comparison of 1:1.5:3 Mix Ratio, Reinforced Slabs Yield load

From the load-displacement graph, the post-peak behavior of slabs can be observed. It is evident from the graph that the slabs with reinforcement, show a smooth curve and gradual decrease in load. Whereas, unreinforced slabs have high slope after the peak load.

4.1.1.2 Energy dissipation

The area under the load-displacement curve gives the total amount of energy. Amount of energy dissipated in every specimen is calculated.

The application of tough-coat has increased the energy dissipation capacity. The TSL itself can absorb a large amount of energy.

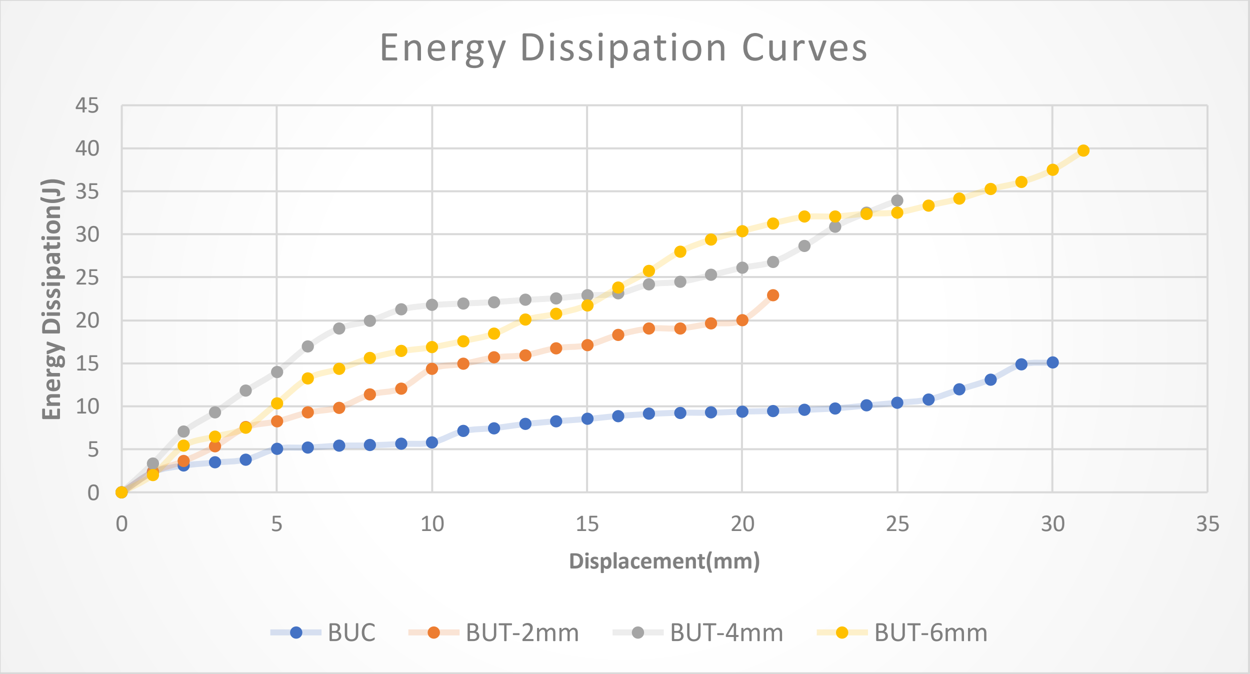


Figure 43: Energy Dissipation in 1:2:4 Mix Ratio, Unreinforced slabs.

The value of total energy in uniform slabs, by varying thickness of tough-coat is given below.

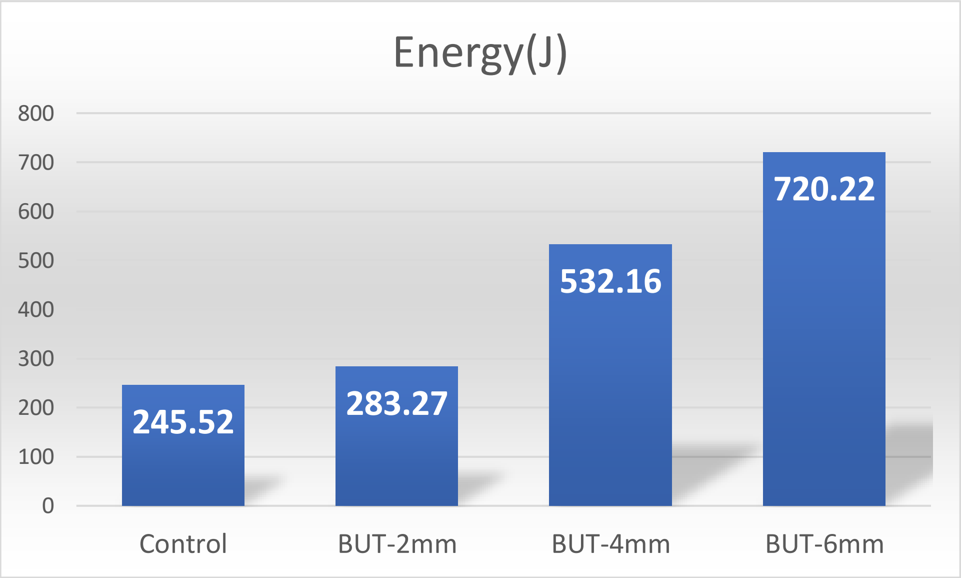


Figure 44 : Comparison of 1:2:4 Mix Ratio, Unreinforced Slabs total energy.

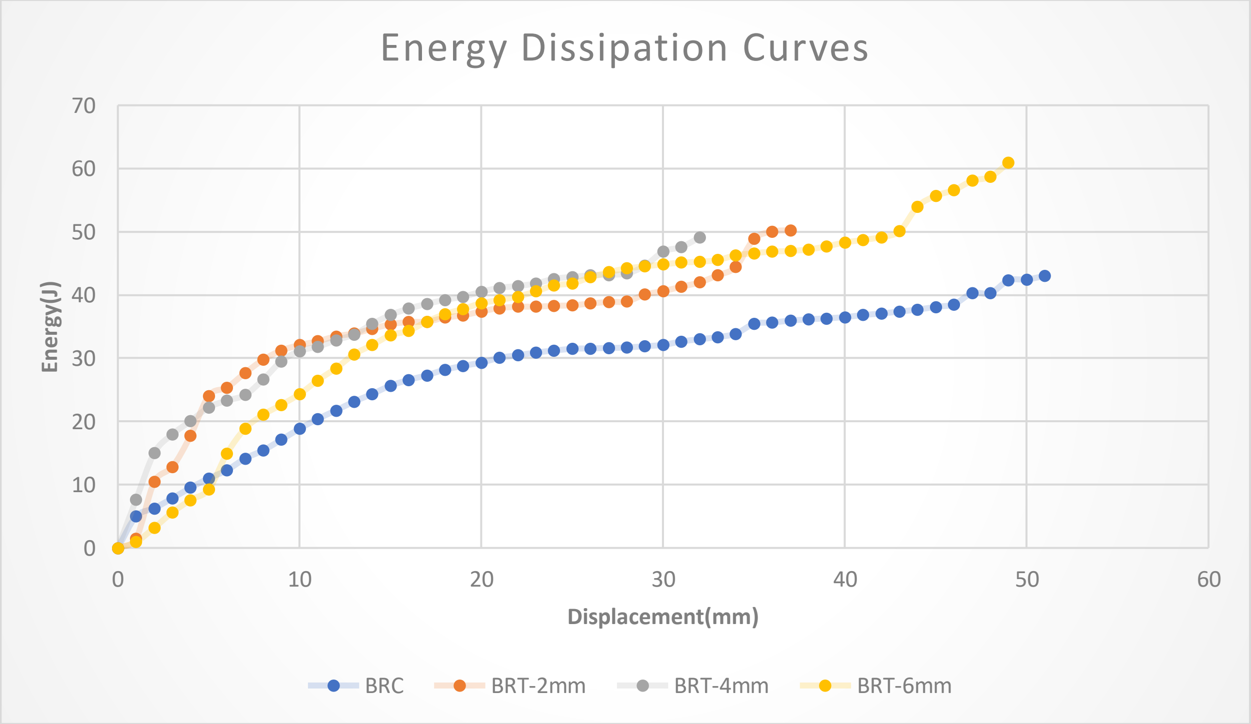


Figure 45: Energy Dissipation in 1:2:4 Mix Ratio, reinforced slabs.

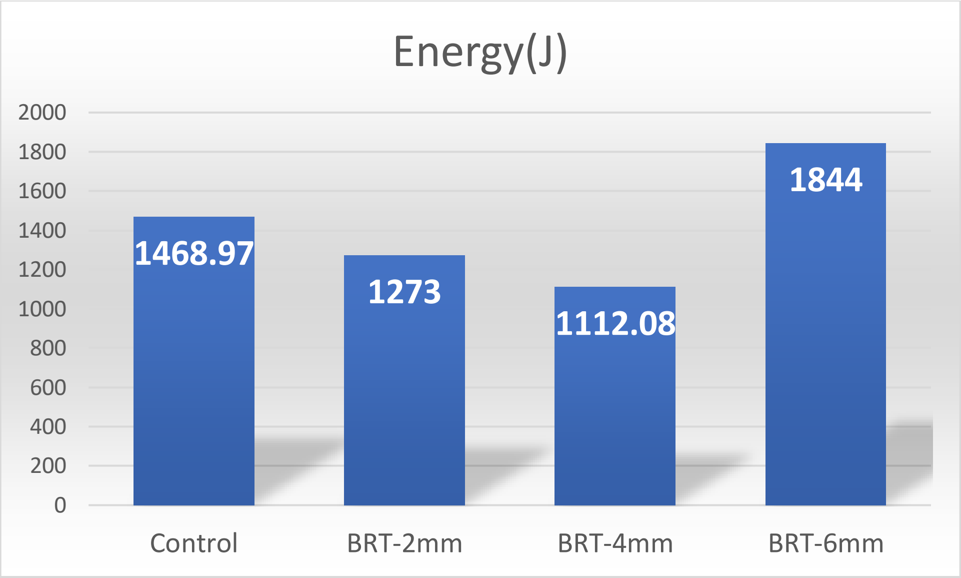


Figure 46: Comparison of 1:2:4 Mix Ratio, reinforced Slabs total energy.

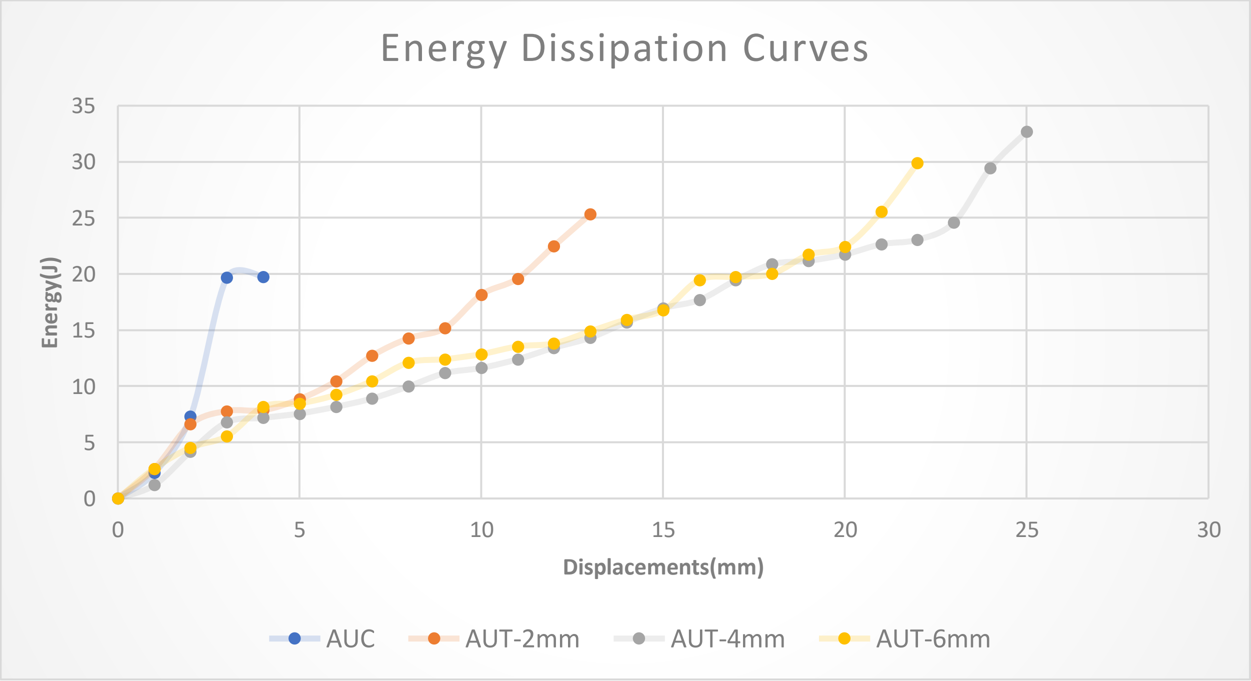


Figure 47: Energy Dissipation in 1:1.5:3 Mix Ratio, Unreinforced slabs.

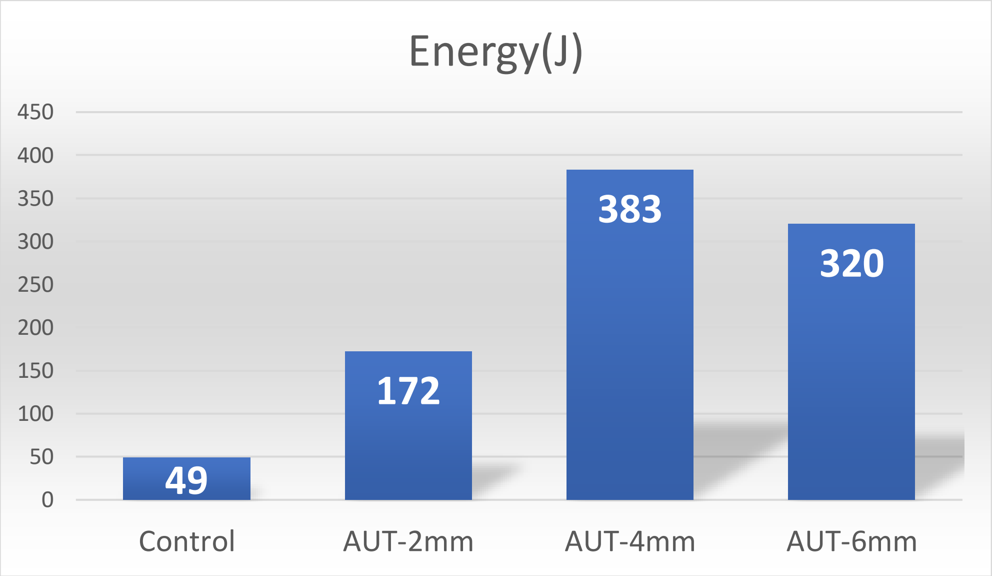


Figure 48: Comparison of 1:1.5:3 Mix Ratio, Unreinforced Slabs total energy

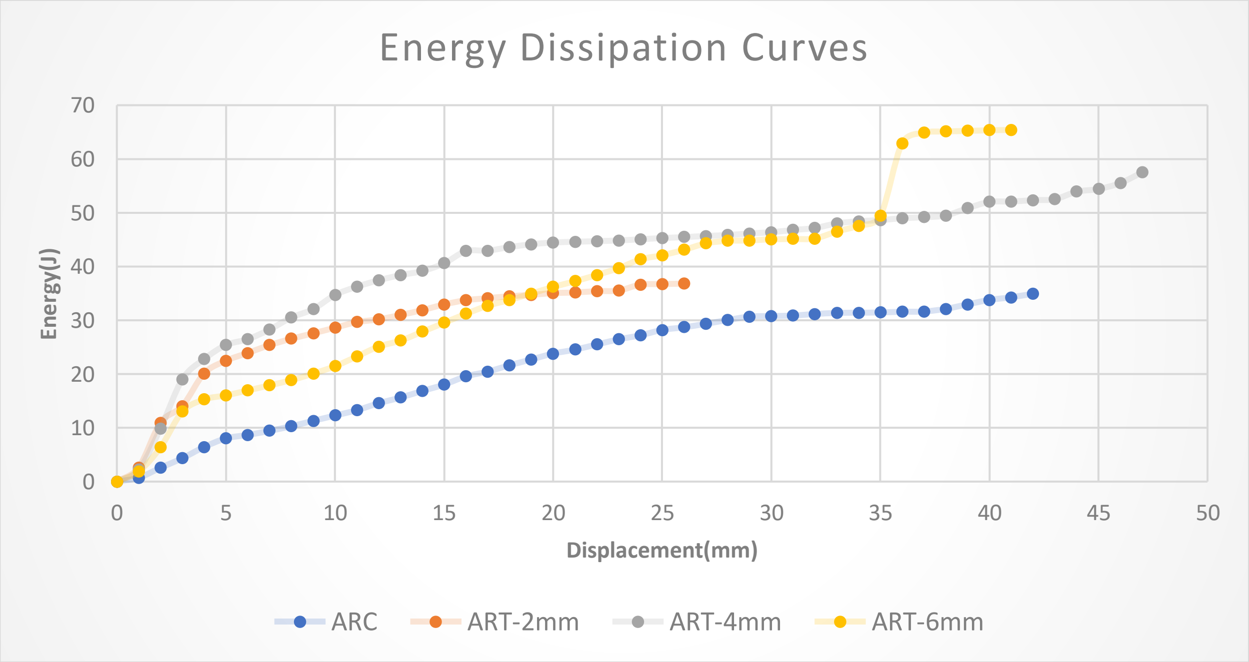


Figure 49: Energy Dissipation in 1:1.5:3 Mix Ratio, reinforced slabs.

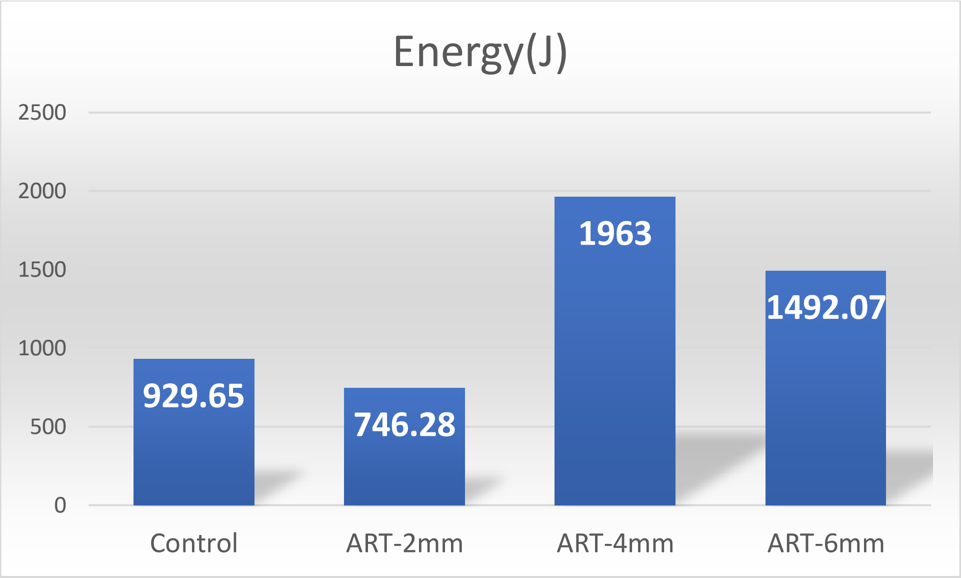


Figure 50: Comparison of 1:1.5:3 Mix Ratio, reinforced Slabs total energy

Energy dissipation is the area under the curve. Slabs which undergo large deflection, has high total energy. The slabs with reinforcement, has greater value of total energy.

4.1.1.3 Ductility

Concrete is the most suitable material in the construction industry due to its capability to attain any shape or size. Many other properties of concrete, like its strength and hardness, makes it suitable for structural applications. Concrete shows brittle behavior, which is not admissible in structures. Potential use of concrete in structure demands it to be ductile, in contrast to its brittle behavior.

Steel reinforcement is extensively used to overcome the brittle nature of concrete. Various other techniques (like confinement) are introduced to reduce the brittleness of concrete and to enhance its ductility. TSL is also known in this regard to enhance the ductility. Following graphs show the effect of TSL on ductility.

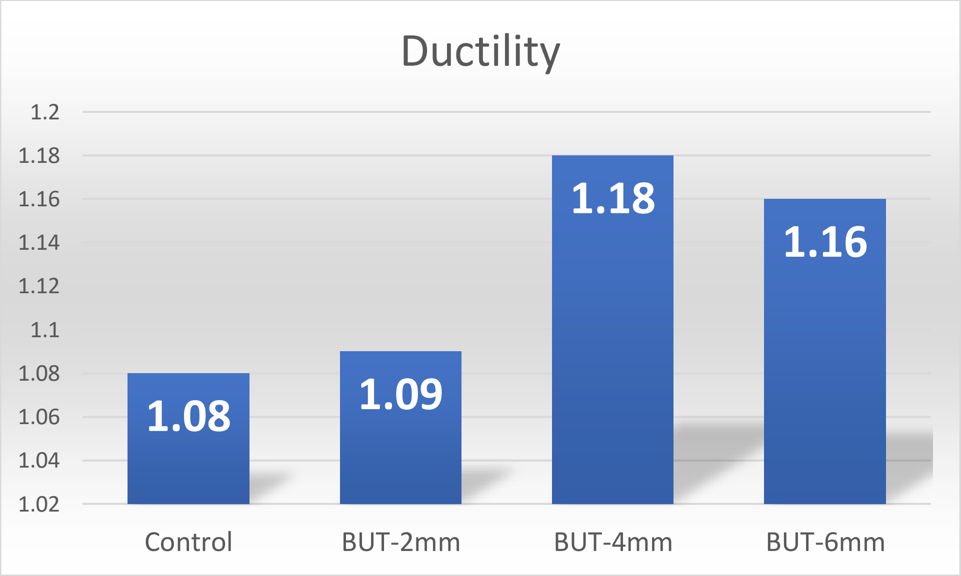


Figure 51: Comparison of 1:2:4 Mix Ratio, Unreinforced Slabs Ductility.

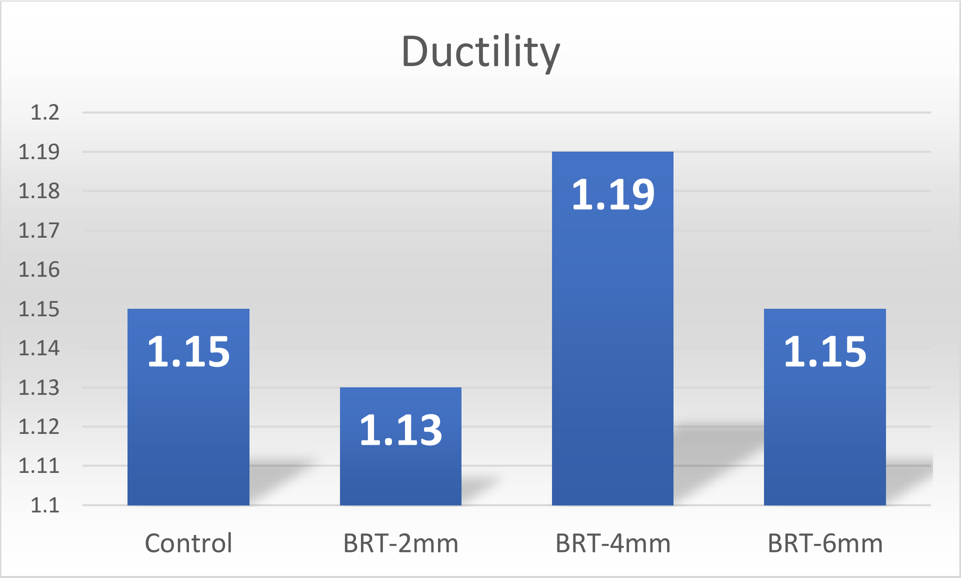


Figure 52: Comparison of 1:2:4 Mix Ratio, reinforced Slabs Ductility.

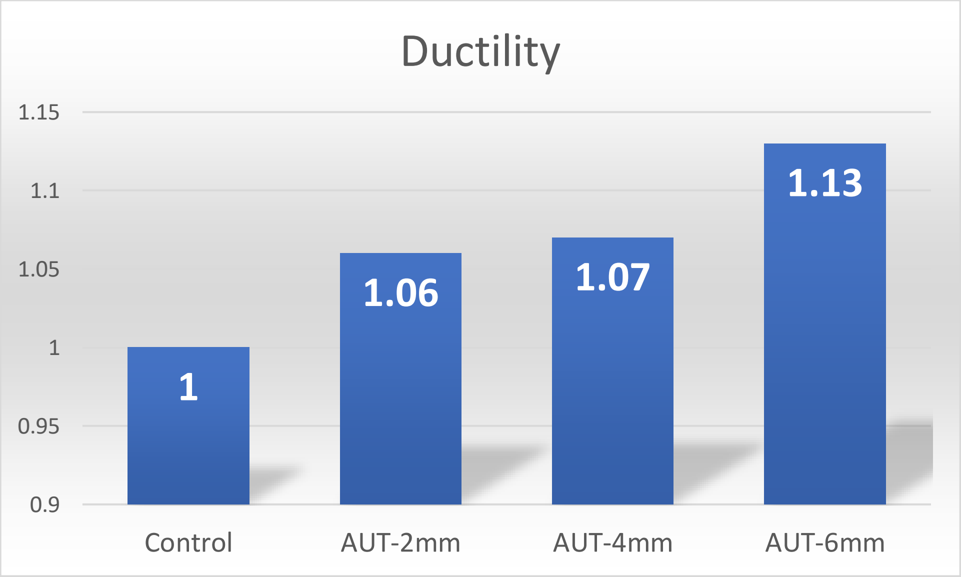


Figure 53: Comparison of 1:1.5:3 Mix Ratio, Unreinforced Slabs Ductility.

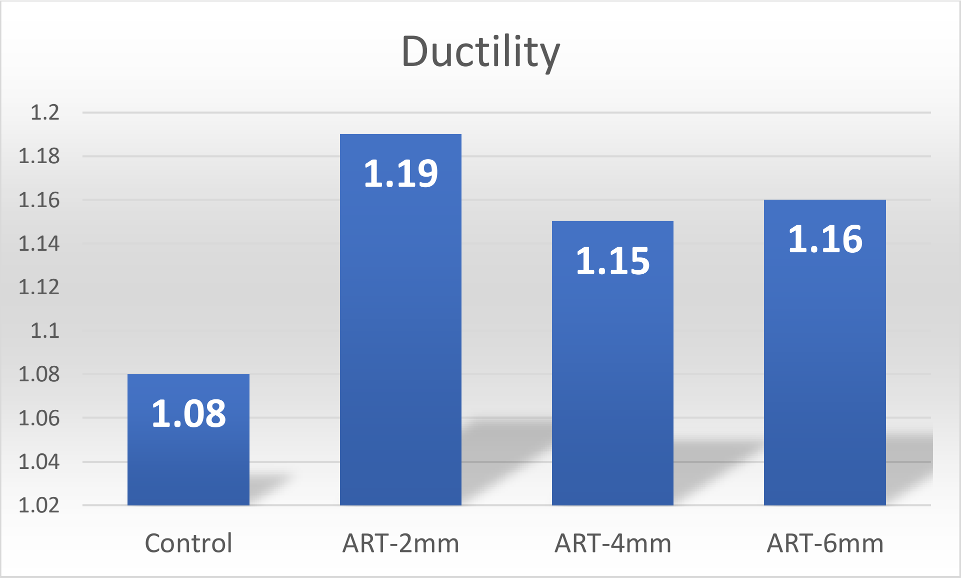


Figure 54: Comparison of 1:1.5:3 Mix Ratio, reinforced Slabs Ductility.

4.1.1.4 Stiffness

Stiffness refers to the ability to resist any deformation. It is an important parameter in structures. Stiffness at critical points (like yield or peak) important. Greater the stiffness, lesser will be the deformation.

Stiffness at peak load and yielding can be calculated from load-displacement curve. The following graphs will help in comparing the effect of Tough-Coat on different slab specimens.

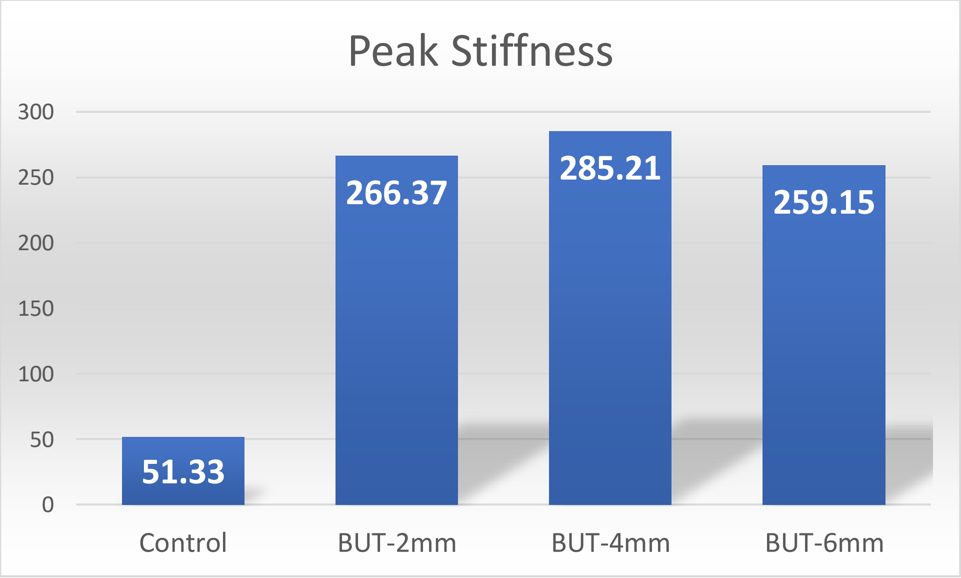


Figure 55: Values of Peak stiffness for 1:2:4 Mix Ratio, Unreinforced Slabs.

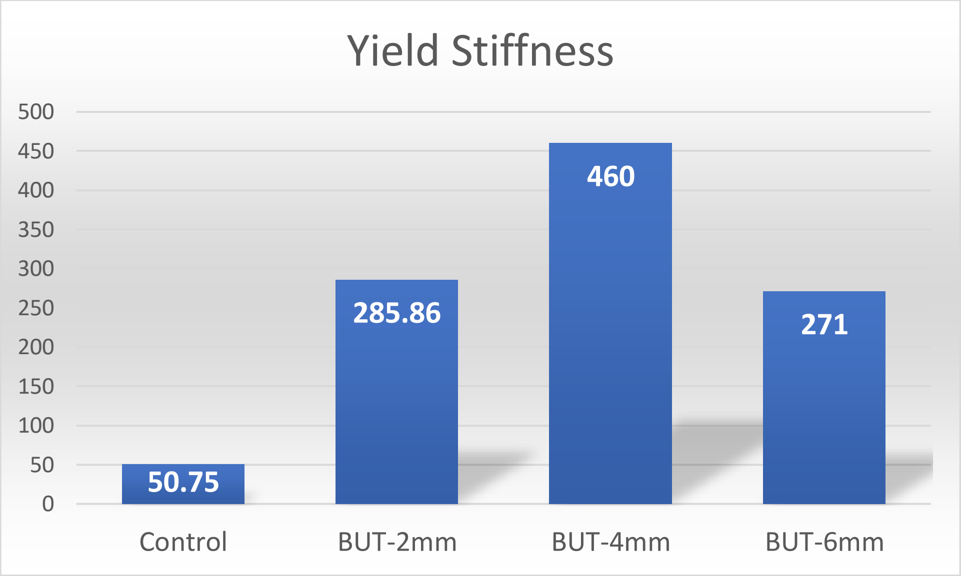


Figure 56 : Values of Yield stiffness for 1:2:4 Mix Ratio, Unreinforced Slabs.

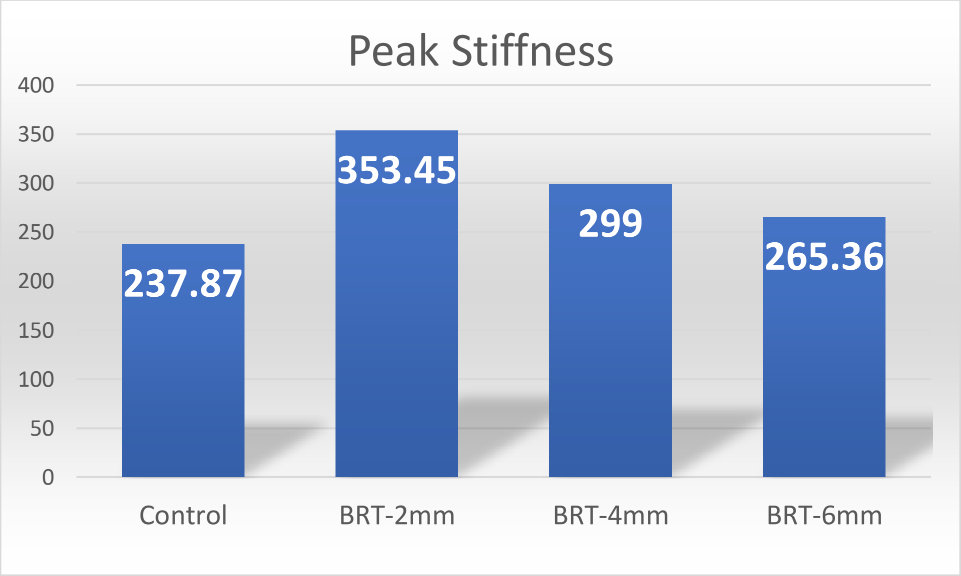


Figure 57: Values of Peak stiffness for 1:2:4 Mix Ratio, reinforced Slabs.

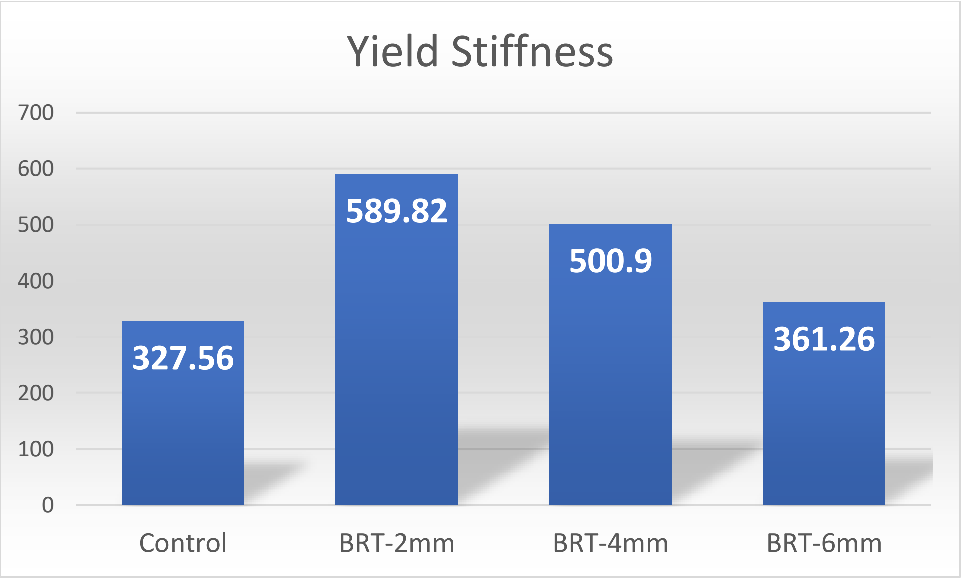


Figure 58: Values of Yield stiffness for 1:2:4 Mix Ratio, reinforced Slabs.

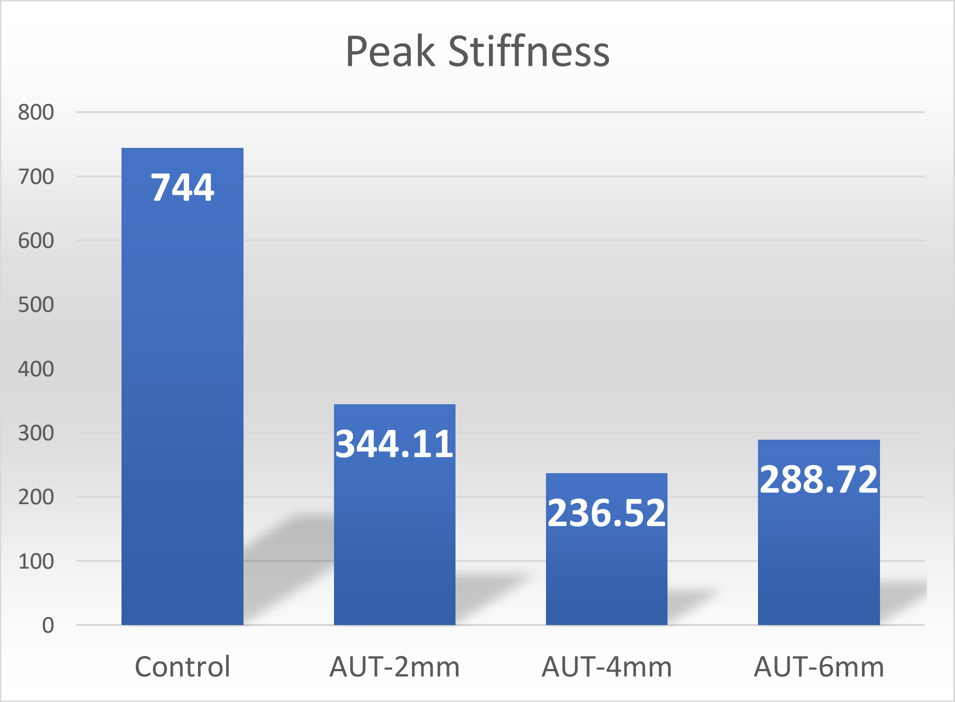


Figure 59: Values of Peak Stiffness for 1:1.5:3 Mix Ratio unreinforced slabs

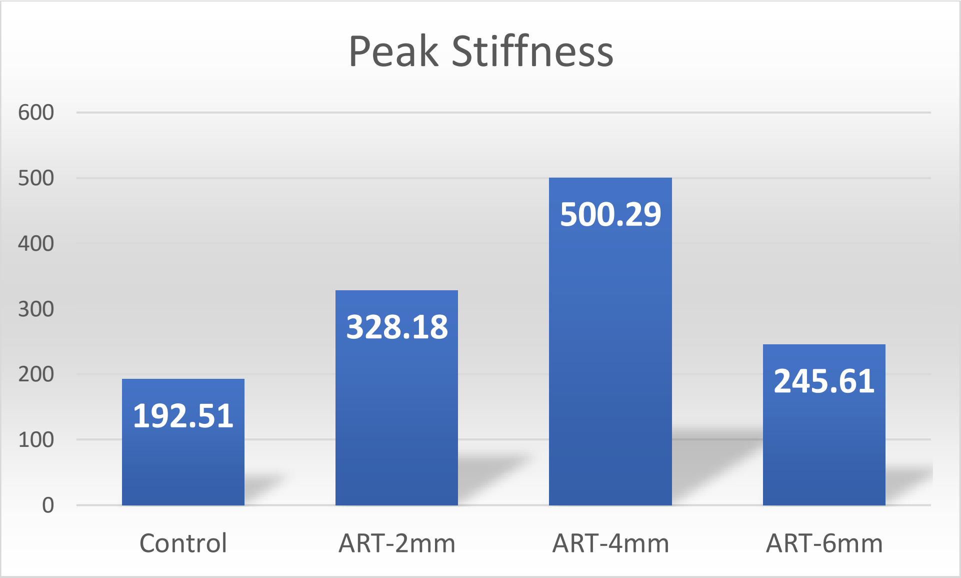


Figure 60: Values of Peak Stiffness for 1:1.5:3 Mix Ratio reinforced slabs

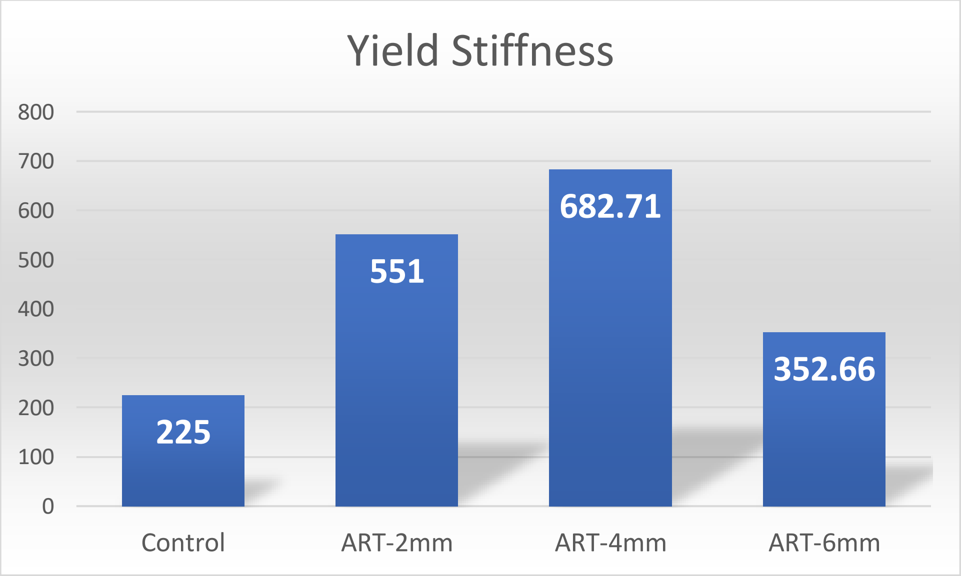


Figure 61: Values of Yield Stiffness for 1:1.5:3 Mix Ratio reinforced slabs

4.1.2 Comparison of Poly-urea and Tough Coat

Poly-urea has been used since a long time in mining and tunneling sector. After successful application of poly-urea in mining sector, now it is being used in structures to increase the strength and ductility. It is applied with the help of special plural-component spray. It also requires highly skilled labor and other resources.

Here it arises the need of another material, which can deliver same performance and also has easy application. The aim of this research is to compare the performance of two different TSL's in terms of energy dissipation, peak load, yield load, stiffness and ductility. So, the new TSL selected for comparison is Tough-Coat 150. It is applied by simple brush technique, just like ordinary paint.

In this part, the comparison is done between poly-urea and tough-coat 150. Both are applied by two different methods. Poly-urea is applied by spray, while tough-coat is applied with help of simple brush technique.

Comparison of various parameters is given below;

4.1.2.1 Peak and Yield Load

Ultimate and yield load capacity has been increased by both poly-urea and tough-coat. Peak load value of the slab also increases by increasing the thickness. But the comparison shows that tough-coat has increased this value more as compare to the poly-urea.

Here is the comparison of enhanced peak and yield load values for various specimens;

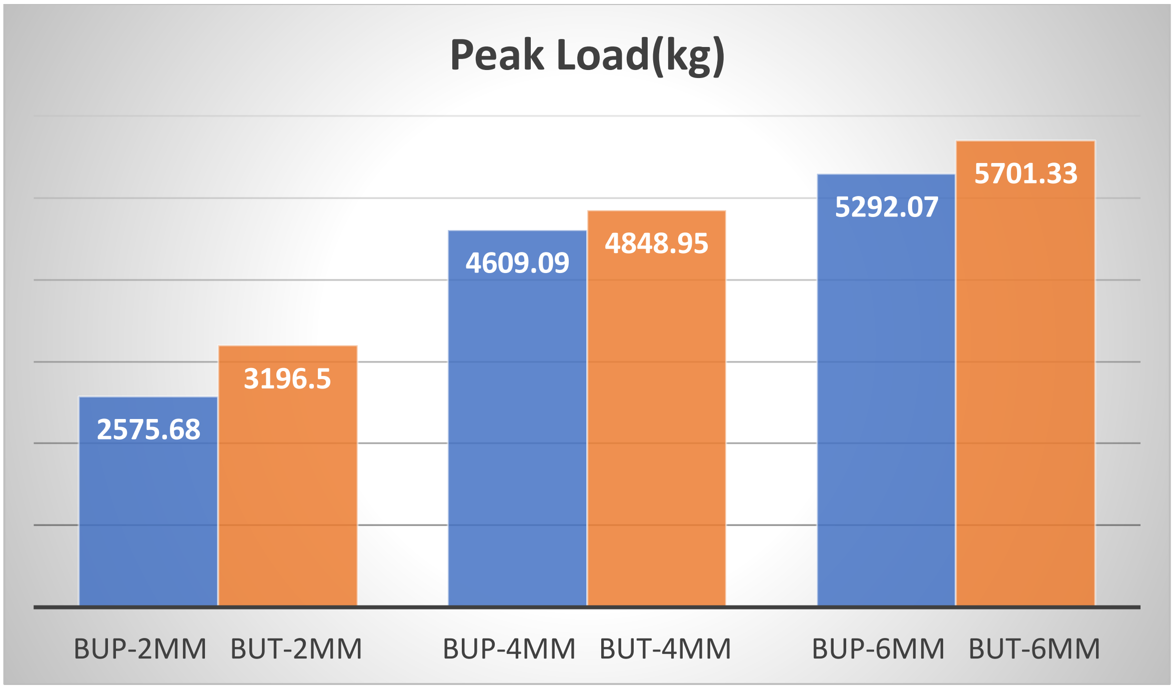


Figure 62: Comparison of peak load values for Tough-coat and Poly-urea coated, 1:2:4 mix ratio, unreinforced slabs.

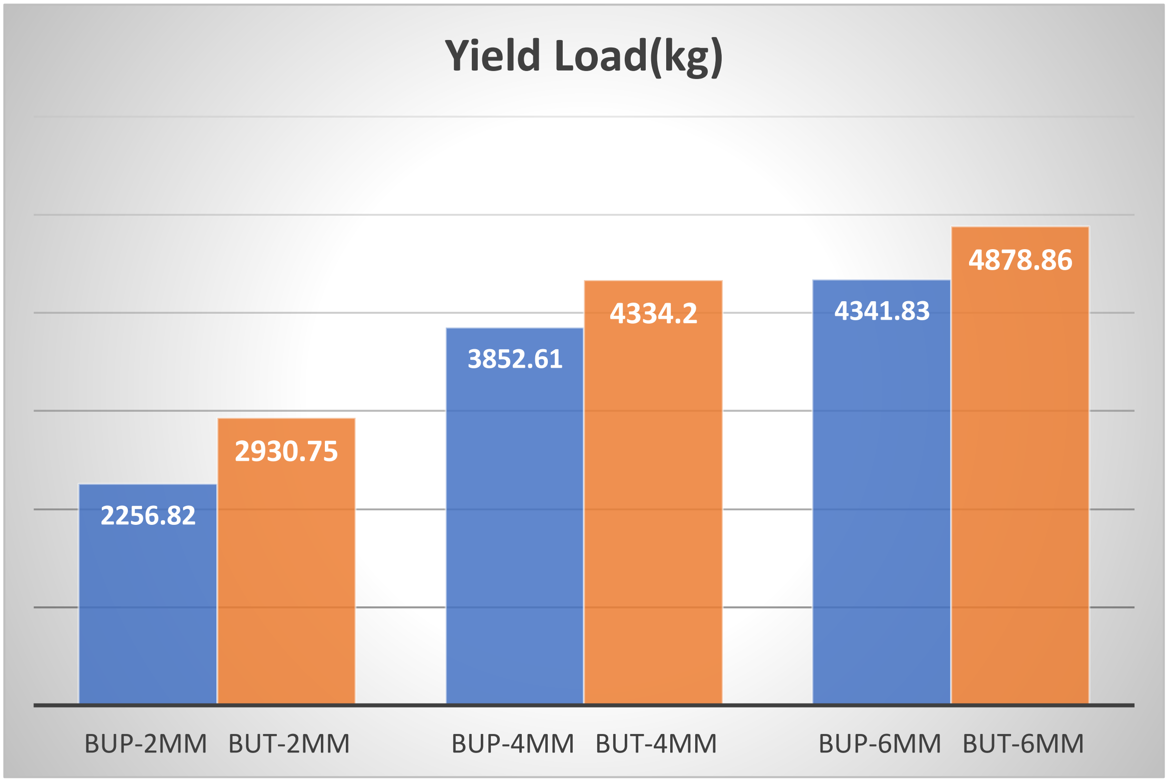


Figure 63: Comparison of Yield load values for Tough-coat and Poly-urea coated, 1:2:4 mix ratio, unreinforced slabs.

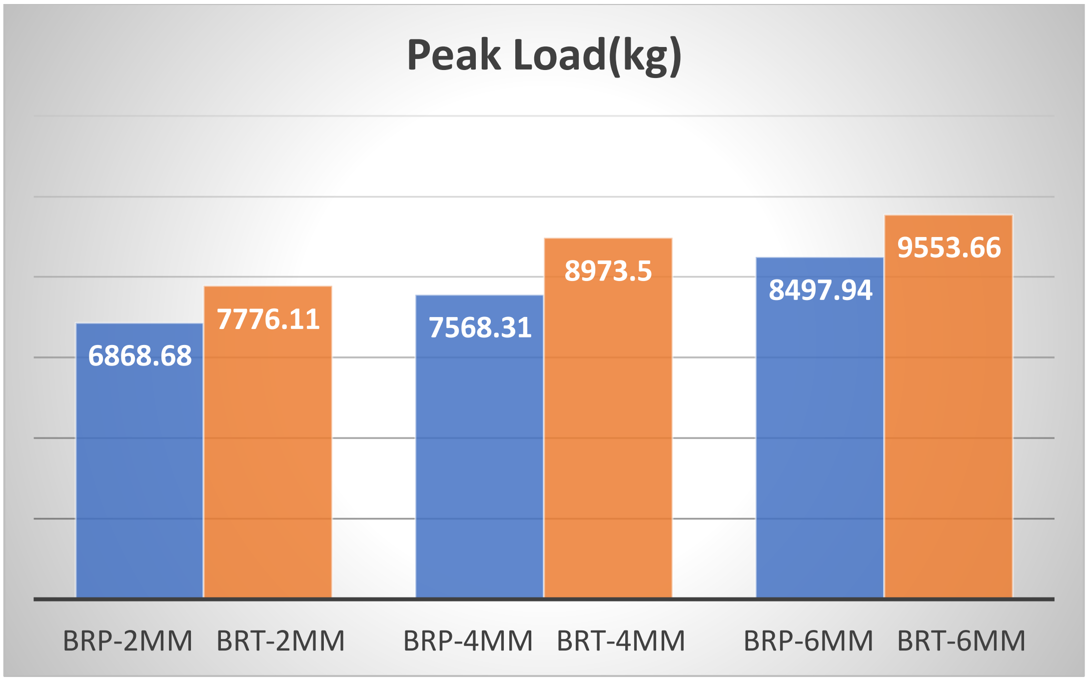


Figure 64: Comparison of peak load values for Tough-coat and Poly-urea coated, 1:2:4 mix ratio, reinforced slabs.

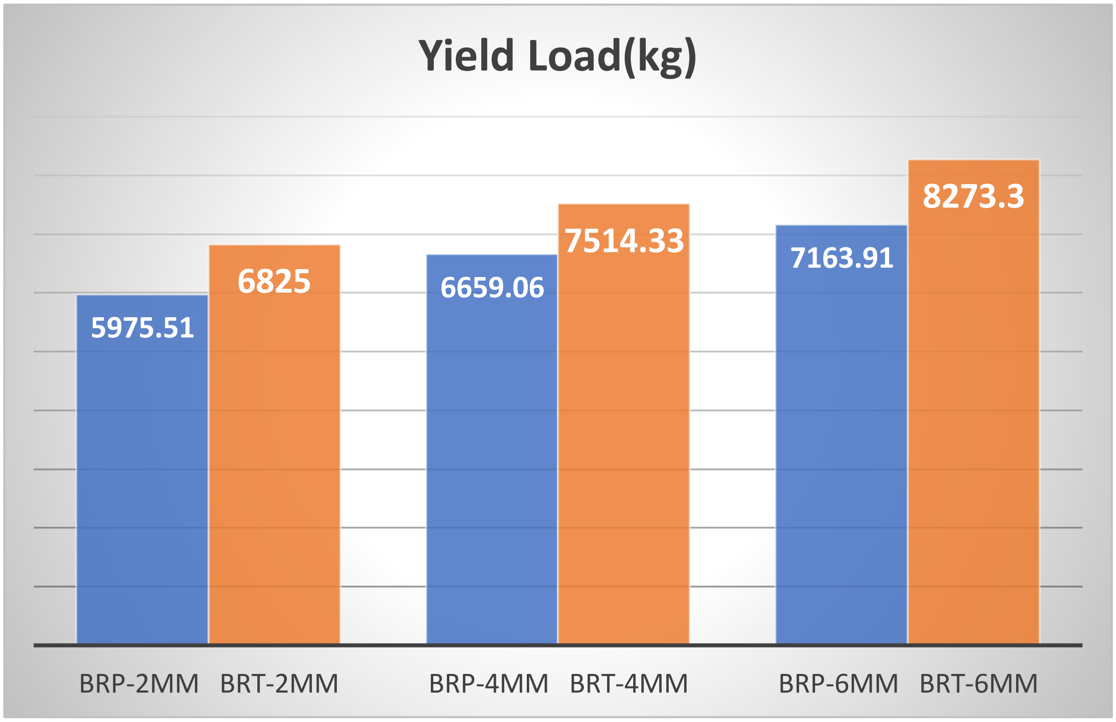


Figure 65: Comparison of yield load values for Tough-coat and Poly-urea coated, 1:2:4 mix ratio, reinforced slabs.

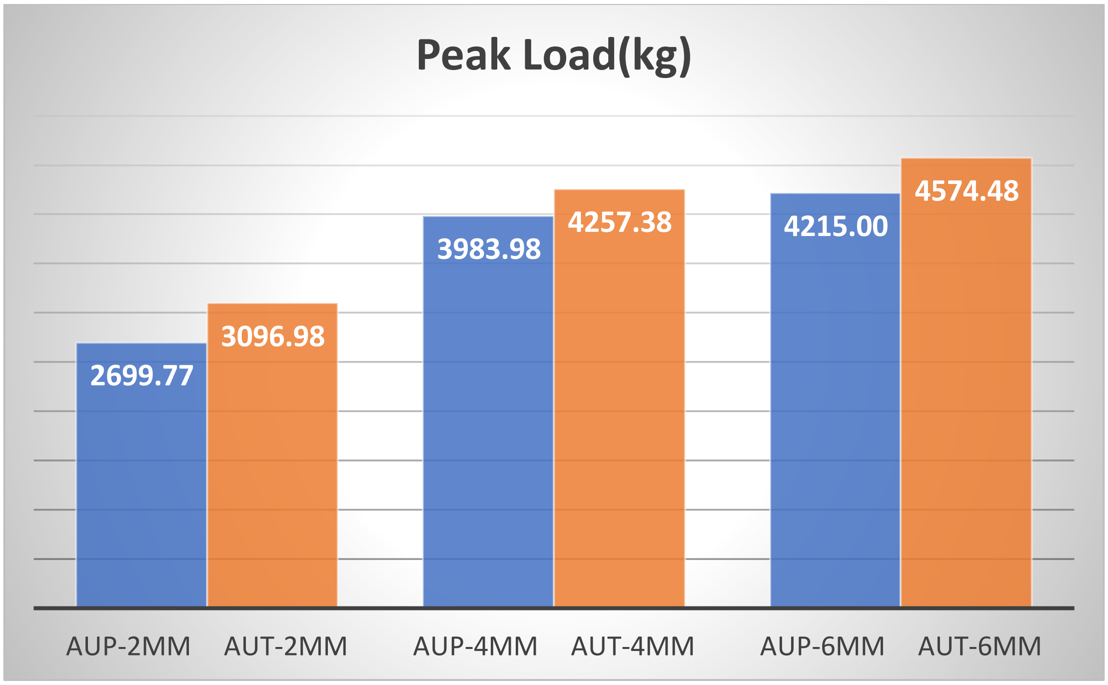


Figure 66: Comparison of peak load values for Tough-coat and Poly-urea coated, 1:1.5:3 mix ratio, unreinforced slabs.

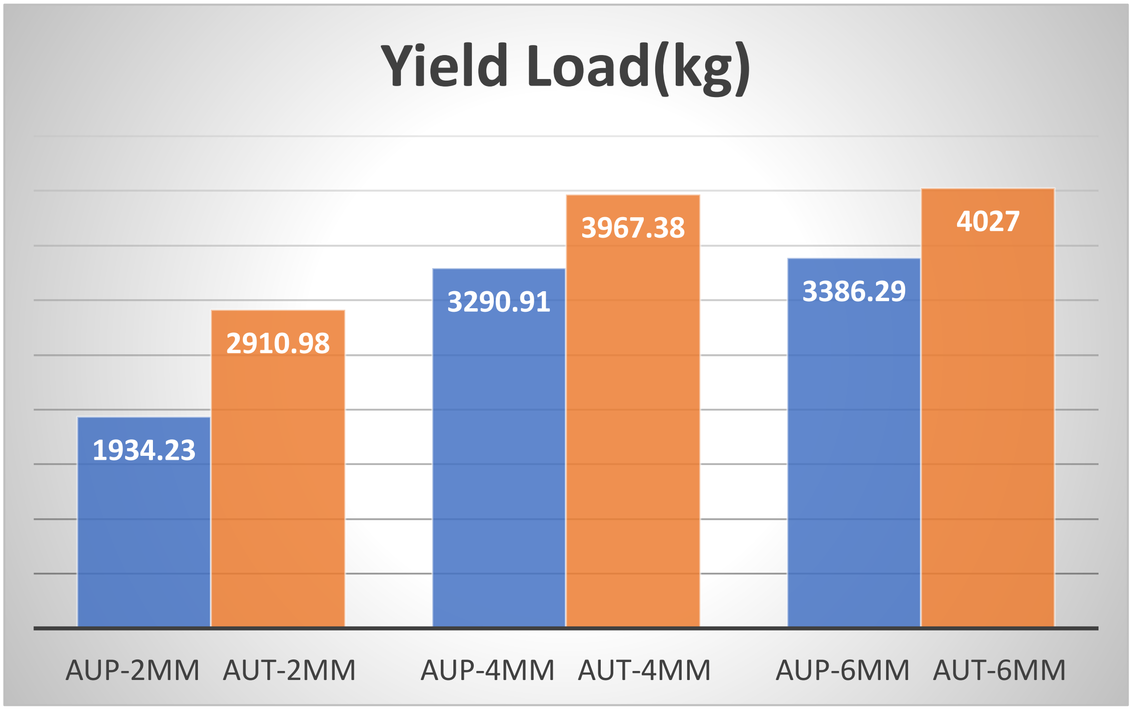


Figure 67: Comparison of Yield load values for Tough-coat and Poly-urea coated, 1:1.5:3 mix ratio, unreinforced slabs.

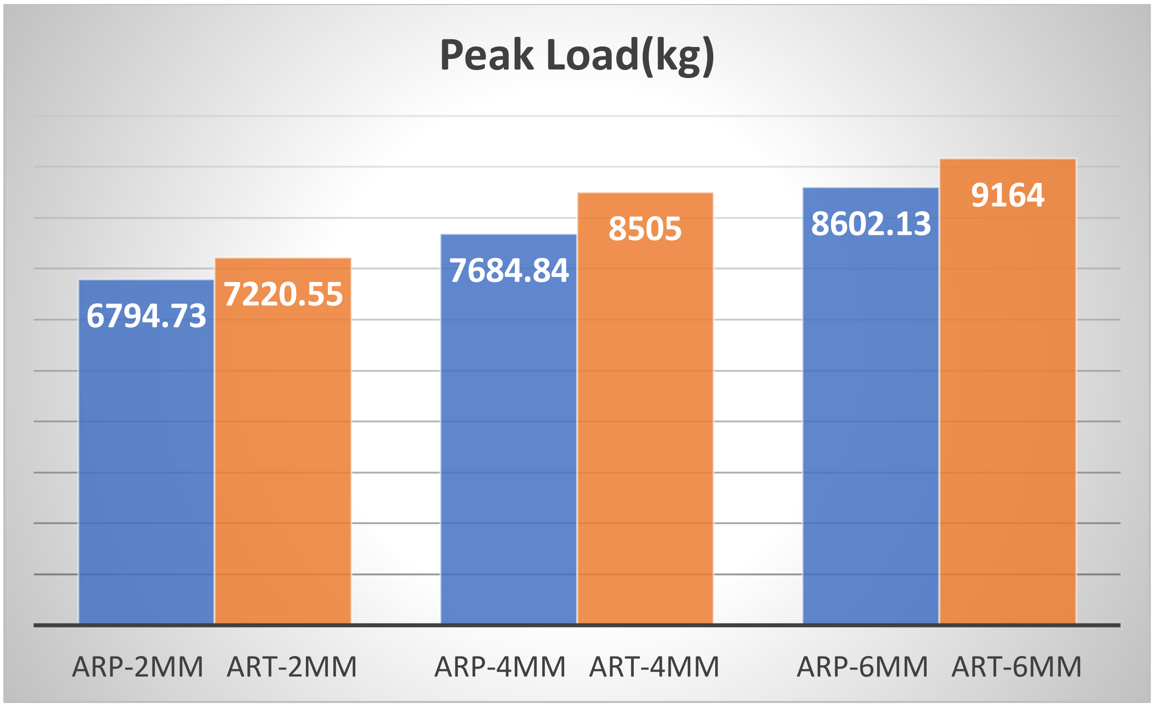


Figure 68: Comparison of peak load values for Tough-coat and Poly-urea coated, 1:1.5:3 mix ratio, reinforced slabs.

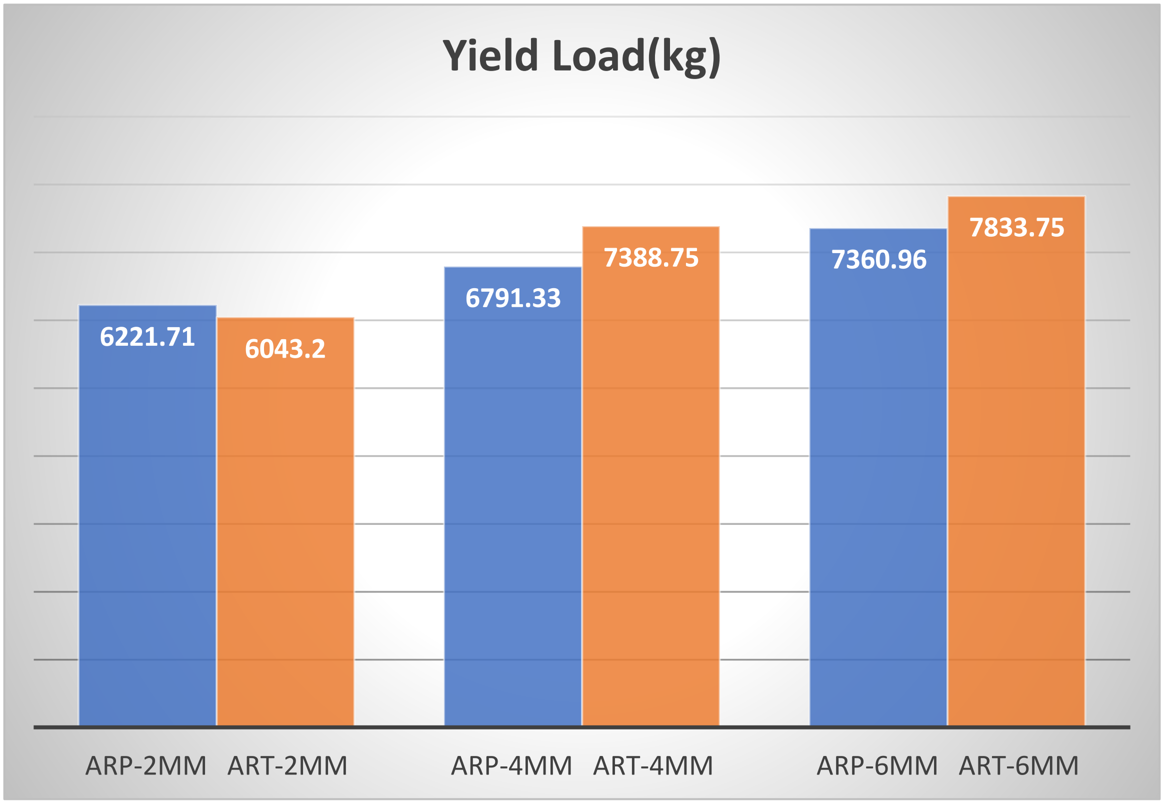


Figure 69: Comparison of Yield load values for Tough-coat and Poly-urea coated, 1:1.5:3 mix ratio, reinforced slabs.

4.1.2.2 Energy Dissipation

Area under the load-displacement curve gives us the total amount of energy dissipated by the slab. Poly-urea and Tough-coat both has increased the energy dissipation in slabs.

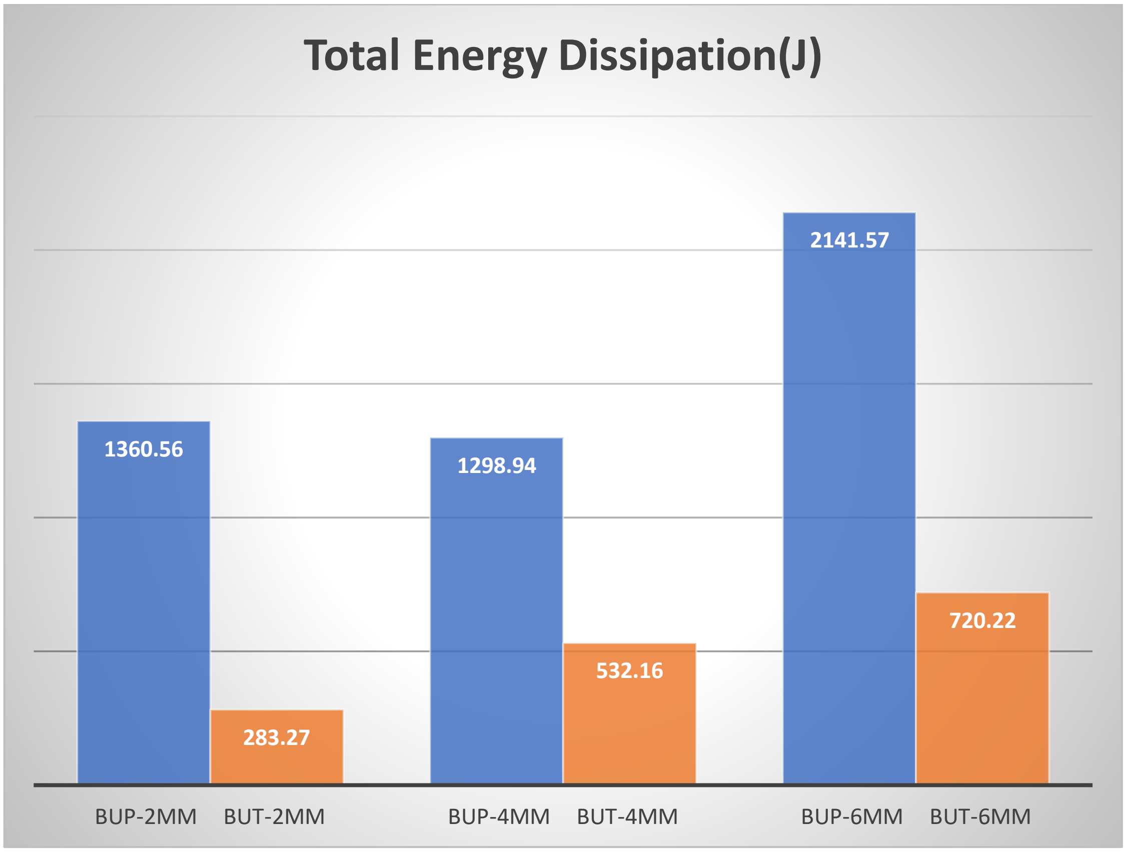


Figure 70: Comparison of total energy values for Tough-coat and Poly-urea coated, 1:2:4 mix ratio, unreinforced slabs

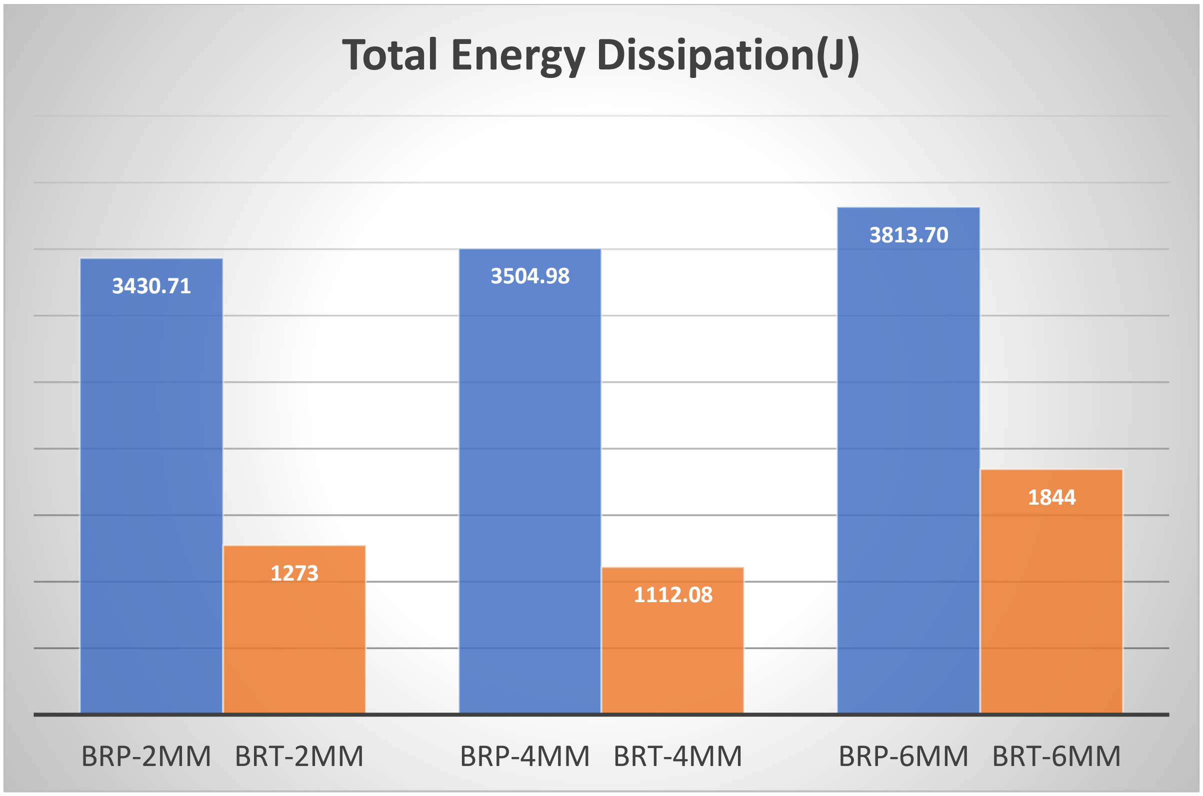


Figure 71: Comparison of total energy values for Tough-coat and Poly-urea coated, 1:2:4 mix ratio, reinforced slabs.

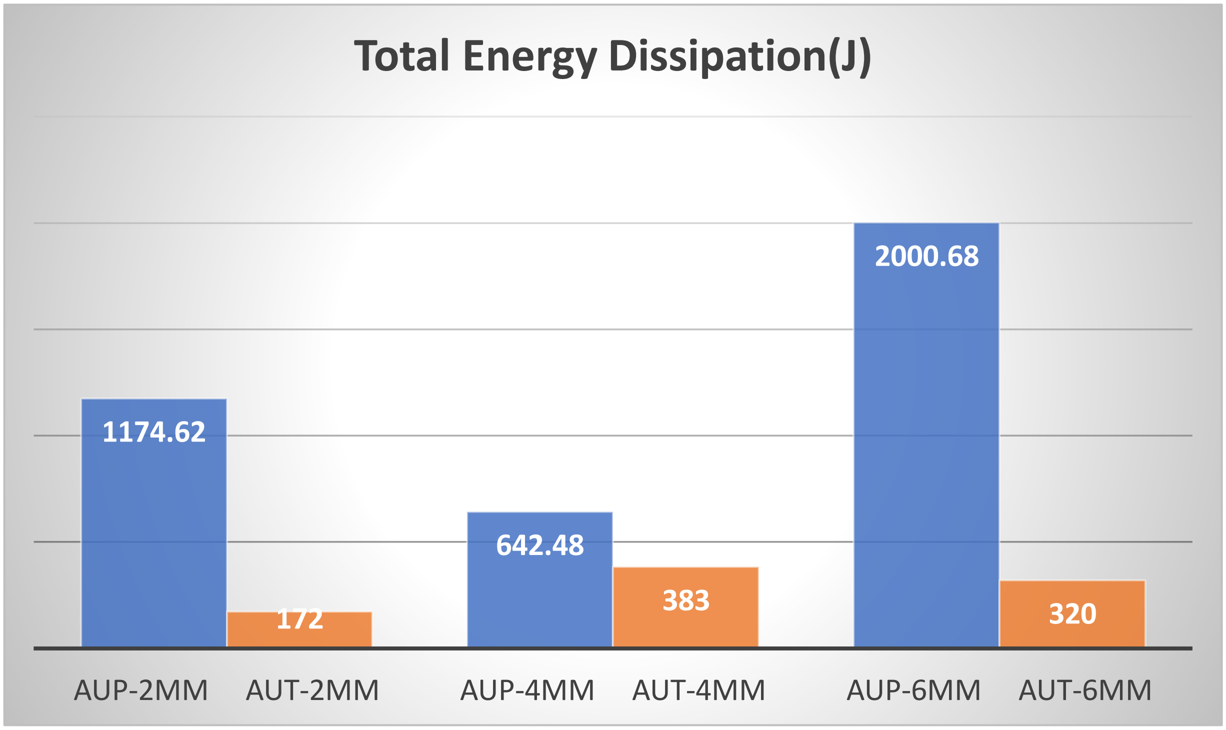


Figure 72: Comparison of total energy values for Tough-coat and Poly-urea coated, 1:1.5:3 mix ratio, unreinforced slabs.

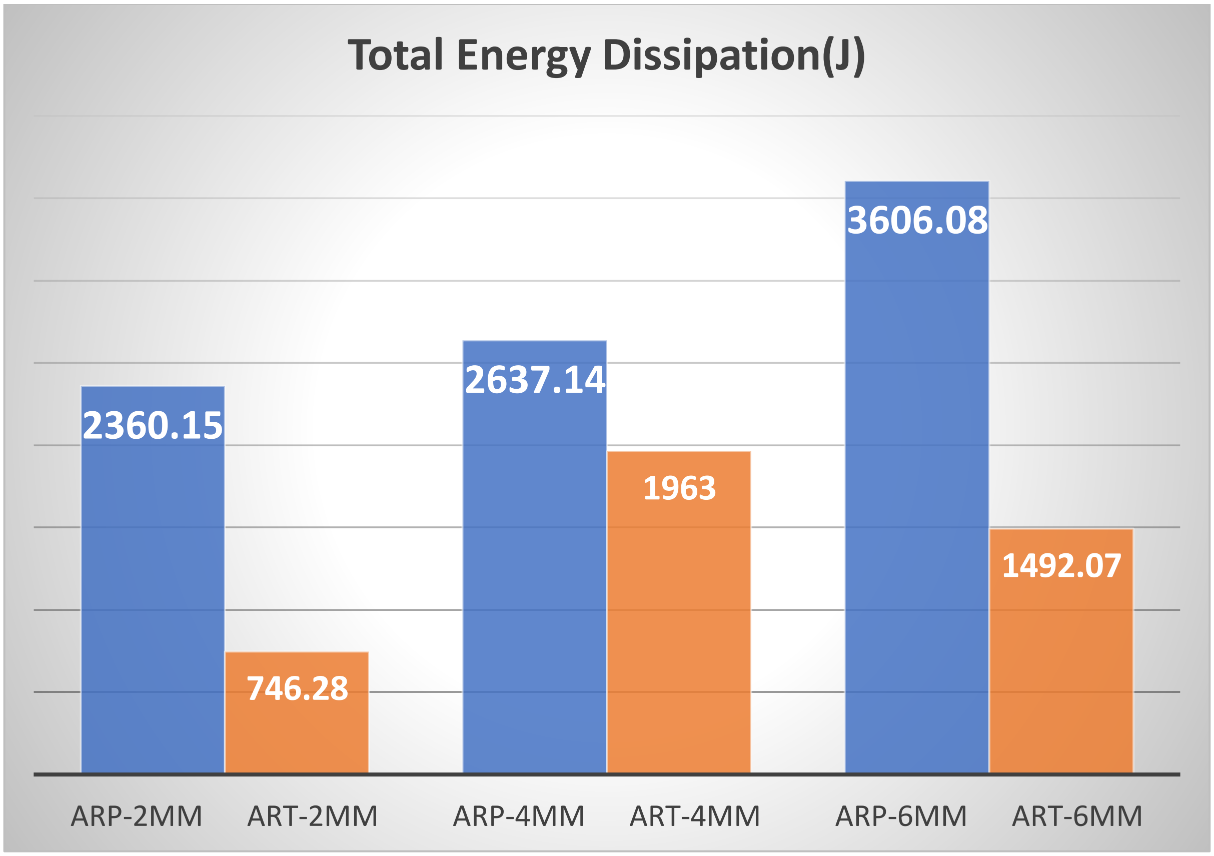


Figure 73: Comparison of total energy values for Tough-coat and Poly-urea coated, 1:1.5:3 mix ratio, reinforced slabs.

Energy dissipation is total area under the load displacement curve. Peak load capacity is greater for tough-coat. But poly-urea has shown more total energy dissipation.

4.1.2.3 Ductility

Concrete shows brittle behavior, which is not admissible in structures. Potential use of concrete in structure demands it to be ductile, in contrast to its brittle behavior. Those materials are more preferred, which increase the ductility of concrete.

Here is the comparison of enhanced ductility by poly-urea and tough-coat:

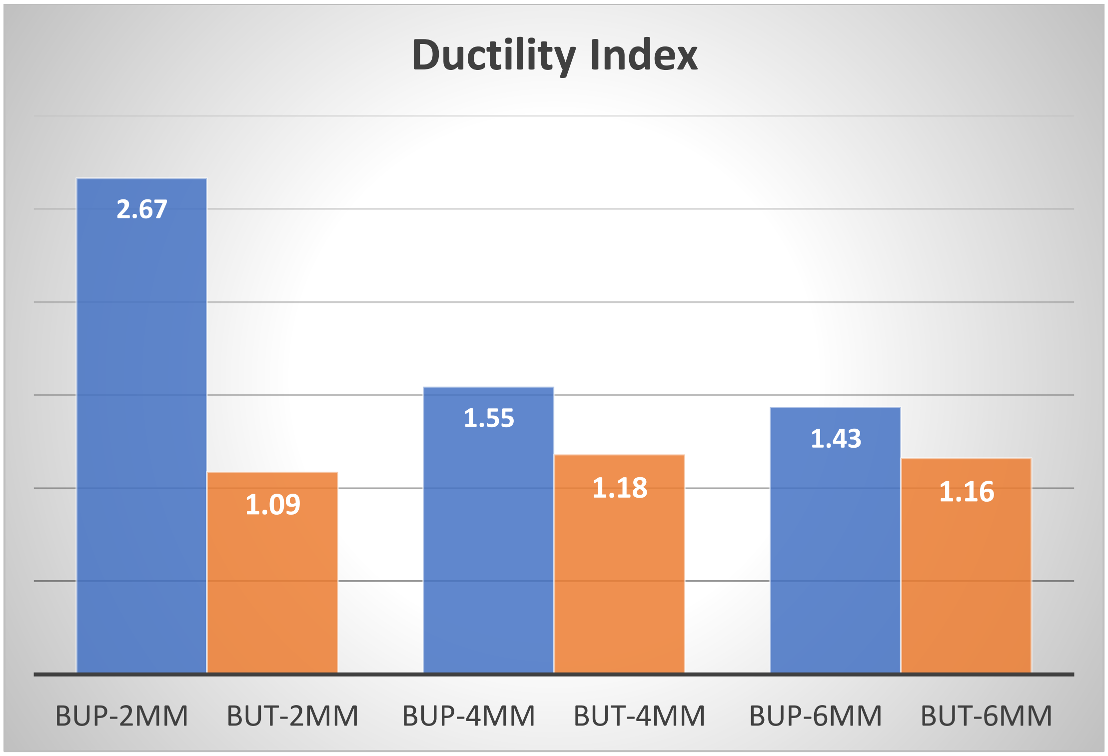


Figure 74: Comparison of ductility values for Tough-coat and Poly-urea coated, 1:2:4 mix ratio, unreinforced slabs.

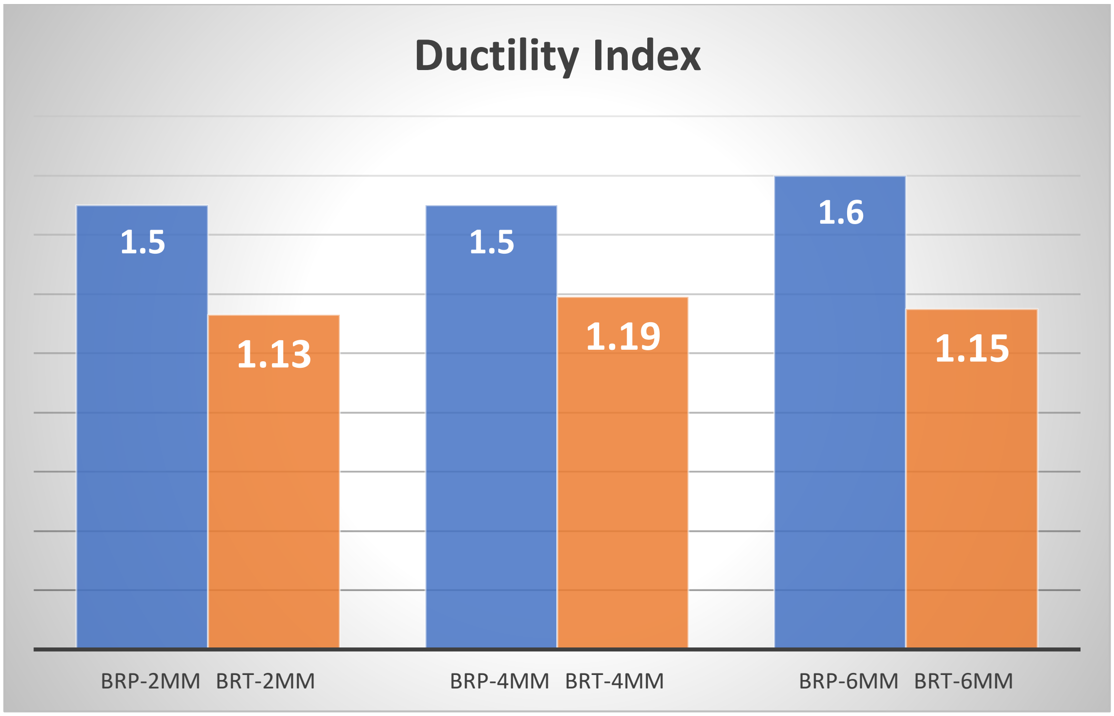
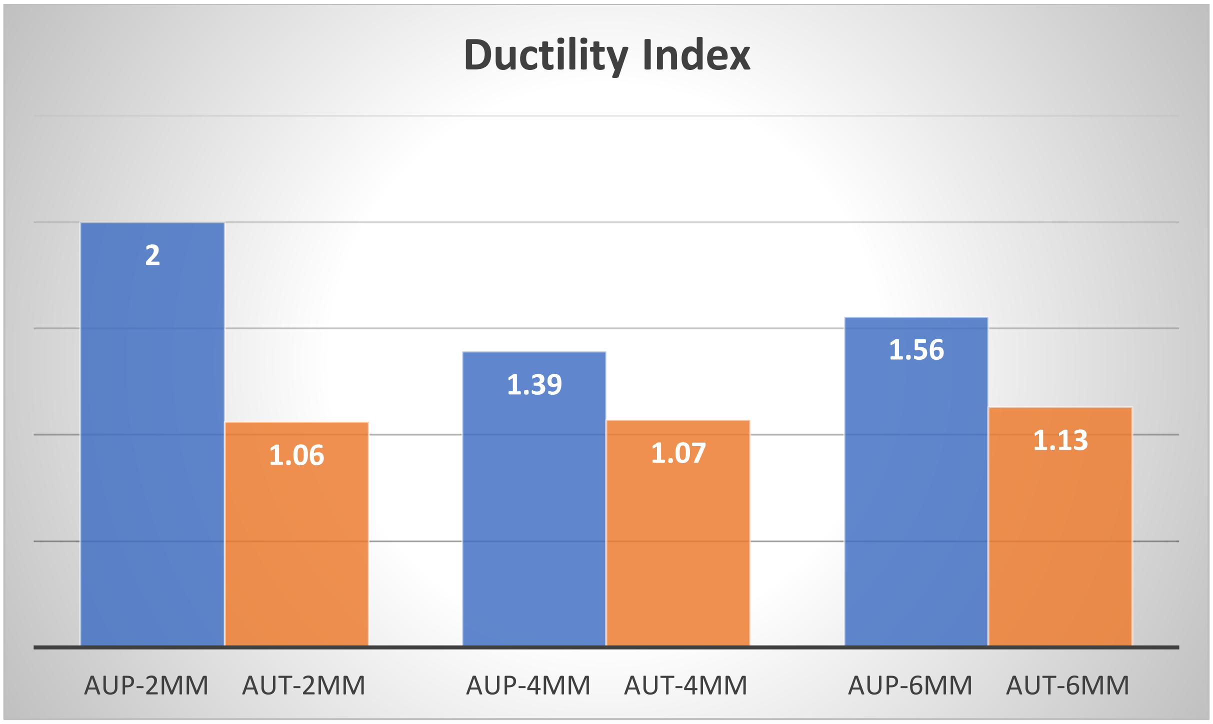


Figure 75: Comparison of ductility values for Tough-coat and Poly-urea coated, 1:2:4 mix ratio, reinforced slabs



.*Figure 76: Comparison of Ductility values for Tough-coat and Poly-urea coated, 1:1.5:3 mix ratio, unreinforced slabs.*

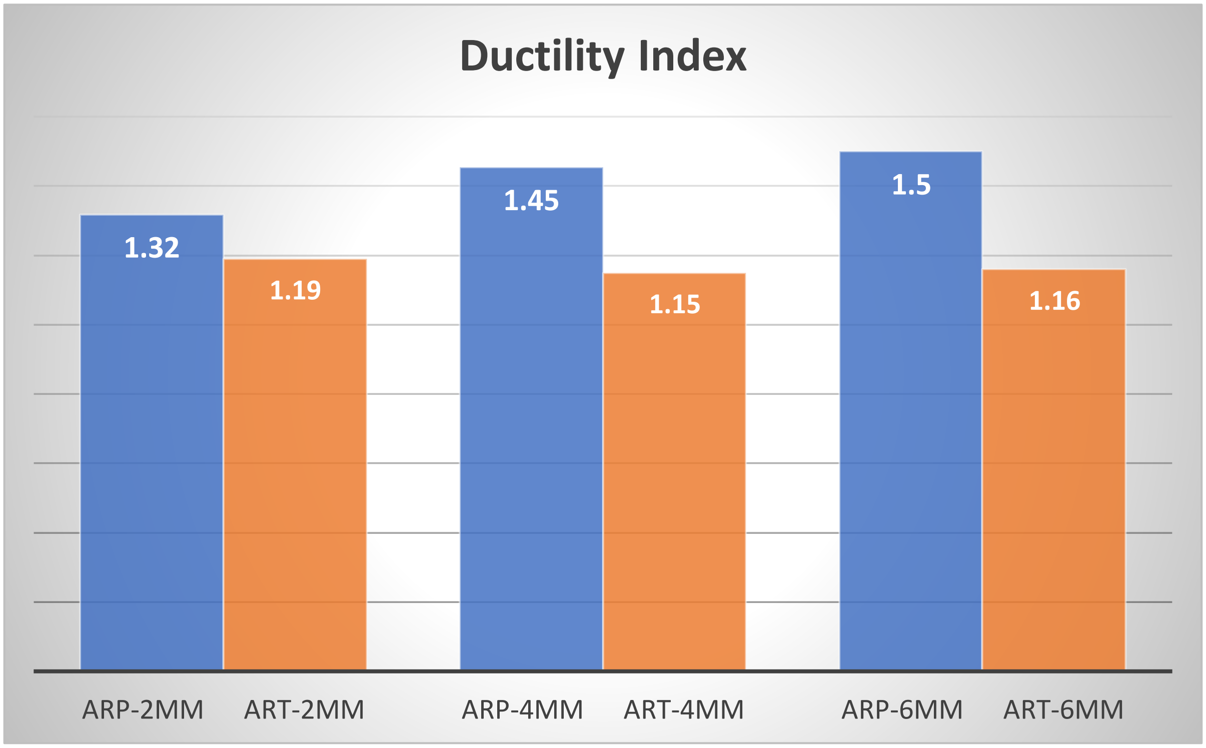


Figure 77: Comparison of Ductility values for Tough-coat and Poly-urea coated, 1:1.5:3 mix ratio, reinforced slabs

4.2 Analysis

It is clear from the graphs shown in the previous section that Tough-Coat application did result in an increase in strength for the slabs. Furthermore, an increase in Tough-Coat thickness also resulted in an increase in slab strength in terms of both Yield and Ultimate loads.

When comparing concrete strengths, it can be seen that there was negligible effect of a change in mix ratio for slabs coated with Tough-coat as opposed to data for Control slabs. It can therefore be inferred that Tough-coat was a dominant factor in determining slab strengths when applied instead of the mix ratio used in casting of concrete.

4.2.3 Assessment of Parameters & Conclusions

All parameters previously determined (Stiffness, Peak Load, Yield, Ductility and Energy Dissipation) were found to have improved with the application of Poly-urea and tough-coat on the slabs. More energy was dissipated due to application of Poly-urea while at the same time, collapse occurred at a fairly greater displacement for these slabs. On the other hand, tough-coat showed an increase in ultimate load carrying capacity.

This goes on to show that control of effective energy dissipation in critical or sensitive areas is possible with the application of Poly-urea. Furthermore, Poly-urea and tough-coat application can result in aesthetically pleasing structures.

4.3 Recommendations

Given the results obtained in this study as well as those discussed in the literature review, use of TSL may be recommended for strengthening / enhancing ductile performance of flexural members in a structure such as slabs and beams. Also due to higher ductility, it may also be recommended to enhance seismic performance of structural components.

However the following variables need to be studied for more in-depth knowledge into Polyurea performance and to improve the reliability of results over a wide spectrum of applications:

- Behavior of slabs with large spans when treated with TSL
- Effect on confinement of compression members
- Effect of differing steel reinforcement ratios in TSL-coated slabs
- Effect of change in dimensions of TSL-coated slabs

5 References

ARCHIBALD, J. F. (2001). Assessing acceptance criteria for and capabilities of liners for mitigating ground falls. *Mining Health and Safety Conference, Sudbury, Ontario, April 2001, 31 pages.*

Ayman S. Mosallam , K. M. M. (2003). Strengthening of two-way concrete slabs with FRP composite laminates. *Construction and Building Materials, 17*, 43-54.

Collins, M., & Mitchell, D. . (1987). Prestressed Concrete Basics. Ottawa, ON, Canada. *Canadian Prestress Concrete Institute*.

D.D, T. (2001). Thin Spray-on liners for underground rock support. *17"' Int. Mining Congress and Exhibition of Turkey. IMCET200I. Eds. E. Unal, B. Unver & E. Tercan. Ankara. Turkey, pp. 57-65*.

Espley, S. J., Tannant, D.D.,Baiden, G, and kaiser, P.K. . (1999). design criteria for thin spray-on membranes for underground hardrock mining." *CIM-AGM, Calgary, Alberta*.

ESPLEY, S. J., GUSTAS, R., HEILIG, J., and MOREAU, L.H. . (2011). Thin spray-on liner research and field trials at INCO". Surface Support Liners: Membranes, Shotcrete and Mesh, . *Australian Centre for Geomechanics , Australia. Sect.25*.

H. Yılmaz, S. S., A. Z. Toper. (2003). *Emerging Support Concept: Thin Spray-on Liners* Paper presented at the International Mining Congress and Exhibition ot Turkey.

HENDERSON, N., and LOUW, D. . (2001). Underground performance of Mondi® Rock-Hold™ a structural membrane. *Surface Support Liners: Membranes, Shotcrete and Mesh. Australian Centre for Geomechanics, Perth. Sect.28*.

HEPWORTH, N., and LOBATO, J. . (2002). Tekflex resin spray field trials – Neves Corvo Mine, Portugal. *2nd Int. seminar on Surface Support Liners: Thin Sprayed Liners, Shotcrete, Mesh. Crowne Plaza Sandton, RSA. Sect.19*.

J., E. (2000). Assessment of the applicability of legislation,pertaining Hi the prevention of rock related accidents occurring at South African metalliferous mines. . *M.Sc. Research Report. University of the Witwatersrand.Johannesburg*.

Lacerda, L. (2004). Shotcrete and Other Surface Support Liners. *Proceedings of SME Annual Meeting Feb. 23-25, Denver, Colorado, 2004*.

LEWIS, B. (2001). Mondi Rock-HoldTM the development of this structural membrane support. *Surface Support Liners: Membranes, shotcrete and Mesh. Australian Centre for Geomechanics, Perth. Sect.18*.

Moreau, L. H. (2006). Thin Spray-on Liners: Assessment of Support Performance Under Dynamic Loading Conditions. . *The University of British Columbia*.

Mpunzi, P., Masethe, R., Rizwan, M., & Stacey, T. . (2015). Enhancement of the Tensile Strengths of Rock and Shotcrete by Thin Spray-on Liners. *Tunnelling and Underground Space Technology, 369-375*.

oladapo, i. o. (1964). Cracking and Failure in Plain Concrete Beams. *Magazine of Concrete Research 16*(47), 103-110.

P., A. J. F. M. R. A. L. (1992). The evaluation of thin polyurethane surface coatings as an effective means of ground control. *Prat. Int. Svmp. on Rock Support in Mining and Underground Construction, Balkema. Rotterdam, pp. I OS-1 IS*.

pirrodi, F. a. (2011). THE APPLICATION OF GRP AND THIN SPRAY LINER SUPPORT PRODUCTS IN A TYPICAL BLOCK CAVE MINING METHOD TO ENHANCE SAFETY AND PRODUCTIVITY.

Potvin, Y. (2002). Towards a common understanding of TSL applications in mines. *2nd International Seminar on Surface Support Liners: Thin Sprayed Liners, Shotcrete, mesh*.

REYNOLDS, D. O., and LEACH, A.R. . (2002). The use of engineered cements in thin section support systems for water sensitive strata. *2nd Int. Seminar on Surface Support Liners: Thin Sprayed Liners, Shotcrete, Mesh. SAIMM, Sandton, RSA, Sect.6*.

SPEARING, A. J. S., BOREJSZO, G., and CAMPOLI, A. . (2009). The application of a structural thin support liner (TSL) on mines. *43rd U.S. Rock Mechanics Symposium and 4th U.S.-Canada Rock Mechanics Symposium*.

Xianhong, M., & Yupu, S. . (2007). Residual Tensile Strength of Plain Concrete Under Tensile Fatigue Loading. *Journal of Wuhan University of Technology-Mater. Sci, Ed. Sept 2007, 564-568*.

Yilmaz, H. (2010). Tensile Strength Testing of Thin Spray-on Liner Products (TSLs) and Shotcrete. *Journal of the Southern African Institute of Mining and Metallurgy, 559-569*.

Yilmaz, H. (2011). Development of Testing Methods for Comparative Assessment of Thin Spray-on Liner (TSL) Shear and Tensile Properties. *Johannesburg: University of the Witwatersrand*.

Youssef, E.-F. E. (2008). Flexural Behavior of Protected Concrete Slabs after Fire Exposure.