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MASTER OF ENGINEERING (CIVIL)

DUCTILITY PERFORMANCE OF CONCRETE CONTAINING DIFFERENT PERCENTAGE OF RECYCLED PLASTIC AND RECYCLED CONCRETE AGGREGATES

By

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Submitted to the College of Science and Engineering in partial fulfilment of the requirements for the degree of Master of Engineering (Civil) at Flinders University Adelaide, Australia.

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Declaration of Authorship

I certify that this work does not incorporate, without acknowledgement, any material previously submitted for a degree or diploma in any University; and that to the best of my knowledge, does not contain any material previously published or written by another person except where due reference is made in the text.

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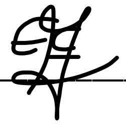

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We did it all together! Thank you!

Ne ja dolem te gjithe se bashku! Faleminderit!

Executive Summary

According to (Tarmac, 2022), concrete is the most widespread composition in the construction world, but its manufacture and applications are complex. When produced, concrete has a substantial environmental impact due to its energy consumption and releases of greenhouse emissions where 4-5% of the worldwide total of CO_2 is caused by cement production (Hamakareem, n.d.). On 3 March 1983, a research ream funded by the government approximated that almost 17% of worldwide landfill was the product of concrete-based waste

To reduce the concrete's impact and to produce an eco-friendlier product that can be adopted worldwide, a more environmentally approach needed to be found. This approach is related to the utilisation of plastic waste by combining it with coarse aggregates.

As this is the first study of its kind, an engineered structural recycled plastic aggregate within the concrete mixture had to be tested and examined. By maintaining all parameters within the mixture unchanged, except the key factor, the recycled plastic, which had substituted volumetrically the coarse aggregates, 28 cylinders and 7 big panels were manufactured and tested, with a total volume of 336 litres, throughout this research program to examine the ductility performance of concrete. The key timelines for the tests were in an earlier phase of 7 days, and later on 35 days of curing.

From the observed data, which are explained during this thesis, the concrete mixes that contained less dosage of these recycled atoms, display better parameters in line with the compressive strength and the ductility performance. Furthermore, a reduction in the workability of the fresh batch of concrete is typically associated with the incorporation of plastic aggregates.

Anyway, through this research was found that due to the high durability that these atoms with a unique three-dimensional design had, they have the potential to be reused in subsequent concrete mixes without incurring a substantial performance penalty.

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1.0 Introduction

1.1 Overview

For many decades now, all over the world, single-use plastics is a growing affair that has caused huge quantities of plastic-based waste. Because of their heavy impact on the environment, if left unchanged, plastic will leave serious consequences for future generations. Australia itself produces approximately 3.4 million tonnes of plastic waste each year, where only 320 000 tonnes were recycled, which is less than 10%, and the remaining tonnes are disposed of either in landfills or oceans (Statistics, 2020). Moreover, waste plastic is an onerous challenge that the world is facing due to the recycling process. According to Its base mix is made of cement, fine aggregate, coarse aggregate, water, and some admixture (Chowdhury, n.d.). When reinforced with steel, concrete demonstrates higher tensile strength properties.

The properties of concrete can change when additives or admixtures are added to its mix. Nowadays, natural coarse aggregates can be substituted by plastic waste aggregates; in this case, it will be beneficial for both environmental issues and the ductility performance of concrete (Fernando Pacheco-Torgal, 2019). In other words, it has been founded that if the quantity of plastic waste aggregates increases, it will also affect the increasement of concrete's ductility.

On the other hand, waste plastic is an onerous challenge that the world is facing due to the recycling process. According to (Statistics, 2020) it has been confirmed that during the 2018-2019 year, 75.8 million tonnes of waste was generated in Australia. Construction waste consists of inert material such as soil, sand and non-inert material for example metals, wood, and plastic (P. Rendell, 2018). In a way to recycle plastics and so on to contribute to maintain it in lower values, the incorporation of plastic waste within concrete has been a recent subject for construction industries.

From another point of view, studies have shown that the unfavourable geometry of plastic aggregates, is a key factor that contributes to poor strength and workability (Commission, 2014). However, Toberite is a new type of concrete that has been discovered by Seels Technology. This brand replaces the coarse aggregates with artificial ones called Atoms, which have a unique three-dimensional design that leads to a better self-reinforcing due to the property of occupying their own space among cement, sand, and water. (Vreugdenburg, 2020) states that Toberite is a huge benefit to suppliers as it surpassed all the ongoing relationships with Seels Technology and this research will help to fill the gap on understanding how the ductility performance of concrete will be affected by adjusting these key parameters.

There have been previous kinds of research in the concrete industry. (Kim, 2010) confirmed that by using Polyethylene Terephthalate (PET), reinforced concrete specimens exhibit 7-10 times greater ductility performance compared to those without fibre reinforcement. Moreover, no one tried to place these engineered geometry atoms of plastic within a concrete mixture. The stakeholders are going to benefit from this research because substituting natural aggregates with Toberite Atoms will lead to strength development and sustainability of concrete. A potential solution could be provided for environmental harm and the management of plastic waste by incorporating this plastic into concrete.

This research is based on two different shapes such as Round Determine Panels (RDP) and cylinders. About the concrete mixture, a combination of Toberite plastics and recycled coarse aggregate (RCA) has been analysed. In more, the testing is based on various percentages of Toberite and RCA to have a better understandable point on how much plastic can the concrete mixture handle for an improvement workload.

1.2 Thesis Structure

This thesis presents the finding from experimental tests undertaken across 1 trial mix, so the student will know the use of tools, materials, and the test process, and 6 final mixtures where different percentages of Toberite have been used within each batch of concrete. The tests completed at the Tonsley Laboratory consisted of over 336 litres of concrete, which includes 4 cylinders with dimensions of 100 mm x 200 mm and 1 panel with a dimension of 75 mm x 800 mm for each mixture; this leads to a total of 7 panels and 28 cylinders prepared during the experimental program. This thesis outlines 6 key sections as presented below:

- Introduction: This section gives a general background of concrete and other materials such as coarse aggregates. A quick overview refers to waste plastic which leads to difficulties in managing the recycling of plastic.
- Literature Review: This chapter highlights an understanding related to all materials and processes within this thesis, as well as environmental impacts associated with current practices of concrete.
- Experimental Methodology: It outlines the methodology used for this research work. The tests during this program include the slump test, compression test, and ductility performance of concrete specimens.

- Results and Discussion: This section focuses on the detailed experimental results which give a demonstration of all the data obtained across the experiments. According to the aim of this research work, the results of the Ductility test have been explained in a correlation of the Energy Absorption and the Load/Displacement Area. An analysed of the obtained data is clearly presented within this chapter, and it then discusses how the different percentage of engineered geometry of plastics impact the ductility performance of concrete.
- Conclusion: This section summarises the key observations and analysis which have been taken from the above chapter of the results. It also presents the contributions of this research and its significance in the construction world, and its relevancy to Australian Standards.
- Future research direction: This part identifies the future research possibilities and provides ideas for future research when using Toberite atoms.
- References: They can be found in the last pages of this thesis, and they are presented in The Harvard reference style.
- Appendices: It contains details that are relevant to this thesis such as Risk Assessment Form, as well as photos captured during mixing and testing days.

2.0 Literature Review

2.1 Background Information

According to (GIATEC, 2017), the earliest recording of concrete structures date back to 6500BC by the Nabataea traders in regions of Syria and Jordan. People of these countries used concrete to create floors, housing structures, and underground cisterns (GIATEC, 2017). For many years now, concrete is considered a strong and durable material in the construction world. When working with concrete, it has to be known the correct mixing proportions prior to the mixing day. If not so, the consistency will get weakened, and the final result will be disappointed and undesirable. Moreover, the more concrete is going to be mixed, the stronger it will be. Once the concrete is mixed, it will result in gaps where the cement and aggregates have not been thoroughly blended; this leads to the creation of weak points in the finished product. By following the concrete cures fundamentals, concrete takes a whole month to attain full strength, and it is essential to keep the concrete moist during this period. For this reason, therefore the 28^{th} day of curing is usually applied through research and concrete tests (Hamakareem, n.d.).

2.1.1 Traditional Concrete Mixture

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Figure 1: Traditional concrete mix design

Everywhere in the world, concrete is a dominant compound in construction. Its traditional receipt consists of the following components: cement, fine aggregate, coarse aggregate, water, and some admixture (Lysett, 2019), as it is shown in Figure 1. (Tarmac, 2022) states that traditional concrete is conventional concrete with a wide range of construction applications including commercial, residential, industrial, agricultural, and infrastructure usage. It also can be designed to achieve individual requirements such as workability, rate of strength gain, durability, porosity, compressive strength, as well as concrete ductility.

2.1.2 Plastic Waste

Nowadays, plastic waste is an onerous challenge that the entire world is facing due to the recycling process. Plastic materials are a common component in the building and construction industry due to their durability, and energy efficiency because they can easily be installed.

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Figure 2: Plastic waste in construction sector

(Yizhaki-Madar, 2022) states that some examples of plastic application are as follow:

- Walls, roofs, and doors are insulated with polyurethane foam.
- Windows, canopies, and curtain walls are composed of a glazed material called Polycarbonate.
- PVC and polyethylene are used to make internal cladding walls and flooring.

In Figure 3, according to (Yizhaki-Madar, 2022), among all the other industries, the building and construction sector is the major industry that can minimize plastic accumulation by ensuring proper waste management and long product lifespans.

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Figure 3: Production and waste of plastic for the year of 2015

However, in a way to recycle plastic and maintain it at a minimum value, the incorporation of plastic within concrete has been a recent subject in the construction and building sector. In addition, the current methodology process for plastic disposal needs to be improved, otherwise, its long-harmful effect on the environment would be worse over the upcoming years.

2.1.3 Relevant Standards

A relative standard to complete was required to be chosen for the scope of this project, in order to ensure accuracy for the tested results. Extensive research was undertaken relatively to the standards, with the scope of having as much reliable data as possible throughout this master thesis. A list of relevant Australian Standards is provided in Table 1 below. Except for the Australian Standard, because of the lack of a proper standard to study the ductility of the panel, throughout this thesis, it was deemed necessary to find a relevant standard to control the process of testing the panel specimens. For this reason, the most adequately chosen standard was the ASTM C1550 of the year 2019, which stands for the American Society for Testing and Materials.

Table 1: Relevant Standards

Standard Code	Standard Name
AS 1012.2	Preparing concrete mixes in the laboratory
AS 1012.3.1	Determination of properties related to the consistency of concrete - Slump test
AS 1012.9	Compressive strength tests - Concrete, mortar and grout specimens
AS 1141.5	Particle density and water absorption of fine aggregates
AS 1141.6	Particle density and water absorption of coarse aggregates
ASTM C1550-19	Standard Test Method for Flexural Toughness of Fiber Reinforced Concrete (Using Centrally Loaded Round Panel)

2.2 Materials

This section will highlight the concrete constituents that will be used throughout the experimental work for this project research.

2.2.1 General Purpose Cement

Figure 4: General Purpose Cement

GP Cement is the most prominent component used in concrete. It starts to set when mixed with water because it causes a series of hydration chemical reactions. Due to its properties, a cement is called a binder because it adheres to other materials within a mixture to bind them together (Cement Australia, 2011). However, the production of cement has significant negative impacts on the environment. Cement production, as a main binder in concrete, contributes approximately 5-7% of the global CO_2 emission (Aliakbar Gholpamour, 2020/1). Because of the high level of consistency and versatility, General Purpose Cement is an ideal choice for all construction applications. For more, the requirements for the GP Cement can be found in Australian Standards AS3972 General Purpose and blended cement.

2.2.2 Recycled Coarse Aggregates

(H.-K.Kang, 2013) explain that the recycled concrete aggregates (RCA) are created as a consequence of road or building demolitions. This application began to start at the end of World War II when an excessive demolition of dwellings happened and with the used aggregates Europe started to rebuild

(Buck, 1977). The properties of RCA change in comparison to the natural aggregates, so their behaviour performance within concrete mixtures was expected to be different.

Figure 5: Recycled coarse aggregates

From another point of view, the major advantage of the use of recycled coarse aggregates (RCA) is the minimum environmental impact when comparing to the alternative way of sending the waste into landfill.

2.2.3 Fine Aggregate

Fine aggregate consists of any particles smaller than 4.75 mm in diameter. It fills voids between coarse aggregates, and it provides resistance against shrinking and cracking (Deloney, n.d.).

For this research project, sand is used in its surface saturated condition prior the mixing day for the water absorption purpose.

Figure 6: Fine Aggregates

2.2.4 Toberite Atoms

Figure 7: Toberite Atoms

Seels Technology is the company who invented and manufactured the Toberite atom that is an essential key in this thesis. Because of its unique three-dimensional engineered geometry, these atoms are acting as a filler material within the concrete matrix. The main factor why this material is chosen for the experimentation methodology is due to its waste-based material which means they are recycled and reduces the detrimental environmental impact.

2.2.5 Superplasticiser

Admixtures, or additives, are materials which are added within the concrete mixture to change its properties. For this mix design, it has been used a liquid superplasticiser called MasterGlenium SKY 8700 for a performance improvement, like a water reducer. Water reducers are used to increase the workability without requiring an increment of water-cement ratio and the ability to work with a low w/c ratio and still obtained slump retention, makes the chosen superplasticiser a unique solution (Builders, 2020).

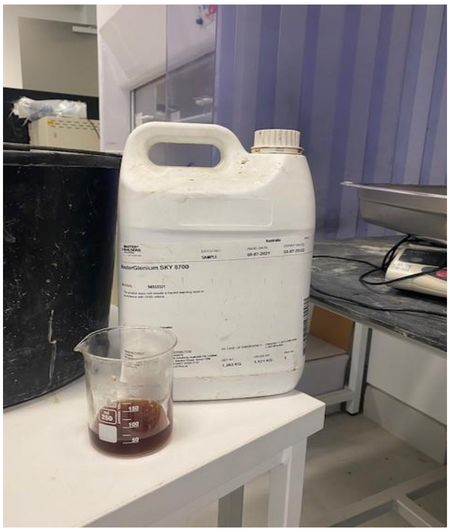


Figure 8: MasterGlenium SKY 8700

2.3 Research Gaps

From reviewing the existing literature, this thesis report focuses on the use of three-dimensional plastic atoms in the preparation of great panel specimens with the scope of ductility performance study. There have been previous kinds of research in the concrete industry. One of the researchers, (Kim, 2010), confirmed that by using Polyethylene terephthalate (PET), reinforced concrete specimens exhibit 7-10 times greater ductility performance compared to those without fibre reinforcement. Anyway, the predominant research gap withing this research is testing the Toberite atoms themselves, so further testing is desirable. This brand replaces the coarse aggregates with artificial ones which are called Atoms; they lead to a better self-reinforcing due to the property of occupying their own space among the other constituents within a concrete matrix (Vreugdenburg, 2020). This research will help to fill the gap on understanding how the ductility performance of concrete will be affected by adjusting these key parameters. Moreover, this plastic atom component is important because not only will behave as a filler, but it will also help bridge the gaps formed when concrete begins crushing and cracks appear. From this point of view, this double effect as a filler and a crack bridge, is the unique strength that Toberite has.

2.4 Research aims and novelty

The main focus of this research is on the use of Toberite by interacting with recycled coarse aggregates (RCA). To clarify the purpose of this project and to provide clear outcomes, some research aims have been outlined as follows:

- ✓ To examine the influence of the different percentages of recycled plastic on the ductility performance of concrete.
- ✓ Measuring the ductility performance of Toberite concrete by performing Round Determine Panel (RDP).
- ✓ To compare the effects when 6% of fresh dosage and 6% of used Toberite have been set in two different mixes of concrete.

When having a look through the previous theses, testing the ductility of RDP has been recommended for future work. Although there are previous studies at Flinders University regarding the Toberite atoms, no one tried to place these engineered geometry atoms of plastics within a concrete mixture and could measure the energy absorption regarding big panels. As such, the obtained results from this thesis cannot be directly compared to that from previous research. Additionally, reusing a small percentage of Toberite atoms, respectively 6% of dosage, and comparing with another mix where all the key parameters are maintained the same except for the plastics which are fresh Toberite atoms, has not previously been compared. However, given the results, a potential solution could be provided for environmental harms and the management of plastic waste by incorporating this plastic in concrete; the geometrically engineered waste-based concretes can be beneficial within the industry, and they are encouraged and welcomed to be adopted in the future.

3.0 Experimental Methodology

3.1 Preliminary Work

Some preliminary works have been required before commencing any work in the laboratories. Many standards were researched to ensure that all mixing and testing procedures were followed in order to obtain quality and accurate results. In addition, it was needed to have beforehand all the required materials for making concrete as well as building the specific moulds for panel specimens. All the tests have been proceeded in the laboratories of Tonsley, hence, it was necessary to complete Risk Assessments, and Safe Operating Procedures (SOP) for areas and equipment.

3.1.1 Risk Assessment

In accordance with University's policy, an important step to be completed before commencing any work on laboratories was the Risk Assessments to identify any potentially hazardous material that has been used during the project. In particular, this involved the MasterGlenium SKY 8700 Superplasticiser for which the risk assessment form can be found in the Appendices section.

3.1.1 Safe Operating Procedures

For a successful experimental procedure, the use of Safe Operating Procedures (SOP) was important inside the laboratories area where it aimed to conduct a task safely while providing a high quality of its outputs. This includes SOP for the machines such as vibrating table and concrete mixer. Due to their big dimensions, another important issue that is necessary to discuss these safety procedures was when safely transporting the panels from the curing room to the test room. The other significant stage was the safety induction which was conducted by a member of the Technical Staff from Flinders University. This task included emergency shutdowns for machines, and what to do on an evacuation occasion or when being in contact with dangerous materials and liquids.

3.2 Mix Designs

One of the keys to a successful experimental procedure is the preparation of a baseline mix for which all the other mixes will follow. The main form of analysis came through the casting of concrete cylinders and panels; AS1012 states that the standard sizing of moulds that were used in experimentation is 200 mm x 100 mm, whereas C1550-19 confirms that the size of the panel is 75 mm x 800 mm as it is shown in Figure 1. AS

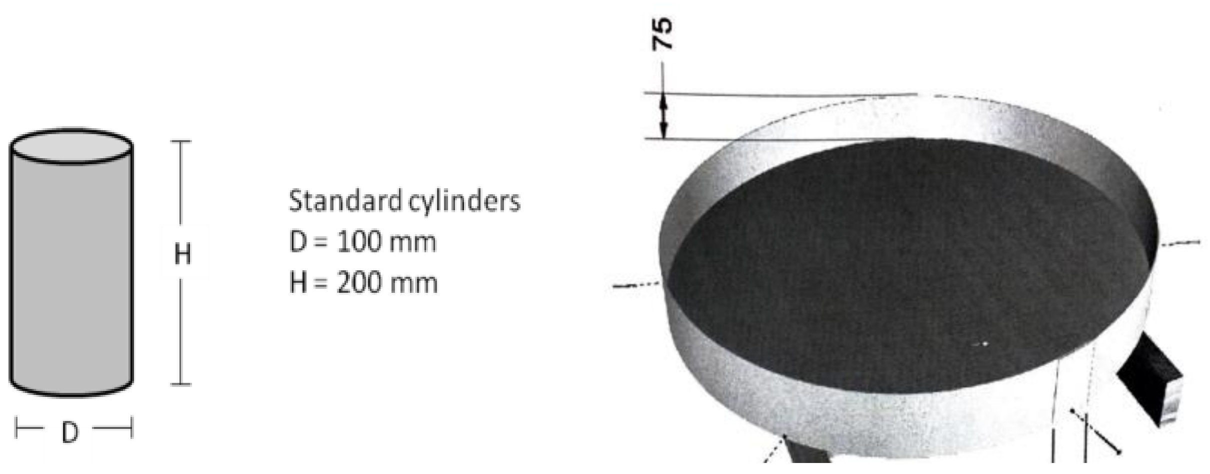


Figure 9: Cylinder and panel dimensions

Before any mixes were designed and prepared, a trial mix was completed to become familiar with the necessary requirements throughout the thesis. Table 1 demonstrates the detailed mix design whilst all the relative photos and procedures are shown in the Appendices section.

Table 2: Trial mix design

Trial Mix Design (100% RCA)		
Mix size =	0.048	m^3
Required RCA =	52.44	kg
Required Toberite =	0	kg
Required Sand =	32.2	kg
Required cement =	17.94	kg
Required superplastisicer =	53.82	ml
Required water for CA absorption =	3.464	kg
Required water for FA absorption =	0.184	kg
Required water for cement =	5.288	kg
Effective w/c ratio =	0.222	

The results from this trial mix design can be found in below Table 2. For the compressive strength, it was aimed at a low-to-normal strength concrete mix which performed at approximately 20-25 MPa. Additionally, all the compressive strength results are accepted and taken as correct because the purpose of this project research was the ductility test, not the strength of the concrete.

Table 3: Trial mix results

Cylinder Specimens					
Compressive Strength (Mpa) 7 days		**Compressive Strength (Mpa) 35 days**		**Panel 35 days**	
Test a	**Test b**	**Test a**	**Test b**	**Max Load kN**	**Displacement mm**
12.79	14.13	21.61	23.48	18.617	0.5

For all final mixes, all aggregates were in the saturated dry condition when added to the concrete mixer for this reason that no additional water absorption could occur. In addition, despite the aggregates' conditions, even the other constituents have been held constant for each batch of concrete. The main parameter that varies between mixes is the Toberite atom which was substituted with an equivalent volume of Coarse Recycled Aggregates (RCA) as required by the 'Standard Toberite' mix design. A summary matrix displaying all final mixes of concrete is provided in Table 3.

Table 4: Mix Matrix

Mix number	1	2	3	4	5	6
Mix name	100% RCA	6% fresh Toberite	6% used Toberite	12.5% Toberite	25% Toberite	50% Toberite
Total volume	48 L	48 L	48 L	48 L	48 L	48 L
Saturated surface dry RCA (kg)	55.904	52.55	52.55	48.916	41.928	27.952
Saturated surface dry sand (kg)	32.384	32.384	32.384	32.384	32.384	32.384
Toberite	0	1.282	1.282	2.564	5.128	10.256
GP cement (kg)	17.94	17.94	17.94	17.94	17.94	17.94
Water (kg)	4	4	4	4	4	4
MasterGlenium SKY 8700 Superplasticiser (mL)	53.82	53.82	53.82	53.82	53.82	53.82
Required water for CA absorption (kg)	3.464	3.464	3.464	3.464	2.598	2.598
Required water for FA absorption (kg)	0.184	0.184	0.184	0.184	0.184	0.184
Total w/c ratio	0.222	0.222	0.222	0.222	0.222	0.222
Effective w/c ratio	0.426	0.426	0.426	0.426	0.426	0.426

Where the total w/c ratio represents all the water within the concrete mix, whilst the effective w/c ratio excludes these values of water and expresses only the water that is reacting and contributes directly to the overall concrete strength. The results of the w/c ratio came by following the below formulas:

$$Effective\ w/c\ ratio = \frac{Water\ (kg)}{GP\ Cement\ (kg)}$$

$$Total\ w/c\ ratio = \frac{Water\ (kg) + Water\ required\ for\ CA\ (kg) + Water\ required\ for\ FA\ (kg)}{GP\ Cement\ (kg)}$$

3. 3 Mix and Specimen Preparation

Several parameters need to be tested across all mix designs in order to determine the influence that the Toberite had. For all mixes, slump test, compressive strength, and ductility test were tested. Each batch of concrete was approximately 48 Litres and included a total of 28 cylindrical specimens and 7 Round Determine Panels (RDP) prepared throughout this research with a total volume of 336 Litres.

The first step to being undertaken in preparing the specimens was the sieving and cleaning of both fine (FA) and recycled coarse aggregates (RCA). In accordance with AS 1141.5 and AS 1141.6 a test portion of 500 g was taken to sieve through a 4.75 mm sieve for the sand, whilst a sample of at least 2 kg was taken for RCA. Once all the weighted aggregates were washed and dried with a towel, they were soaked in the water for at least 24 hours as it is shown in Figure 2.

Figure 10: RCA and FA soaked in water

To start with the mixing procedure, all RCA and FA were placed first in the pan mixture per following the AS 1012.2. After two minutes of mixing, GP cement can be added; while mixing, the superplasticiser and water needed to be enhanced within; after 2 minutes of mixing, it was required for the mix to rest for another 2 minutes. At this point, a slump test has been taken under AS 1012.3.1. For this research, there was no slump target because the focus was on the replacement of RCA with Toberite which means that all slumps were accepted in this thesis. A light coating of Lanoform has been applied to all moulds to ensure that the concrete would not stick to the inside of the moulds and it will make possible an easy removal after 24 hours. Next, following AS 1012.8, both cylinders and panels were vibrated appropriately in order to remove the air voids as it is shown in Figure 3 and left to harden for 24 hours.

Figure 11: Vibrating the specimens

After the assigned timing, the specimens have been removed from their moulds and left to the curing process. Because of the great dimensions of the panels, it was not possible to make the process of the saturation in a water bath so, another solution took place in this phase. In addition, in order to test all mixtures under the same conditions, a cover of the specimens with plastic sheets has been taken into consideration to replace the tank water bath for the evaporation issue. For the cylinders a sealed plastic sheet has been used; 2 out of 4 cylinders have been tested for the compressive strength when reached 7 days, whilst the other 2 have been tested in their 35 days. Regarding the curing of panels, they should be maintained in a continually moist condition, so in the current case, the concrete specimens have been well-wrapped with plastic sheets for the 35 days until the testing day as it is demonstrated in Figure 12. Despite the usage of different plastic covers between the panel and the cylinders, the important fact is that every mixture is tested under the same conditions.

Figure 12: Curing process of the specimens

When the specimens were ready for testing, it was required to grind the top of cylinders so a uniform pressure can be loaded on the specimens in the testing machine. That process has been undertaken by the laboratory technician according to university policies. The grinding process it is shown in the below Figure 13.

Figure 13: Grinding process for cylinders

4.0 Results and Discussion

This chapter discusses the detailed results of the scope of the project. The below-given results are collected in accordance with all methodologies provided in Section 3.0 by following the relevant standards as it is demonstrated in Chapter 2.1.3. The experimentally tests have been made for seven mix designs in total, where the first mix design was defined as a trial mix and it is not analysed and discussed in this section, but its data can be found in Section 3.2.

In order to adjust all the key parameters within the mixes, a control mix design was designed to accomplish this scope. This mix was a standard concrete mix that utilised General Purpose cement, recycled coarse aggregates (RCA), fine aggregates (sand), a small amount of water, as well as the liquid admixture MasterGlenium SKY 8700 with a function as a water reducer. By having all the above-mentioned parameters constant throughout each mix, this method allows this research to present the effect of only one varied parameter; in this case, the key parameter that is going to be varied is the Toberite atom.

Furthermore, mix 2 of this project theses, was designed with all parameters remaining the same as the control mix, except the coarse aggregates which were substituted with 6% of fresh Toberite to identify its effects when replaced, on ductility performance of concrete. On the other hand, a comparison between two mixes design where one mix included 6% fresh Toberite and the other one contained 6% of used plastic, has been made for the ductility purpose and to define how the reused plastic will impact the panel's testing.

To move on, for the other mixes design, the recycled coarse aggregate (RCA) was replaced volumetrically with Toberite atoms in the following percentages: 12.5%, 25%, and lastly 50% of waste plastic.

4.1 Compressive Strength

Compressive strength is tested by breaking cylindrical concrete specimens in a special machine designed to measure this type of strength in accordance with Australian Standards AS 1012.9. By measuring in this way, the strength of a given concrete mixture can be determined the appropriate uses of concrete. In order to obtain these results, for each mix, two cylinders with corresponded dimensions of 100 mm x 200 mm were tested on day 7, whilst two other cylinders were tested on day 35 when the panel test was due. For this research, the w/c ratio has been maintained unchanged for all mix designs such that any movement in compressive strength can be strongly attributed to the only varying parameter across the project, respectively the impact of three-dimensional atoms. Table 5 and Table 6 show the results for each cylinder tested on their specific days.

Table 5: Compressive Strength of cylinders tested on day 7

	Test a (Mpa)	Load a (KN)	Test b (Mpa)	Load b (KN)	Average (Mpa)
Mix 1- 0% Toberite	20.18	158.5	20.47	160.8	**20.325**
Mix 2- 6% fresh Toberite	23.4	184	23.2	182	**23.3**
Mix 3- 6% used Toberite	20.29	159.4	21.24	166.8	**20.765**
Mix 4- 12.5% Toberite	22.68	178.1	23.22	182.4	**22.95**
Mix 5- 25% Toberite	20.63	161.925	21.32	167.4	**20.975**
Mix 6- 50% Toberite	18.86	148.2	20.49	160.9	**19.675**

Table 6: Compressive Strength of cylinders tested on day 35

	Test a (Mpa)	Load a (KN)	Test b (Mpa)	Load b (KN)	Average (Mpa)
Mix 1- 0% Toberite	27.41	**215.138**	28.3	**243.045**	**27.855**
Mix 2- 6% fresh Toberite	28.96	**227.334**	30.96	**243.045**	**29.96**
Mix 3- 6% used Toberite	30.01	**235.572**	29.06	**228.084**	**29.535**
Mix 4- 12.5% Toberite	26.34	**206.74**	28.56	**224.186**	**27.45**
Mix 5- 25% Toberite	26.28	**206.265**	27.05	**212.378**	**26.665**
Mix 6- 50% Toberite	22.2	**174.3**	18.7	**152.024**	**20.45**

According to the tabulated results, the concrete's compressive strength decreased as the sample contained more Toberite atoms. As it can seem, the used percentages of plastic atoms have been set within the concrete mix in small amounts such as 6%, 12.5%, 25%, and 50%, thereupon, the final result of the compressive strength does not have too much difference between those samples. The maximum strength of concrete that has been reached in this research was approximately 30 MPa and it belongs to the mixture that contains 6% of Toberite atoms.

As it is mentioned earlier in this paper, a target of 40 MPa was aimed at related to the compressive strength in the sample's 35th days, but it was not reached in any of the specimens. Several reasons might have caused these results, but the most likely that have influenced the results could have been the water-cement ratio; hence, a lower w/c ratio leads to a higher strength of concrete.

Figure 14 demonstrates the comparison of compressive strength between the different dosage rates that have been tested throughout this thesis, where the blue line represents the test results on day 7 whereas the orange line stands for the results on day 35.

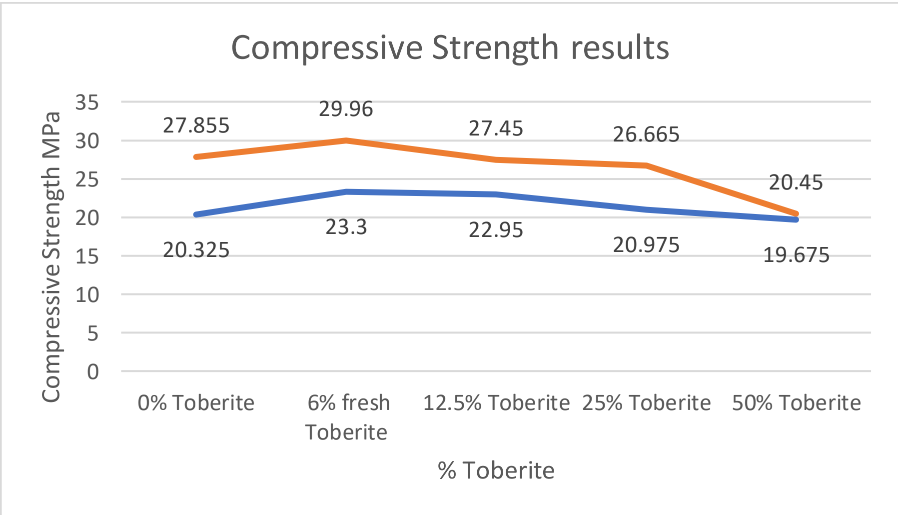


Figure 14: Comparison of compressive strength between 7 and 35 day

From the above graph, can be noted that the orange line which represents the test on day 35, is higher compared to the blue one that stands for day 7. Of course, this result is expectable because as AS3600 provides, the concrete sample achieved its full strength in 28 days. If the control mix (100% RCA) will be excluded from the graph when comparing only the specimens that contain plastic within its mixture, a decrease in strength is displayed. This decrease in compressive strength may have happened because of the poor adhesion between the plastic aggregates and the cement paste. An after-failure test for a cylindrical specimen is shown in Figure 15.

Figure 15: Concrete specimen after failure

Another aim of this research was the comparison between two mixes that contain the same amount of ingredients in the mixture, except that one included fresh Toberite but the other one reused plastic atoms. Figure 16 compares these two samples when reached 7 days of testing.

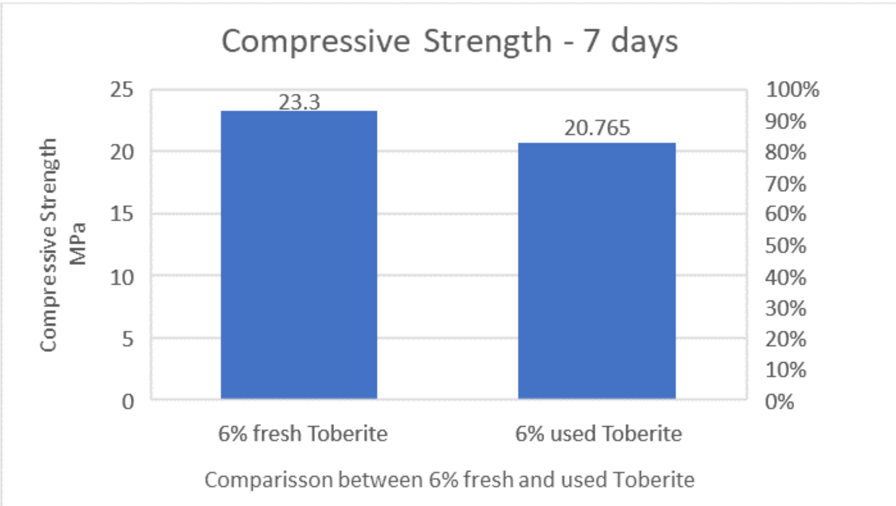


Figure 16: Compressive Strength 7 days

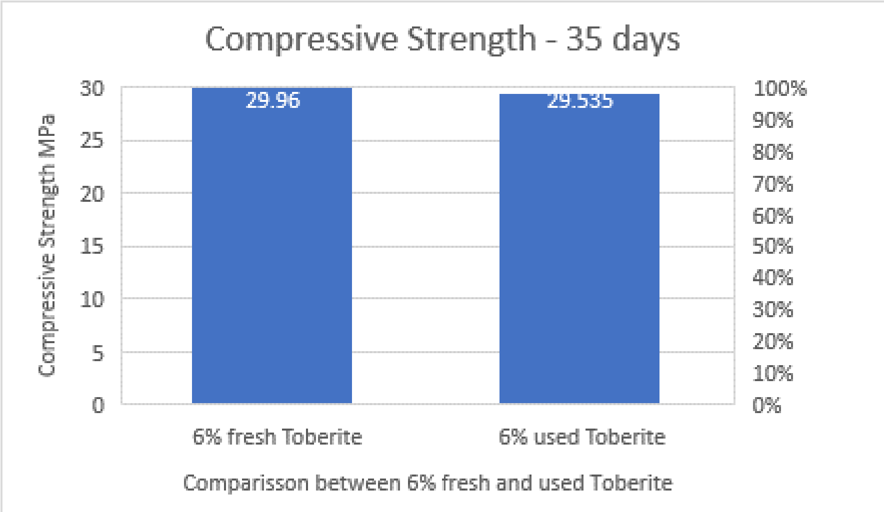


Figure 17: Compressive Strength 35 days

Regarding Figure 16, an approximate alteration of 3% happened between both mixtures on their 7th day. Let us say that this is a 'great' percentage when the mix matrix format is the same. Anyway, this change can be justified from the air voids within the specimen as it is presented in Figure; the air voids cause a lower strength of concrete. Moreover, from the provided results, can be noted that there is a slight difference between fresh and used Toberte of approximately 2.5% in their final compressive strength tests. So, the construction and building industries can reuse Toberite atoms repeatedly, without changing the outcome of the concrete's strength.

Figure 18: Air voids in the cylindrical sample

4.2 Ductility performance of concrete

Ductility is the ability of reinforced concrete members to undergo considerable deflection prior to failure. (Hamakareem, n.d.) states that the ductility characteristic of concrete is significant in seismic areas because in this case, the structure provides signs of failure and prevents total collapse. In other words, ductility is the capability of a material to sustain a permanent deformation under a tensile load up to the point of fracture. ASTM C1550-19 is the relevant standard that has been followed for the required process and measurement of the ductility test. This standard method covers the determination of flexural toughness of fiber-reinforced concrete expressed as energy absorption in the post-crack range using a centrally loaded round panel (RDP) supported on three symmetrically pivots as is demonstrated in Figure 19. The nominal dimensions of the panel are 75 mm in thickness and 800 mm in diameter.

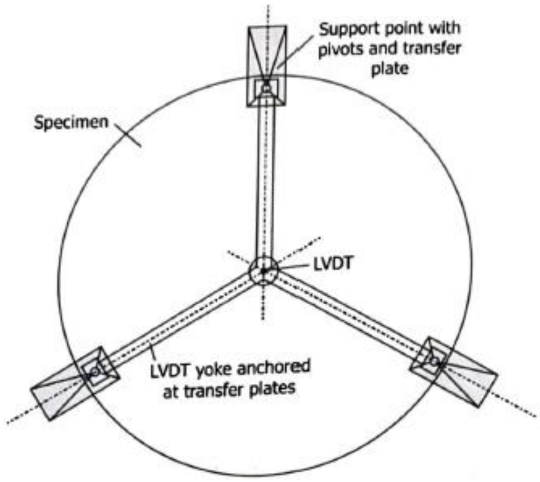


Figure 19: A plan view of panel settled in the ductility testing machine

The scope of the whole project is to study the ductility of round panels, so a deep analysis is made on their behalf. As per Figure 19, the supports where the panel is laying shall be capable of supporting a load of up to 100 kN applied vertically at the center of the specimen. Also, they shall be sufficiently rigid so they would not displace in the radial direction by more than 0.5 mm between the onset of loading and 40 mm central deflection for a test under the ASTM C1550-19. Additionally, these supports are designed to provide sufficient ductility to resist structural collapse after the yield strength of the concrete has been achieved (Olivia, 2015). Furthermore, a central displacement of at least 45.0 mm has been considered a possible error when starting the testing machine. A real photo captured during the panel’s testing is shown in Figure 20 and it corresponds to the mixing matrix of 25% Toberite atoms.

Figure 20: Ductility test of RDP

The ductility of concrete can be measured by adjusting the load-deflection record by subtracting extraneous deformations associated with compliance of the load train and crushing of concrete under the load point and at the supports. During the testing of the specimen, the assigned equipment did measure two displacements, relatively known as Channel 7 and Channel 8. The first one measured the displacement above the panel, where all these analyses are based, whilst Channel 8 measured the displacement underneath the panel which is not taken too much into consideration.

The energy absorption is calculated as the area under the load-net deflection curve between the origin and the specified central deflection as Figure 21, given from the standard, confirms. A summary of the maximum energy absorption of each mix design is shown in Table 8. Following the ASTM C1550-9 standard, the determination of the energy absorption is defined at central deflections of 5 mm, 10 mm, 20 mm, and 40 mm. Regarding the units, the displacement from the testing equipment has a unit of micron; because the load and net deflection measured should be in units of kiloNewtons (kN) and millimetres (mm), in order to get a resulting measure of energy in Joules (J), a conversion of 1 µm=0.001 mm is made.

Table 7: Energy absorption for each mix design

	Energy Absorption (Joules)			
Number of Panels	**E5**	**E10**	**E20**	**E40**
Panel 1 - 100%RCA	20	23	26	28
Panel 2 - 6% fresh Toberite	23	26	29	34
Panel 3 - 6% used Toberite	26	32	38	47
Panel 4 - 12.5% Toberite	25	34	42	71
Panel 5 - 25% Toberite	40	63	99	156
Panel 6 - 50% Toberite	56	100	173	290

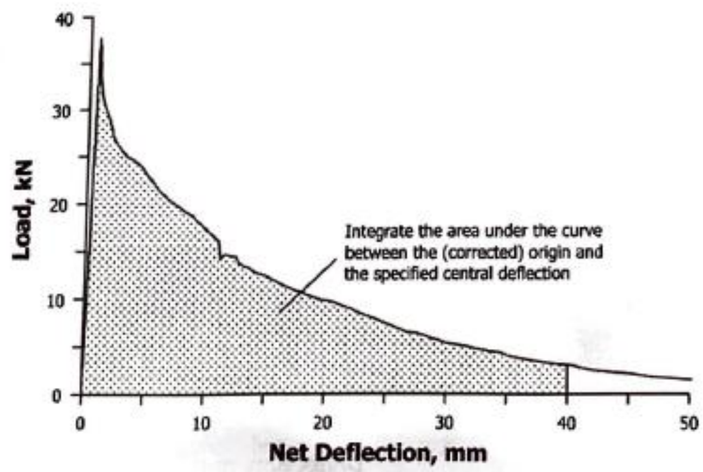


Figure 21: Energy absorption obtained from the load/area curvature

From Table 7 can be confirmed that the maximum energy, as was expected, was absorbed from panel 6 which contained the greatest amount of Toberite in this research, at the central deflection of 40 mm. On the other hand, for the same central deflection, the control mix design absorbed the minimum energy during the test. From another point of view, if a comparison of data, beginning from left to the right, would be, can be noticed that an increment of energy absorption happened for all mixes.

Below are given six graphs that correspond to the six-mix matrix that has been tested throughout this research. The blue line stands for the displacement that happened underneath the panel, which can be neglected, whilst the orange line represents the real displacement that happened during the test.

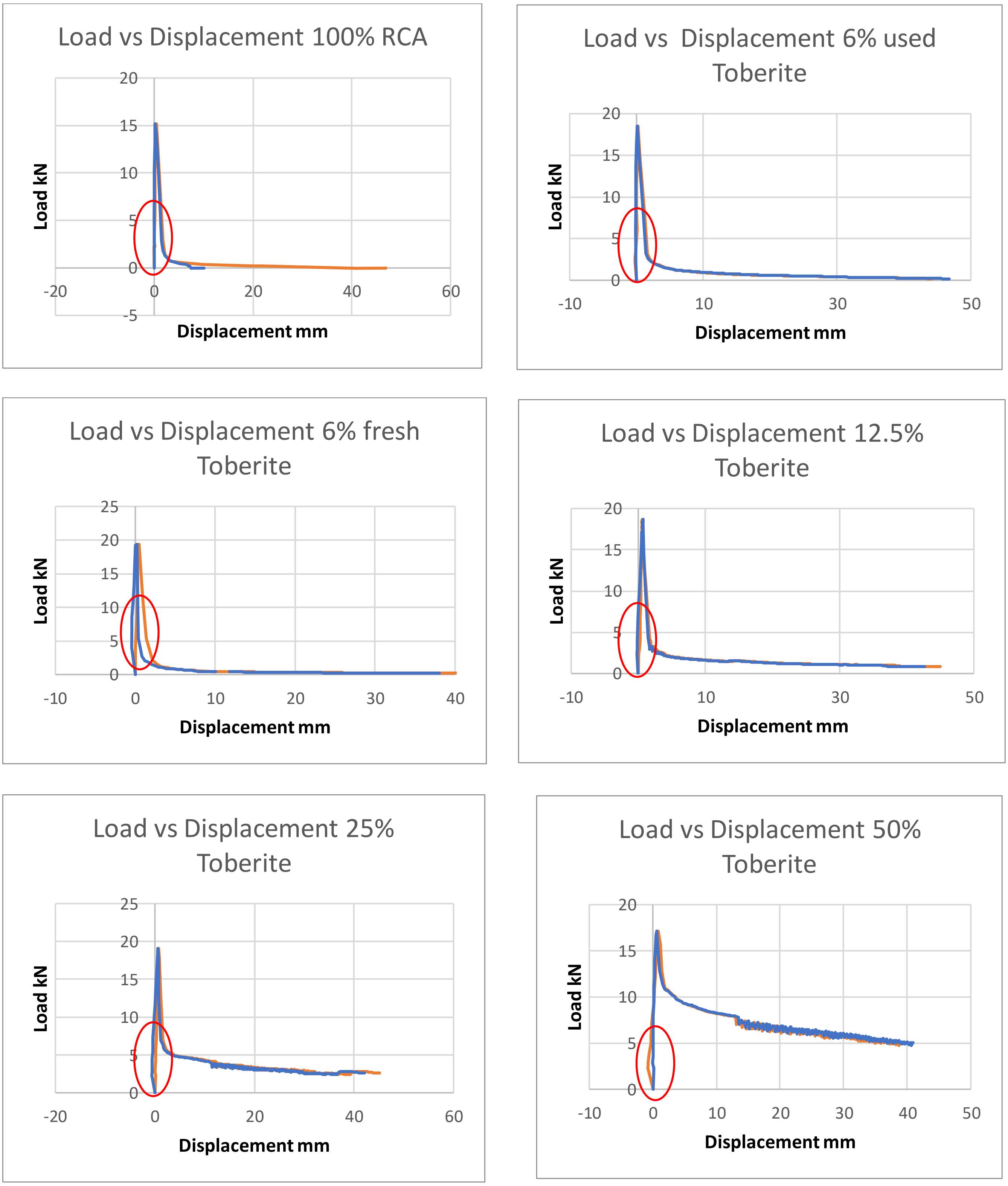


Figure 22: Load vs Displacement for 6 mixes

Each of the above graphs have a slighlty displacement result starting from the origin showing by the red circle. According to ASTM C1550-19, if the deflection of the specimen was measured through the loading mechanism of the testing machine, this record includes extraneous displacements that must be deleted from the deflection record to reveal the net deflection of the specimen. In other words, the displacement of the actuator relative to its immediate supports includes the deformations of the testing machine, load cell, and load transferring fixtures, plus that of the specimen and crushing of concrete at the point of loading. Therefore, deformation associated with the crushing of concrete around the load point must not be included in the assessment of load train compliance; hence, only the portion of the displacement record that displays essentially linear behavior shall be used. Due to the page limitation that this paper has, only one mix among the overall of six matrixes, has been corrected and represented in Figure 23 which corresponds to mix design with 6% Toberite atoms. The graph displays a closer look by formatting the x axis from 40 mm to 10 mm for a better view.

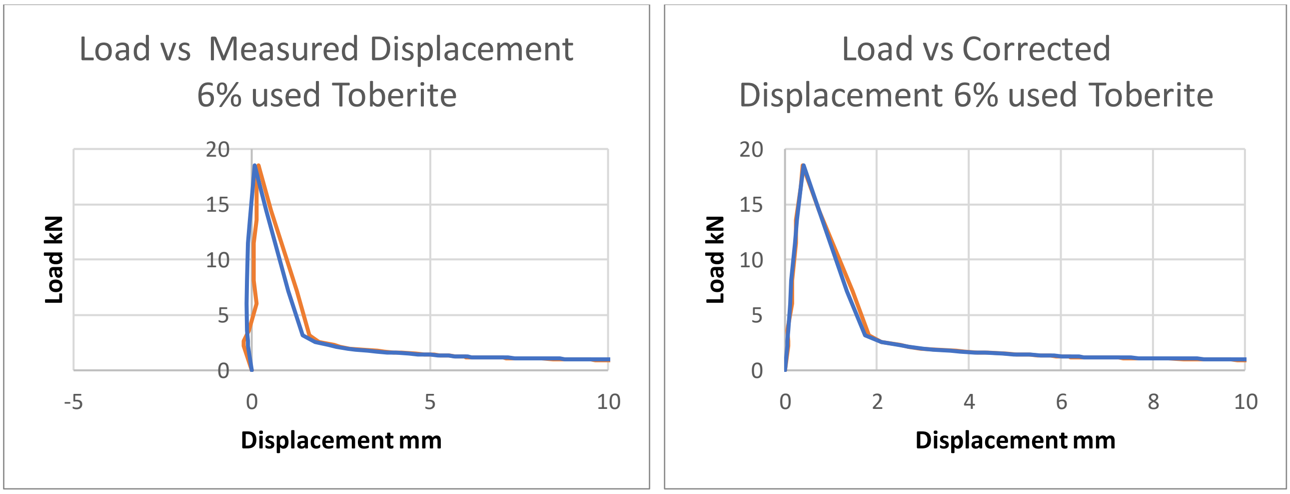


Figure 23: Corrected load/deflection train for a 6% Toberite concrete mixture

To further analysis, a maximum load peak is demonstrated in Figure 24. Matrix 2 has the maximum peak load which corresponds to a mix design that contains 6% fresh Toberite. From this survey, can be said that the mix design that has a lower number of Toberite atoms within its mixture, displays weakness against a greater load, such as in the current case-mix number 6 which includes 50 % Toberite and could affoard a peak load of 17 kN.

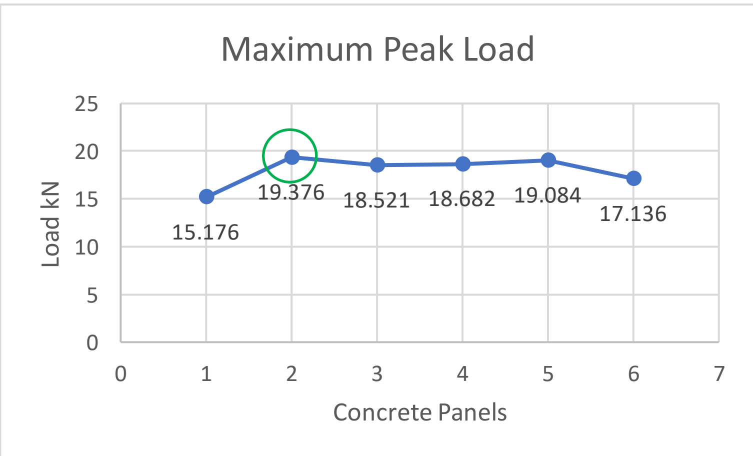
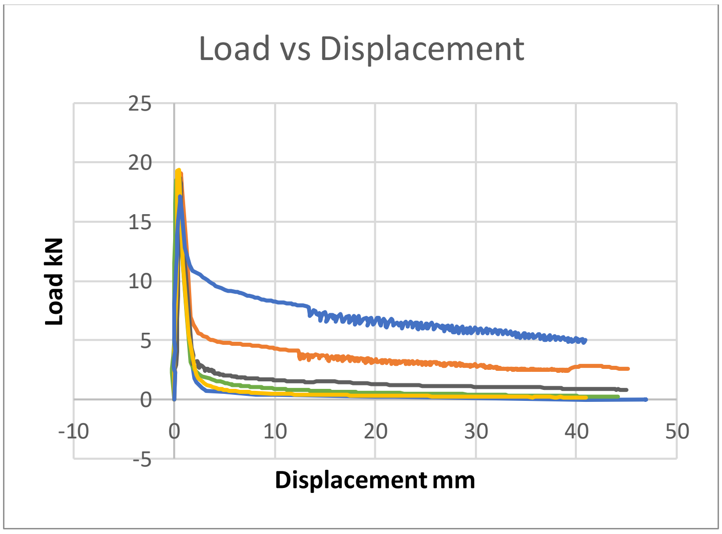


Figure 24: Maximum peak load for all mix matrixes

As a summary for the ductility section, a synopsis of all matrixes is demonstrated in Figure 25. The below graph represents a load versus displacement conclusion for each mix that has been tested and analysed throughout this research project. Each mix design corresponds to a different line colour as it is shown in the relevant legend. To conclude, determination of the load compliance using measurements of true and apparent specimen deflection is most reliable undertaken using data from the part of the load-deflection history for a specimen obtained prior to cracking of the concrete matrix.



Panel 1 - 100% RCA	-	Panel 1
Panel 2 - 25% fresh Toberite	-	Panel 2
Panel 3 - 6% used Toberite	-	Panel 3
Panel 4 - 12.5% Toberite	-	Panel 4
Panel 5 - 6% fresh Toberite	-	Panel 5
Panel 6 - 50% Toberite	-	Panel 6

Figure 25: Summary of Load/Displacement results

4.4 Slump Test

Workability of concrete is a property of fresh concrete mixture. According to (Mahajan, 2021), the workability of concrete mainly depends on the water-cement ratio but other factors such as aggregate particle size distribution or chemical admixtures impact the concrete to be workable too. A presentation of how the concrete slump test can be done is shown in below Figure 18.

Figure removed due to copyright restriction

Figure 26: Concrete slump test method

For all mix designs across this thesis, the workability of concrete has been measured through the slump test by following the AS1012.3.1. The slump test was not a key factor for the scope of this project; however, it has been measured during the early stage of each batch of concrete. The derived results from these tests are demonstrated in Table 6.

Table 8: Concrete Slump Test results

Number of mix matrix	*Name of mixture*	*Slump test result*
Mix 1	100% RCA	194
Mix 2	6% fresh Toberite	73
Mix 3	6% used Toberite	75
Mix 4	12.5% Toberite	69
Mix 5	25% Toberite	70
Mix 6	50 % Toberite	no slump

This research found that the best workability of concrete has been reached when RCA has been replaced with 12.5% of Toberite which had a slump test of 69 mm. However, there was not too much difference in the slump test for mixes 2, 3, and 5 where the corresponded slump test results are 73 mm, 75 mm, and 70 mm, respectively. The worst-case to work with, was the last mix, with 50% of Toberite where the slump test has not been reached as it is present in Figure 20 (left).

(Patil, n.d.) states that a value of 0-25 mm stands for low workability of concrete; hence, a small, or zero slumps, means that the concrete is stiff. For the current case, it can be confirmed that the high percentage of Toberite occupying the volume of this mix caused this result of the concrete slump test. On the other hand, some concrete has high workability when the slump test result varies on a range of 100-175 mm. The slump test for the control mix, 100% RCA, which has a high workability is presented in Figure 20 (right).

Figure 27: Slump test for 50% Toberite (left) and for 0% Toberite (right)

5.0 Conclusion

In general, most results obtained from this research were in accordance with the expected results hypothesised before testing was completed. All experimental methodologies were completed in agreement with Australian Standards except for the panel's testing where an American Standard has been chosen in absence of an Australian one. Conclusions were drawn on the effect of compressive strength, slump test, and ductility performance of concrete when Toberite atoms, which are plastic waste-based, were incorporated as a partial volumetrically replacement aggregate within a concrete mix.

According to the concrete workability, based on the data collected from the slump test provided from each batch of fresh concrete, the following conclusion can be drawn: the workability is depended on the dosage of Toberite used in a mix. Dosages of Toberite of 50% became less workable in contrast to the mix designs below 25% of plastic.

Throughout the curing stages, it was found that the compressive strength and the ductility of the concrete were impacted by the percentage of Toberite. Therefore, a concrete mix that contains a lower amount of Toberite shows a greater strength of concrete compared to the mix that has 50% of plastic. In other words, an increase in Toberite dosage leads to a decrease in both compressive strength and ductility performance of concrete. On behalf of ductility, from the obtained results it is confirmed that likely the compressive strength, a concrete matrix that included less amount absorbed greater energy before failure, rather the one which contained more plastic atoms within its mixture.

When a comparison between two same concrete mixture with the only difference in fresh and reused Toberite atoms has been made, from the derived results can be noted a slight difference between them, which leads to a conclusion that these types of plastics can be reused over again without impacting the specimen or structure functionality.

This research had a limitation of Toberite material, so the analysis has been provided for a maximum of 50% of Toberite, but for future works, it is suggested to extend the ductility tests to the specimens beyond this percentage, maybe to a target that includes 75% or 100% of Toberite dosage. All in all, additional research is required on this new brand of Toberite plastic before its application in the construction and building industries.

6.0 Future Research Directions

Further research is required to better understand the factors influencing the ductility performance of concretes containing plastic waste aggregates. In particular, this type of plastic, respectively Toberite atoms, currently represent a clear gap in scientific literature. For this reason, more investigations could be done on their impact on the concrete, by testing alternative sizes and geometries.

According to Toberite concrete, throughout the test, it was observed that mixes containing Toberite atoms did not break apart after failure easily, as it has seemed in the control mix where the percentage of plastic was zero. An upper and downer view of cracks for both panels, respectively 0% Toberite and 12.5% Toberite, is demonstrated in the below Figure 11 and Figure 12.

Figure 28: An upper view of the failure of the control mix panel (left) and failure of the Toberite concrete panel (right).

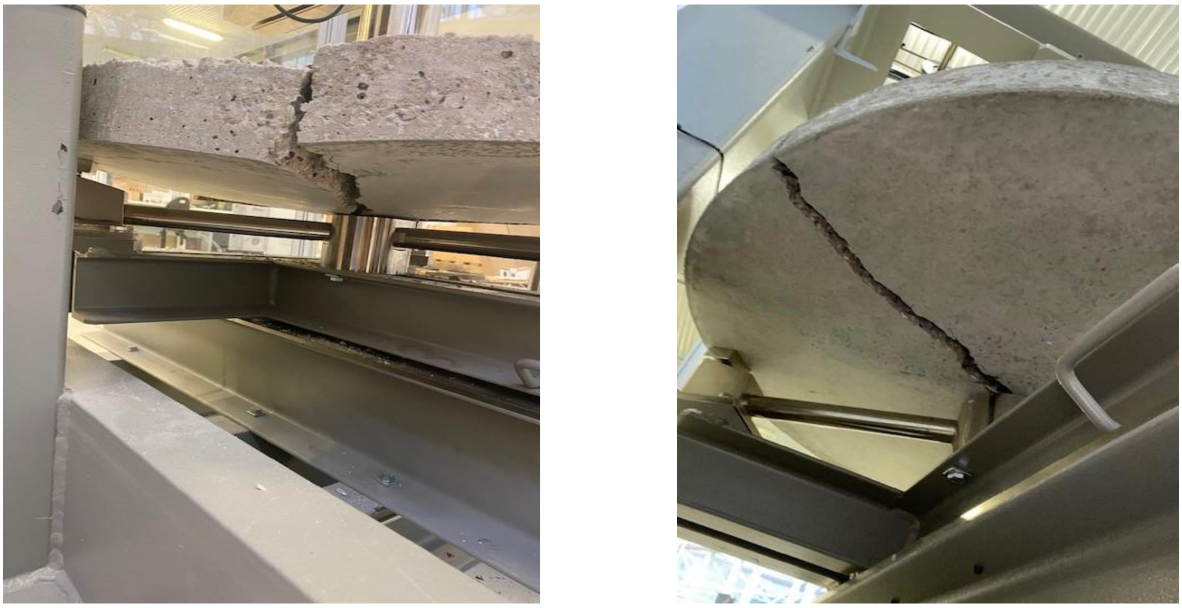


Figure 29: A downer view of the failure of the control mix panel (left) and failure of the Toberite concrete panel (right).

As seen in the above photos, it is clearly shown that mixes containing Toberite atoms held together when a load is exerted on them, whilst the mix without plastic failed easily and it cracked into three notable pieces. Additionally, this example prevents the observed difference in failure modes and the recommendations for future work for the post-cracking performance of Toberite concrete.

Moreover, another direction for future work can be an additional test for the ductility performance when using greater percentages of Toberite atoms. This research stopped with a mixture design of 50% of plastic due to the material's limitation, but a desirable object for the company that produces Toberite atoms, Seels Technology, is testing the ductility of shotcrete panels when using a 100% of Toberite within the mixing matrix.

To help standardise future tests, it is recommended to keep all concrete constituents constant, such as the same ratio of water-cement. Moreover, a detailed investigation and comparison can be made between a mixture design with 100% of used Toberite and the other one by using the same value of atoms but fresh ones.

Finally, a relevant structural standard would be beneficial for the industry in order to allow the Toberite concrete to be assessed by following this standard assessment.

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asily%20and%20not%20withstand%20the%20test%20of%20time.
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8.0 Appendices

8.1 Risk Assessment Form

Flinders University — RISK ASSESSMENT FORM

List identified hazards and detail measures taken to eliminate / minimise the risks:
(boxes on this form will expand to fit text)


Click to add image

Risk Assessment No.	1
Reference to SWP/SWMS No.	

College/Portfolio	College of Science and Engineering	**Area/Unit**	Laboratory	**Location**	Room G_09	**Area/Unit Manager**	Westley Penney
Task/Procedure	MasterGlenium SKY 8700 Superplasticiser	**Workers consulted / involved**	Westley Penney	**Date**	16/03/2022	**Review Date**	16/03/2022

Identified Hazard before controls		Risk Assessment			Risk Controls	Residual risk			Implementation
No.	**Description**	**Consequences**	**Likelihood**	**Risk Measure (see matrix)**	**Control measures**	**Consequences**	**Likelihood**	**Risk Measure (see matrix)**	**Date controls implemented / reviewed**
1	Skin Contact	First Aid	Unlikely	Low	Use of impermeable gloves during the lab	First Aid	Unlikely	Low	16/03/2022
2	Eye Contact	First Aid	Unlikely	Low	Safety transparent glasses to be wear	First Aid	Unlikely	Low	16/03/2022
3	Swallowed	First Aid	Highly Unlik	Low	Immediately rinse mouth and drink water	First Aid	Highly Unli	Low	16/03/2022
4	Inhalation	First Aid	Unlikely	Low	Respiratory mask protection to be wear	First Aid	Unlikely	Low	16/03/2022

Review the risk measured, and the controls implemented are still relevant and effective, then please select one of the following:

A The assessment reveals that the potential risk to health and safety from the use of the plant/equipment/procedure is not currently significant. [x]

B The assessment reveals that the potential risk to health and safety from the use of the plant/equipment/procedure is significant. However controls are in place that reduce risk as low as is reasonably practicable. [ ]

Note: If the risk level is still **Extreme/High** after controls are in place, then cease the activity, identify and implement further controls and consult with your manager/supervisor until the risk is reduced as low as reasonably practicable.

To be completed by Supervisor

Review of control measures

I am satisfied that appropriate controls are in place, still relevant and effective and the risk level is as low as reasonably practicable - Yes [x] *No [ ] (*If no, you must do another Risk Assessment.)

Supervisor signature: Date: March 2022

Risk Assessment Form - revised 15 February 2021 — MasterGlenium SKY 8700 Superplasticiser — Page 1 of 2

Figure 30: MasterGlenium SKY 8700 Risk Assessment Form 1

HOW TO ASSESS THE RISK

Step A - Consider the consequences	Step B - Consider the likelihood
For each hazard, consider the consequences if something happens. Consider what could reasonably have happened, as well as what actually happened (if there was an accident/ incident). Look at the descriptions below and choose the most suitable consequence below.	How likely is it that something will happen as a result of the hazard? Choose the most suitable likelihood below.

Consequence	Description	Likelihood	Description
Catastrophic	May cause death, or permanent disability, and/or permanent ill health	Very likely	Expected to occur in most circumstances
Major	Severe injury or illness	Likely	Will probably occur in most circumstances
Minor	Minor (usually reversible) injury or illness resulting in days off work	Possible	Might occur occasionally
First Aid	First aid level medical treatment	Unlikely	Could happen at some time
Negligible	No treatment required	Highly unlikely	May happen only in exceptional circumstances

Step C – Calculate the Risk Level

1. Take the Step A rating and select the correct line in the matrix below.
2. Take the Step B rating and select the correct column in the matrix below.
3. Circle the risk level where the two ratings interse in the matrix below.

Risk level =

Risk Matrix

Consequence	Likelihood				
	Very likely	Likely	Possible	Unlikely	Highly unlikely
Catastrophic	Extreme	High	High	High	Medium
Major injury	High	High	High	Medium	Medium
Minor injury	High	Medium	Medium	Medium	Medium
First aid	Medium	Medium	Medium	Low	Low
Negligible	Medium	Medium	Low	Low	Low

Prioritising Hazards

Risk Level	Priority	Action
Extreme	1	* Cease task/activity immediately; * Implement short term safety controls to make the situation safe; * Notify supervisor/manager and assess activity; and * Do not proceed with task/activity until corrective action has been implemented, and reviewed and approved by the relevant Vice-President and Executive Dean of College or Portfolio Head.
High	2	* Implement short term safety controls to make the situation safe; * Notify supervisor/manager and assess activity; and * Do not proceed with task/activity until corrective action has been implemented, and reviewed and approved by the relevant Vice-President and Executive Dean of College or Portfolio Head.
Medium	3	* Implement short term safety controls. * Notify supervisor/manager and assess activity. * Implement control measures.
Low	4	* Notify supervisor/manager and assess activity. * Implement control measures.

Control Hierarchy	
Elimination	*Remove hazard*
Substitution	*Use a less hazardous alternative*
Isolation	*Eg Restrict access, use in a closed container, fume cabinet*
Engineering	*Eg Trolleys to move loads, guards on machinery, fume cupboard*
Administration	*Eg Training, Safe Work Procedure, signage*
PPE - Personal Protective Equipment	*Eg Gloves, respirator, safety glasses*

See WHS Risk Management Procedure for further details

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Figure 31: MasterGlenium SKY 8700 Risk Assessment Form

8.2 Photos captured during the laboratory experiments

In this section can be found several photos captured during the laboratory process, which aim to demonstrate the process of preparing and testing concrete. The below pictures correspond to the base mixture, all other mixtures have the same process of preparation. The first batch of concrete, respectively the trial mix, is prepared on March 16th, 2022, whilst the last mixture was on May 16th, 2022.

Figure 32: Mixing procedure in the drum

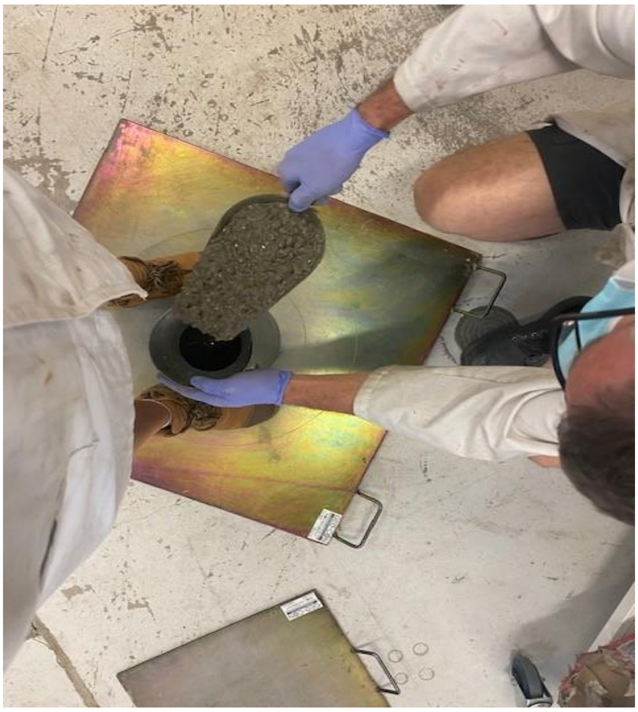

Figure 33: Slump Test

Figure 34: Fill up the moulds

Figure 35: Vibrating the panel

Figure 36: Make a smooth surface

Figure 37: Cover with plastic sheet for the evaporation aim

Figure 38: Compressive Strength test on 7th day

Figure 39: Two cylinders tested on 7th day for compressive strength

Figure 40: Testing the panel on the 35th days

Figure 41: Filling the specified moulds

Figure 42: Cover of the moulds with plastic sheets

Figure 43: Grinding process for cylinders

Figure 44: Panels' Ductility Test

Figure 45: Slump Test

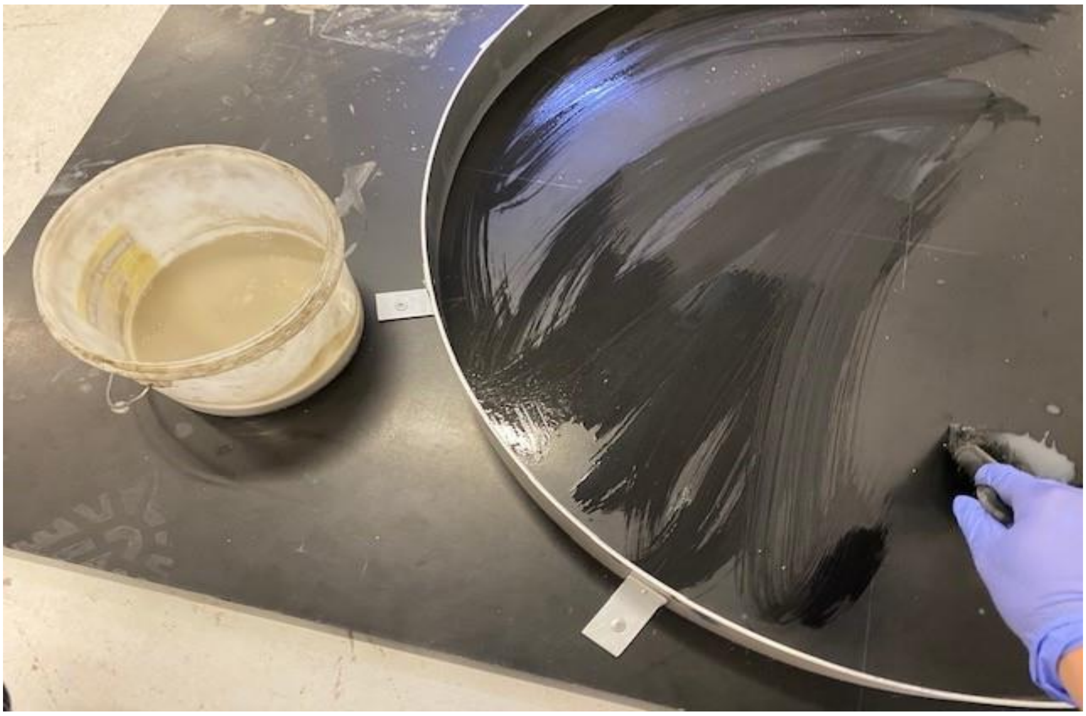

Figure 46: Applying a thin layer of Lanoform

Figure 47: Vibrating process for the cylinders

Figure 48: Resting for 24 hrs to get a harder concrete

Figure 49: Slump Test

Figure 50: Filling the moulds

Figure 51: Slump Test

Figure 52: Vibrating Table

Figure 53: Ductility test