Deformation Properties of Concrete Containing Crumb Rubber from Scrap Tire as a Partial Replacement to Fine Aggregate

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SEPTEMBER 2017

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CERTIFICATION OF APPROVAL

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A Project Dissertation submitted to the Department of

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in partial fulfilment of the requirement for the

BACHELORS OF ENGINEERING (Hons)

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Approved by,

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SEPTEMBER 2017

CERTIFICATION OF ORIGINALITY

I thus proclaim that I am fully responsible for the material this submission and to the best of my insight and conviction, that it contains no material(s) beforehand published or composed by another author except as per specified with the exception where due affirmation is made in this Project Dissertation. Any contribution made to this particular research by associates, with whom I have worked with for my Project Dissertation at Universiti Teknologi PETRONAS is completely recognised.

I likewise pronounce that the intellectual content found in this Project Dissertation is the result of my own work, but to the degree that helps from my colleagues in the completion of the research is fully acknowledged.

………………………………………………

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ABSTRACT

Adding granulated crumb rubber from unrecycled scrap tires in concrete as a partial replacement to fine aggregate in the creation of Rubbercrete has given numerous advantages to not only the environment, but also as its usage of concrete itself. Numerous properties of Rubbercrete are enhanced compared to conventional concrete when crumb rubber is partially replaced with fine aggregate. Nevertheless, there are notable drawbacks to the usage of Rubbercrete which includes the reduction in strength of the Rubbercrete which will eventually limits the use of Rubbercrete in the construction industry. Along these lines, this Project Dissertation will show techniques on manufacturing Rubbercrete on which its compressive strength can be compared to that of conventional concrete, where this said technique includes the adding of Nano silica into the concrete design mix.

Approximately 30 design mixes were designed with usage of Response Surface Methodology (RSM) at three levels of crumb rubber replacement by volume to fine aggregate (0%, 15%, 30%), three levels of Nano silica addition (0%, 2.5%, 5%) and three levels of Fly ash addition (0%, 35%, 70%). Subsequently, six more design mixes were created by the RSM to determine the most optimum design mix from the initial 30 design mixes. These six optimized design mixes are then required for experimental testing (shrinkage test, modulus of elasticity and Poisson’s Ratio test) to determine the deformation properties of Rubbercrete.

Ultimately, it is to be concluded that the addition of Nano silica would refine the extent of the pores and densify the Interfacial Transition Zone (ITZ) between the surface matrix of the aggregates and cement in the solidifying of Rubbercrete. Eventually, the Rubbercrete will obtain a slightly if not, much better compressive strength compared to conventional concrete.

ACKNOWLEDGMENT

The author would like to express his sincerest form of gratitude to Universiti Teknologi PETRONAS (UTP), being a foundation which was set up with the goal to pass on even-handed graduates who are in reality prepared, and in addition have distinctive qualities anticipated that would thrive in the university.

Currently, the author is completing his Bachelor's Degree in Civil Engineering and is in the Final Year Final Semester of studies. It is necessary for all UTP understudies to forego the course known as Final Year Project where they are required to submit this Dissertation report as per requirement.

In this FYP Dissertation Report, the author's encounters with the research will be depicted and documented. The author also want to express his thankfulness to everybody included and additionally to the individuals who gave thoughts and support in finishing this report. A very much appreciated thank you, AP Dr Bashar S Mohammed, whom is the author's FYP Supervisor of Universiti Teknologi PETRONAS (UTP) in paving the way and guiding me throughout the author's journey in this research.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

The main complication of improper solid waste management that has led to environmental problems is due to inadequate management practices (Tinmaz and Demir, 2005). In layman's term, solid waste can be expressed as any form of garbage, sludge from a wastewater treatment plant and even disposed-of materials including solid, liquid, semi-solid, or containing vaporous materials. Solid waste is usually invoked by establishments of outposts and settlements, small or big business venture buildings as well as private enterprises activities (Singh et al., 2011).

One of the solid waste which is in abundance globally is scrap tires where (Thomas et al., 2016) has reported that over more than 500 million units of waste tires which are being dumped prior to any form of treatment in every progressive year once the tires have no longer of any use. In Malaysia alone, the number of scrap tires produced on a yearly basis was close to the range of 8.2 million units which is circa, 57,391 tonnes and about 60% of the scrap tires are dumped via channels which are not known (Thiruvangodan 2006). Figures such as mentioned are indeed worrying especially knowing the threat that unrecycled scrap tire can pose to the environment as well as humans worldwide.

These scrap tires are mostly bulky and occupy unnecessary space. The accumulation of scrap tires at deserted areas suits as an ideal breeding ground for mosquitoes and pests. Besides being non-biodegradable, they have the potential to form a haze danger in instances where the scrap tires are either accidentally or intentionally set on fire (Pelisser et al., 2011). In short, the opportunities to recycle waste tire is limited and ends up being scarce for the usage of the tire.

Therefore, one of the solution, as to properly utilise the “indestructible” scrap tires, is to use crumb rubber (CR) as a partial replacement to fine aggregate in the production of concrete. This partial replacement of CR to fine aggregates in the production of concrete has turned out to be one of best options in managing the ecological balance with additional financial noteworthiness (Guo et al., 2014).

Along the note of ecological balance, Mohammed (2010) verified that the assimilation of CR in concrete had begun back in the 90’s when researchers were focussed on developing a new form of alternative regarding recycled scrap tires to be incorporated in concrete while keeping in mind about the safekeeping of the environment. The conversion of scrap tire to CR begins with the external part of the scrap tire to be processed where the steel wire is removed from the rubber chips and then shredded proceeding with the shredded tire scrap undergoing primary and secondary granulation and the end product is what is known as Crumb Rubber (Mohammed et al., 2012). This CR is then utilised as a partial replacement to fine aggregate in the production of concrete (Mohammed et al., 2012). The now modified concrete produced from this substitution can be described in several ways such as rubber treated cement, rubberized concrete, crumb rubber concrete or Rubbercrete.

1.2 PROBLEM STATEMENT

There are countless of studies that were conducted regarding the partial replacement of fine aggregate using crumb rubber in order to find an alternative for the usage of normal concrete. However, Rubbercrete has its drawbacks mainly in the strength aspect as it is known that fine aggregates are only partially utilised (along with crumb rubber). Mohammed et al.,(2016) further clarify that the decrease in strength such as flexural and compressive strength is deduced to have come from the weak forces of bonding with regards to CR and cement particles.

Therefore, a solution for these drawbacks is indispensable to promote the usage of Rubbercrete in the construction industry where in this research, the usage of Nano silica and fly ash will be used to further increase the strength of the concrete.

Hence, the contemporary procedure of the problem statement is based on regulating three types of tests which study the deformation properties of concrete containing crumb rubber from scrap tire as a partial replacement to fine aggregate. All in all, the accumulation of scrap tires worldwide is creating a huge problem globally in terms of concerns for the environment, thus obliges the government to start by placing resources into encouraging citizens and companies for the utilization of waste tires in concrete as the utilization of crumb rubber concrete is essential to the blasting development industry in developing nations (Batayneh et al., 2008).

1.3 OBJECTIVES

This research aims to study the deformation properties of concrete containing crumb rubber from scrap tire as a partial replacement to fine aggregate which involves the administration of three types of tests which are Compressive Strength test, Shrinkage test and Elasticity of Modulus test. This study is done in order to obtain information to provide attainable suggestions as to improve the authenticity of the analysis to improve the general strength of the concrete mix containing crumb rubber. The study will be tending the accompanying goals;

a) To determine the deformation properties of Rubbercrete containing Nano silica and fly-ash
b) To evaluate the compressive strength of Rubbercrete
c) To find the suitable workability for the concrete mix so as to satisfy the slump criteria before transferring the mix into moulds
d) To analyse the induced stress due to shrinkage formed when the volume of changes when stresses are applied
e) To determine the modulus of elasticity as well as identify the relationship between stress-strain and Poisson's Ratio
f) To be able to develop models based on results obtained

1.4 SCOPE OF STUDY

This study focuses on the actual mixing of concrete using the data from the simulation of Response Surface Methodology. The data provided are the percentage of crumb rubber, Nano silica and fly ash as well as the water-cement ratio in which the mix has to be prepared within an allowable slump limit of 75mm to 100mm. The materials needed besides the ones mentioned is the use of superplasticizer which acts as an admixture for concrete to improve the workability of the concrete. Besides, the role of using superplasticizer is also to control the setting rate and is added to the mix of concrete. The various purposes of Rubbercrete in applications in the real world will not be fully discussed, as the methods of this study is in the laboratory as well where laboratory tests are conducted.

1.5 RELEVANCY AND FEASIBILITY

This project is quite relevant as far as the usage of Rubbercrete is concerned with it provides many benefits to the environment. The first point being that by partially replacing fine aggregates with crumb rubber, a lot of unused and recycled tires which are being disposed of can be utilized without the tires having to be stagnant and dumped without any proper recycling. Hence, by doing so, the issue of saving the environment can be said to contributing to the cleanliness of the earth.

Besides, this research aims to push the construction industry towards using Rubbercrete in several products which could utilize Rubbercrete. One reason being that Rubbercrete can be used to make Traffic Barricades, where if a car were to lose control and ram into a Rubbercrete traffic barricade, that same traffic barricade will absorb the shock instead compared to the car.

The feasibility of this research is at a tolerable level as every material can be found in the lab itself. However, there are the occasional times where fine aggregates and cement have to be purchased from shops nearby the University

CHAPTER 2

LITERATURE REVIEW AND THEORY

2.1 INTRODUCTION TO CRUMB RUBBER CONCRETE (RUBBERCRETE)

Rubbercrete is defined as a special type of concrete which incorporates crumb rubber (granulated scrap tire) as a partial replacement to fine aggregates in the production of concrete. The initial process involves the scrap tire being processed into minute pieces which are called crumb rubber, and the inclusion of this crumb rubber into a concrete mix can be partially or fully. Crumb rubber concrete is what is known as the resulting concrete mix (Mohammed et al., 2012).

2.2 APPLICATION OF RUBBERCRETE

2.2.1 Wall Plaster

Comparatively, for a normal room whether it be a lecture theatre or a bedroom, the room being noisy where a person in another location could hear what is going on in the room is uncanny. Therefore, acoustic features in wall linings are appreciated where it protects the privacy of the ambience in a room. Using Rubbercrete as a form of wall plaster aims to deliver that objective as it is approximately 66% better acoustic characteristics compared to ordinary plaster and dry lining. Besides, Rubbercrete wall lining is also about 83% more thermally efficient compared to using ordinary concrete where it has low thermal conductivity properties which not only keeps the interior of the room cool but also saves energy as well. Retrieved from http://www.walltransform.co.uk/products/Rubbercrete/

2.2.2 Traffic Barricades

When a car crashes into a concrete barricade, the shock is absorbed by the car thus causing greater damage to the car compared to the barricade. As for the utilisation of Rubbercrete traffic barricades, the effects and harm will not be as much as a concrete barricade. What a Rubbercrete traffic barricade does is, it absorbs the shock instead when a car rams into the barricade

2.3 CRITICAL ANALYSIS AND RELEVANCY

As an improved version of ordinary concrete, Rubbercrete is expected to have tonnes of benefits. For one, the particles of crumb rubber in Rubbercrete has a low specific gravity, meaning when the percentage of crumb rubber increases, the unit weight decreases (Mohammed 2010). This implies that Rubbercrete is lighter in weight compared to conventional concrete. Next, the crumb rubber has high air content which is also known as having a hydrophobic nature where the bubbles are taken into account for the mixture of concrete containing crumb rubber thus increasing the air content (Liu et al., 2016). Other benefits of Rubbercrete includes improved slump (increased workability), increased resistance impact (shock absorbance) and electrical resistivity, better ductility and sound absorption with higher noise reduction (improved acoustic properties), low thermal conductivity (energy saving) and also possesses sound proof properties (Onuaguluchi & Panesar 2014; Shu & Huang 2013; Bravo & De Brito 2012; Mohammed et al., 2012; Mohammed & Azmi 2011; Mohammed et al., 2012; Ganjian et al., 2009; Li et al., 2004). Better energy dissipation also exists in Rubbercrete (Youssf et al., 2014).

With the many strengths that can be found in Rubbercrete, along comes the drawbacks. The most notable drawback that comes to mind is the reduction in strength of the Rubbercrete. The reduction in strength ranges from tensile strength, splitting strength, compressive strength and lastly flexural strength (Mohammed et al., 2016). In addition, Young's modulus (which describes the tensile elasticity) increases as crumb rubber is replaced as fine aggregate (Mohammed et al., 2016).

Due to the weakness in strength, the Rubbercrete, in turn, is easier to bend/stretch and deformation will occur quicker when it reaches a certain stress compared to the usual Ordinary Portland Cement (Mohammed et al.,2012). This can be explained, as mentioned previously that the CR in Rubbercrete has hydrophobic nature, meaning, when more air is trapped in the Rubbercrete, there will be lesser and weaker bonding between the CR particles and cement mix. Upon research, the hydrophobic properties found in CR can be accredited to the fact that a type of white solid called "Zinc stearate" is added during the mass-production of rubber tires to repel water (Youssf et al., 2014). Onuaguluchi & Panesar (2014) explains that the non-polar layer of CR actually resists water and traps air around it prompting for the expansion of thickness of the Interfacial Transition Zone (ITZ) between the CR and cement matrix, which eventually ends up with the lessening and weakening of the bonding between the CR particles and cement mix (Mohammed et al.,2016).

2.4 THEORY

It is concluded that due to the weakening of the bonding and the expansion of Interfacial Transition Zone (ITZ), the stress concentration causes internal micro-cracks which will eventually lead to an untimely failure (Thomas et al., 2016; Li et al.,2016; Sadek & El-Attar, 2015; Mohammed et al., 2012). Scrivener and Laugesen (2004) describe the Interfacial Transition Zone (ITZ) as the area of the cement paste surrounding the aggregates that are unsettled by the existence of the aggregate itself. Scrivener et al.,(2004) also followed up by mentioning that the Interfacial Transition Zone (ITZ) is of slow-paced transition and is immensely heterogeneous.

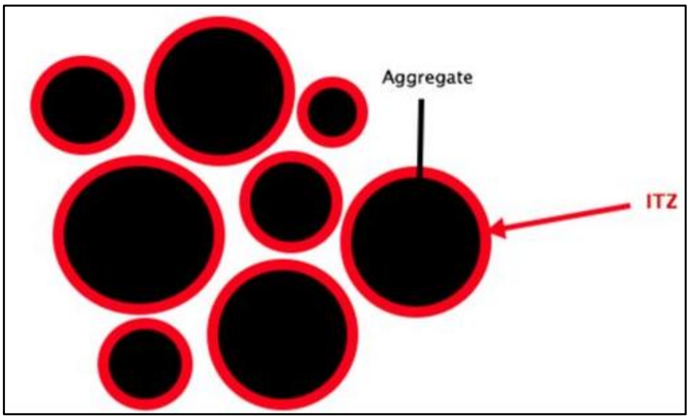


Figure 2.1: Interfacial Transition Zone (ITZ)

In order to handle this issue, the chosen solution for the enhancement and for the densification of the Interfacial Transition Zone (ITZ) is to incorporate Nano silica particles and fly ash into the mixture which can be represented in a chemical equation as below;

$$Ca(OH)_2 + H4SiO_4 \rightarrow Ca^{2+} + H_2SiO_4^{2-} + 2H_2O$$
$$\rightarrow CaH_2SiO_4 + 2H_2O$$

It can be seen that the product of the chemical equation consists of C-S-H (also known as Calcium-Silicate-Hydrate) which is actually a form of gel where it is revealed to be very useful to strengthen the lost strength in the cement when crumb rubber is used in the concrete mixture and when internal cracks are formed (Mohammed et al., 2016).The C-S-H gel would thus fill in the Nano-voids of the cement mix and eventually make it a solid cement mix (Mohammed et al., 2016). The inclusion of fly ash is also used in this study to increase strength to produce the requirement. It additionally goes about as an activator to Pozzolanic response, which additionally delivers more C– S– H gel prompting upgrading the microstructure of concrete (Nili and Ehsani, 2015; Mukharjee and Barai, 2014a).

2.5 RECENTNESS OF LITERATURE REVIEW

Many forms of research have been conducted to rectify this loss of strength found in the cement mix. Rostami et al.,(1993) gave an interpretation where the top surface of the CR was treated, and the end product is found to be that the compressive strength showed a significant increase when constituents such as water, carbon tetra-chloride solvent, and latex admixture were utilised for the surface treatment. A later discovery has shown that Li et al., (1998) has pre-fabricated cement paste with the CR particles, as well as METHOCEL cellulose ether solution in which is reported that the general strength of the Rubbercrete mix has slightly improved. The compatibility between silica fumes and fly ash also leads to the decrease in the thermal conductivity due to the lower thermal conductivity of the two ingredients that were substituted in the concrete mix as reported by Demirboga (2003). Erhan et al., (2004) has found out that by partially substituting cement properties with a mixture of silica fumes and fly ash, the compressive strength has been enhanced due to the filling effect of the silica fume providing a suitable connectivity between the aggregates and cement matrix. Gesoglu and Guneyisi (2007) have reported that their findings of incorporating 10% silica fume as a partial replacement for the cement to have enhanced the general strength and increased chloride penetration resistance for the Rubbercrete. Azevedo et al.,(2012) used fly ash and metakaolin as a cement substitution in the production of Rubbercrete to enhance its qualities. They have discovered that the results show a positive feedback in the enhancement of the strength of the Rubbercrete.

2.6 OVERALL CONCLUSION REMARK

Although the conventional concrete is commonly used in the field of construction and development, most researchers have come up improved and improvised types of concrete structures which are currently existing and available on the market (with Rubbercrete being one of them).

Unfortunately, even with the plenty of technology which is available, traditional concrete is not an eco-friendly material, either to make, utilise or discard. Preparations of obtaining the materials needed to make concrete require a tremendous amount of energy and water must be utilised, and quarrying for sand and other aggregates causes natural destruction and pollution. In addition, cement is also almost guaranteed to be a colossal source of carbon outflows into the atmosphere which directly translates that cement is not environmentally friendly. Up to 5% of the world's aggregate sum of carbon emissions caused by concrete directly contributes to the greenhouse gases. Due to reasons mentioned, the usage of Rubbercrete seems plausible compared to using normal cement.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 PROJECT GANTT CHART & KEY PROJECT MILESTONES

In order to fulfil the requirement of meeting the objectives, this study will be in accordance with the research methodology timeline. The Gantt chart below shows a graphical illustration of how long the research is being conducted and the key dates of this research.

No	Activity	WEEK NO.													
		May-17			Jun-17				Jul-17				Aug-17		
		W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
1	Confirmation on Project Title														
2	Data Gathering														
3	Extended Proposal														
4	Laboratory Work														
5	Submission of Extended Proposal						19th June								
6	Proposal Defence									3rd July					
7	Interim Report														
8	Submission of Interim Report Draft													7th August	
9	Submission of Final Interim Report														14th August

No	Activity	WEEK NO.													
		Sep-17			Oct-17				Nov-17				Dec-17		
		W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
1	Laboratory Work														
2	Progress Report														
3	Submission of Progress Report						25th October								
4	Pre-Sedex										22nd November				
5	Final Report														
6	Technical Paper														30th November
7	VIVA														11th December

Figure 3.1 Gantt Chart & Key Project Milestones

3.2 PROJECT WORKFLOW

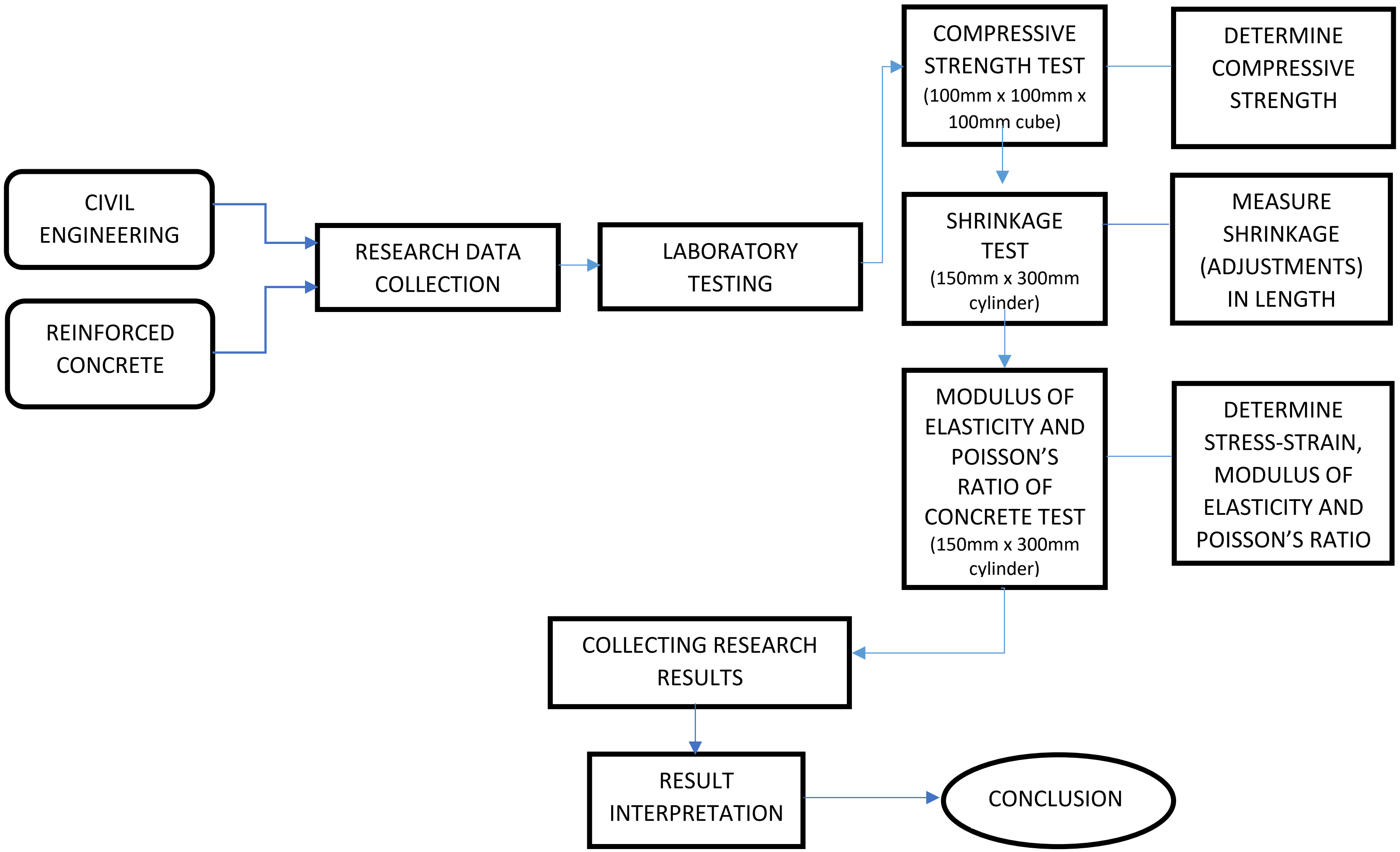


Figure 3.2 Project Flowchart

3.3 MATERIALS USED IN PROJECT

Besides the traditional fine aggregate, coarse aggregate and crumb rubber used for the completion of the research, there are also other important materials needed for this research such as Nano silica, water, fly ash as well as superplasticizer. The design mixes were provided by the Response Surface Methodology constitutes the percentage of each material needed in each mix.

3.3.1 FINE AGGREGATE

Figure 3.3: Fine Aggregate

Fine aggregates are identified as a loose granular substance which is normally pale yellowish dark coloured which are formed due to the disintegration of siliceous and other rocks and becomes the frame constituent of shorelines, riverbeds and sea beds.

For this research, only the portion of the fine aggregate that passes the No 4 sieve (4.75-mm) entirely are the ones which are used in the production of Rubbercrete.

3.3.2 COARSE AGGREGATE

Figure 3.4: Coarse Aggregate

Coarse aggregate is the most important component in the production of concrete where the portion does not pass the No.4 sieve (4.75-mm). Any aggregates greater than diameters 4.76mm is known as the coarse aggregate. These coarse aggregates are the part of a composite material that opposes compressive strength and gives mass to that mentioned composite material.

3.3.3 CRUMB RUBBER

Figure 3.5: Crumb Rubber

Crumb rubber is labelled as a material inferred by reducing tire scraps/rubber into uniform granules where other fortifying materials such as steel, fibre, dust or rock are expelled.

3.3.4 CEMENT

Figure 3.6: Cement

In general terms, cement is a greyish powder which when mixed with sand and water produces concrete. Cement is also a binder material that sets, solidifies and adheres to materials to restrict them together.

3.3.5 FLY ASH

Figure 3.7: Fly Ash

Class F Fly ash which conforms to ASTM C612 refers to the ash produced during the combustion of coal, which is also known as “pulverised fuel ash”. It is used in concrete to improve the workability of concrete, and the strength and durability of hardened concrete.

3.3.6 NANO SILICA

Figure 3.8: Nano silica

Nano silica is also known as silicon dioxide in Nano particles form. In this research, the role of Nano silica (with size 10-25 nm) improves the materials' bulk properties as well as to curb the issue of the imperfect bonding between the cement matrix and crumb rubber. It has been used as an addition to cementitious materials.

3.3.7 SUPERPLASTICIZER

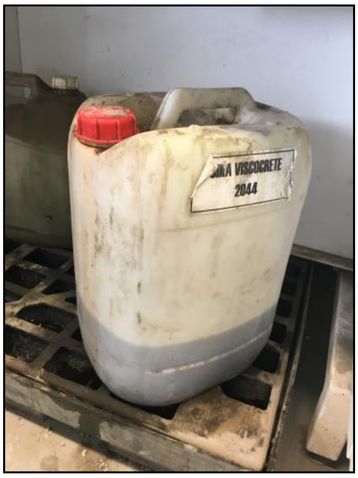


Figure 3.9: Superplasticizer

Superplasticizers are synthetic admixtures utilized where scattered molecule suspension is required. The addition of concrete allows the diminishment of water to cement ratio, thus improving the workability of the mixture. This impact definitely enhances the performance of the hardening cement paste.

3.4 PROPERTIES OF MATERIALS

A sieve analysis which is also known as a gradation test is usually conducted to articulate the particle size distribution of a granular material. Materials such as fine aggregate, coarse aggregate and crumb rubber were put to the gradation test. This sieving method was done in accordance to as per IS: 2386 (Part 1) -1963 where different sieves which were standardized by the IS codes are used. The materials are passed through each sieve of different sizes and the particles left over the different sieves are weighed and the total passing percentage is calculated. Graph models are then developed to show the different gradation and also the comparison between these three materials.

To recap, the three (3) different materials which were tested for the sieve analysis in this research which are;

1) Fine Aggregate
2) Coarse Aggregate
3) Crumb Rubber

3.5 SIEVE ANALYSIS

The table below shows the sieve analysis table for the fine aggregate that was used in the research.

Table 3.1: Sieve Analysis Table for Fine Aggregate

Sieve size (mm)	Weight of sieve (kg)	Sieve + weight of fine aggregate (kg)	weight retained (kg)	Percentage retained (%)	Cumulative percentage retained (%)	Total Passing (%)
5	0.379	0.379	0	0.00	0.00	100.00
No.8(2.36)	0.443	0.443	0	0.00	0.00	100.00
No.16(1.18)	0.337	0.337	0	0.00	0.00	100.00
No.30(0.6)	0.384	2.244	1.86	92.95	92.95	7.05
No.50(0.3)	0.338	0.477	0.139	6.95	99.90	0.10
No.100(0.15)	0.256	0.258	0.002	0.10	100.00	0.00
0.063	0.249	0.249	0	0.00	100.00	0.00
Pan	0.365	0.365	0	0.00	100.00	0.00
Total	2.751	4.752	2.001	100.00	-	-

The table below shows the sieve analysis table for the coarse aggregate that was used in the research.

Table 3.2: Sieve Analysis Table for Coarse Aggregate

Sieve size (mm)	Weight of sieve (kg)	Sieve + weight of coarse aggregate (kg)	Weight retained (kg)	Percentage retained (%)	Cumulative percentage retained (%)	Total Passing (%)
13.2	1.077	1.077	0	0.00	0.00	100.00
9.5	1.079	1.083	0.004	0.13	0.13	99.87
No.4 (4.75)	1.172	3.097	1.925	64.17	64.30	35.70
No.8(2.36)	1.085	2.015	0.93	31.00	95.30	4.70
No.16(1.18)	0.951	1.077	0.126	4.20	99.50	0.50
Pan	0.735	0.75	0.015	0.50	100.00	0.00
Total	6.099	9.099	3	100.00	-	-

The table below shows the sieve analysis table for the crumb rubber that was used in the research.

Table 3.3: Sieve Analysis Table for Crumb Rubber

Sieve size (mm)	Weight of sieve (kg)	Sieve + weight of crumb rubber (kg)	Weight retained (kg)	Percentage retained (%)	Cumulative percentage retained (%)	Total Passing (%)
5	1.206	1.206	0	0.00	0.00	100.00
No.8(2.36)	1.11	1.85	0.74	37.00	37.00	63.00
No.16(1.18)	0.97	2.01	1.04	52.00	89.00	11.00
No.30(0.6)	0.9	1.12	0.22	11.00	100.00	0.00
No.50(0.3)	0.79	0.79	0	0.00	100.00	0.00
No.100(0.15)	0.827	0.827	0	0.00	100.00	0.00
0.063	0.802	0.802	0	0.00	100.00	0.00
Pan	0.744	0.744	0	0.00	100.00	0.00
Total	7.349	9.349	2	100.00	-	-

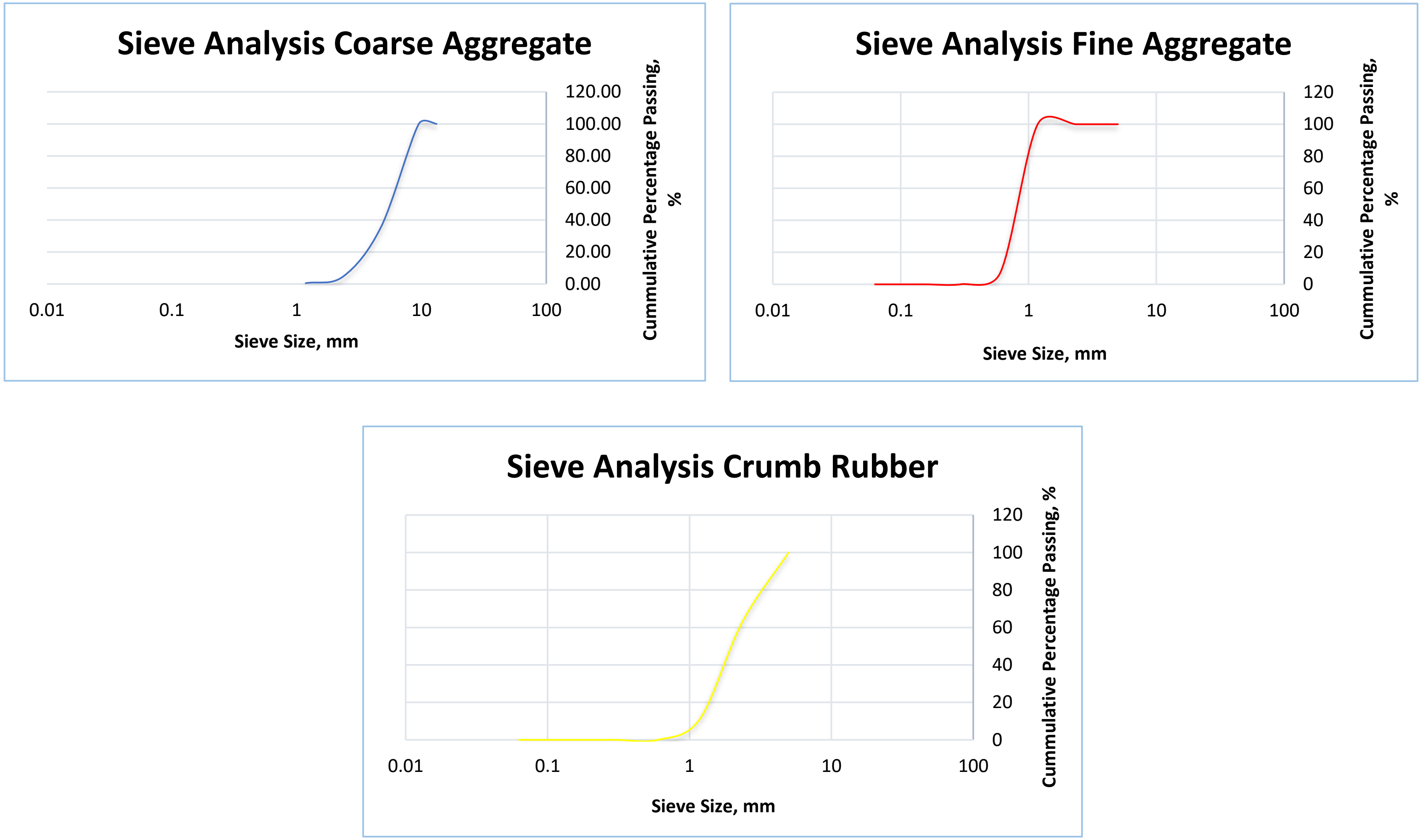


Figure 3.10: Sieve Analysis Graphical Models for Coarse Aggregate, Fine Aggregate and Crumb Rubber

The graph below shows the comparison of sieve analysis table for fine aggregate, course aggregate and crumb rubber that was used in the research.

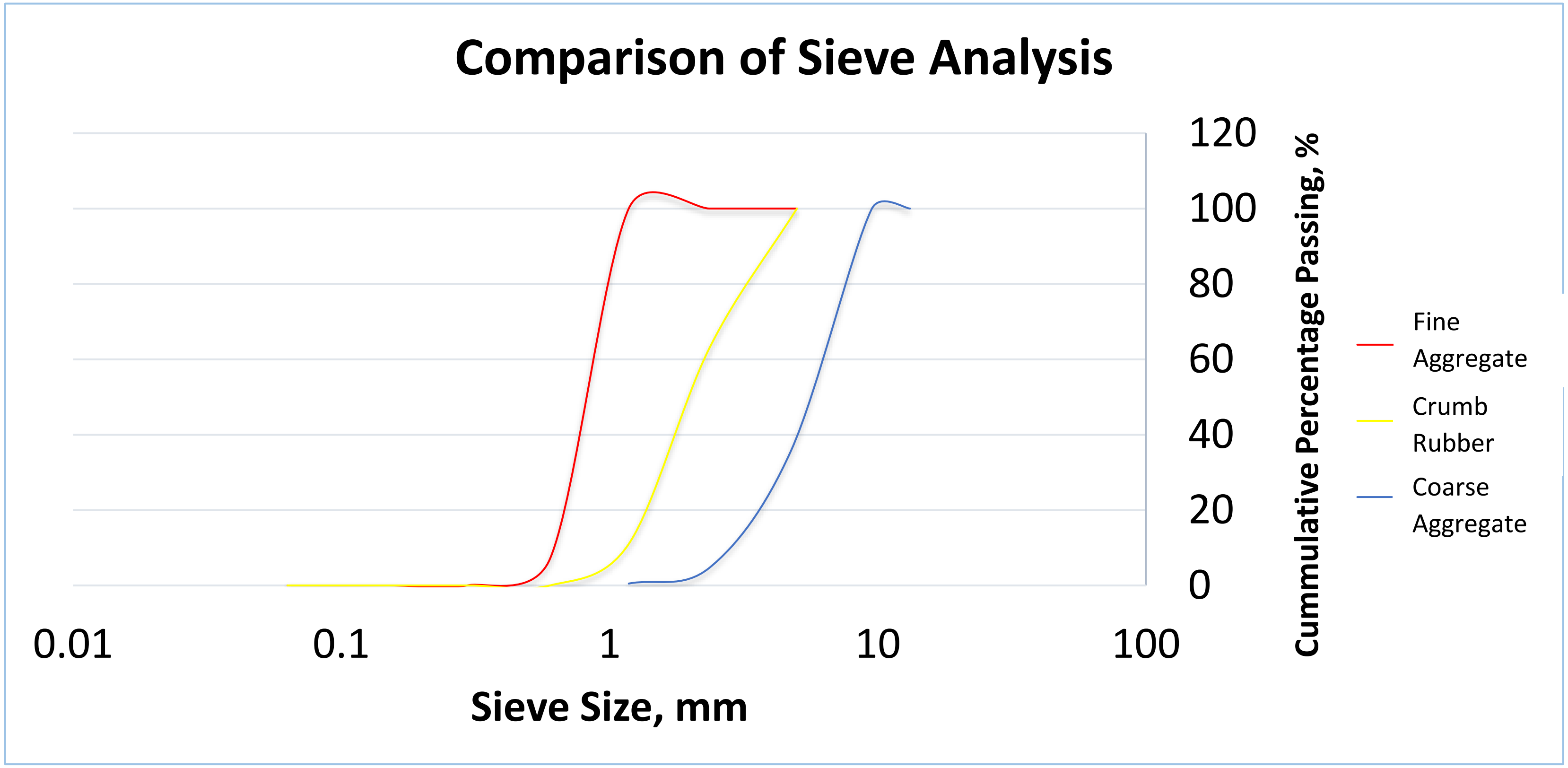


Figure 3.11: Comparison of Sieve Analysis Graphical Models for Coarse Aggregate, Fine Aggregate and Crumb Rubber

3.6 RESPONSE SURFACE METHODOLOGY

Yolmeh (2017) stated that the Response Surface Methodology (RSM) is a statistical technique which is used to simulate experiments and processes.

Figure 3.12: Design Expert 10 Logo

The software Design-Expert 10.0.4, was used to perform the design of experiments to escalate an output variable where the leverage comes from the input variables. A trial of progression of tests is known as runs. The multiple variables to be inputted is what will provide the output response.

Hence, with the usage of the software which runs the Response Surface Methodology, 30 design mixes were designed and prepared at three levels of crumb rubber replacement by volume to fine aggregate (0%, 15%, 30%), three levels of Nano silica addition (0%, 2.5%, 5%) and three levels of Fly ash addition (0%, 35%, 70%).

Thus, a manual calculation is required in order to determine the exact quantity of crumb rubber, Nano silica, fly ash, water-cement ratio, cement and sand required for each mix for all 30 design mixes to be mixed. The three levels of crumb rubber replacement volume which were designed by the Response Surface Methodology can be viewed on the following page, while the Excel calculations are done on the page after that.

Run	CR %	NS %	FA %	w/c
1	0	0	0	0.25
2	15	2.5	35	0.3
3	15	2.5	0	0.3
4	15	2.5	35	0.3
5	15	2.5	35	0.3
6	30	5	70	0.35
7	15	5	35	0.3
8	0	5	70	0.25
9	30	0	0	0.35
10	15	0	35	0.3
11	0	5	0	0.35
12	30	5	0	0.35
13	0	0	70	0.25
14	15	2.5	70	0.3
15	30	0	70	0.25
16	15	2.5	35	0.3
17	30	5	0	0.25
18	15	2.5	35	0.25
19	0	5	70	0.35
20	0	0	70	0.35
21	30	5	70	0.25
22	0	2.5	35	0.3
23	0	5	0	0.25
24	0	0	0	0.35
25	15	2.5	35	0.3
26	30	2.5	35	0.3
27	15	2.5	35	0.35
28	15	2.5	35	0.3
29	30	0	0	0.25
30	30	0	70	0.35

Figure 3.13: 30 Design Mixes generated from the Response Surface Methodology for Compressive Test

Cement kg/m^3	543
Coarse aggregate kg/m3	840
Fine aggregate kg/m3	670
Specific gravity	
Sand	2.6
Crumb rubber	0.95
at volume of (m3):	0.006
Cement (kg)	3.258
Coarse aggregate (kg)	5.04
Fine aggregate (kg)	4.02
add 40% wastage	
at volume of (m3):	0.0084
Cement (kg)	4.5612
Coarse aggregate (kg)	7.056
Fine aggregate (kg)	5.628
Volume sand	2.165

Run	CR (m3)	CR (kg)	NS (kg)	FA (kg)	w/c	cement	sand (m3)	sand (kg)
1	0	0	0	0	1.14	4.56	2.17	5.63
2	0.32475	0.31	0.11	1.60	1.37	2.96	1.84	4.78
3	0.32475	0.31	0.11	0	1.37	4.56	1.84	4.78
4	0.32475	0.31	0.11	1.60	1.37	2.96	1.84	4.78
5	0.32475	0.31	0.11	1.60	1.37	2.96	1.84	4.78
6	0.6495	0.62	0.23	3.19	1.60	1.37	1.52	3.94
7	0.32475	0.31	0.23	1.60	1.37	2.96	1.84	4.78
8	0	0	0.23	3.19	1.14	1.37	2.17	5.63
9	0.6495	0.62	0	0	1.60	4.56	1.52	3.94
10	0.32475	0.31	0	1.60	1.37	2.96	1.84	4.78
11	0	0	0.23	0	1.60	4.56	2.17	5.63
12	0.6495	0.62	0.23	0	1.60	4.56	1.52	3.94
13	0	0	0	3.19	1.14	1.37	2.17	5.63
14	0.32475	0.31	0.11	3.19	1.37	1.37	1.84	4.78
15	0.6495	0.62	0	3.19	1.14	1.37	1.52	3.94
16	0.32475	0.31	0.11	1.60	1.37	2.96	1.84	4.78
17	0.6495	0.62	0.23	0	1.14	4.56	1.52	3.94
18	0.32475	0.31	0.11	1.60	1.14	2.96	1.84	4.78
19	0	0	0.23	3.19	1.60	1.37	2.17	5.63
20	0	0	0	3.19	1.60	1.37	2.17	5.63
21	0.6495	0.62	0.23	3.19	1.14	1.37	1.52	3.94
22	0	0	0.11	1.60	1.37	2.96	2.17	5.63
23	0	0	0.23	0	1.14	4.56	2.17	5.63
24	0	0	0	0	1.60	4.56	2.17	5.63
25	0.32475	0.31	0.11	1.60	1.37	2.96	1.84	4.78
26	0.6495	0.62	0.11	1.60	1.37	2.96	1.52	3.94
27	0.32475	0.31	0.11	1.60	1.60	2.96	1.84	4.78
28	0.32475	0.31	0.11	1.60	1.37	2.96	1.84	4.78
29	0.6495	0.62	0	0	1.14	4.56	1.52	3.94
30	0.6495	0.62	0	3.19	1.60	1.37	1.52	3.94

Figure 3.14: Excel Calculations to determine the proportion of each material in each mix (Compressive Test)

Hence, after all 30 mixes have completed the average 14 days and 28 days compressive strength test, the results are then inputted into the Response Surface Methodology to determine the best and the most optimum design mix for conducting the deformation properties of concrete containing crumb rubber from scrap tire as a partial replacement to fine aggregate. Once the most optimum mix design has been deduced, the values are then inputted into the RSM, and a further six mix designs were generated. These six mix designs which are named M20, M25, M30, M40, M50 and M60 (to represent the concrete strength of 20 MPa, 25 MPa, 30 MPa, 40 MPa, 50 MPa and 60 MPa) where similarly, the percentage of crumb rubber, Nano silica, fly-ash, water-cement ratio and superplasticizer content are provided. Each of the six model designs has its own 28 day strength which was calculated and concluded by the analysis of the software using the Response Surface Methodology. In addition, the desirability of each of the six design mixes has its own desirability ratio which shows how close that the values can be replicated in real life shall the experiment be repeated.

In addition, the Design-Expert software provides statistical processes to design the limitations and boundaries for the deformation properties tests to be carried out. These statistical significance using the results obtained for the 14-day and 28-day compressive strength test are based on a basis of analysis of variance (ANOVA). This ANOVA process hence provides and identifies each factor on the desired outcome in terms of graphical representations of Normal Plot of Residuals, Residual vs Predicted and Residuals vs Run graphs where the models are implied to be significant model terms hence six further experiments are designed.

Below shows the calculations provided by the Design-Expert 10.0.4 software to obtain the six design models to be mixed in order for the deformation properties of Rubbercrete to be investigated.

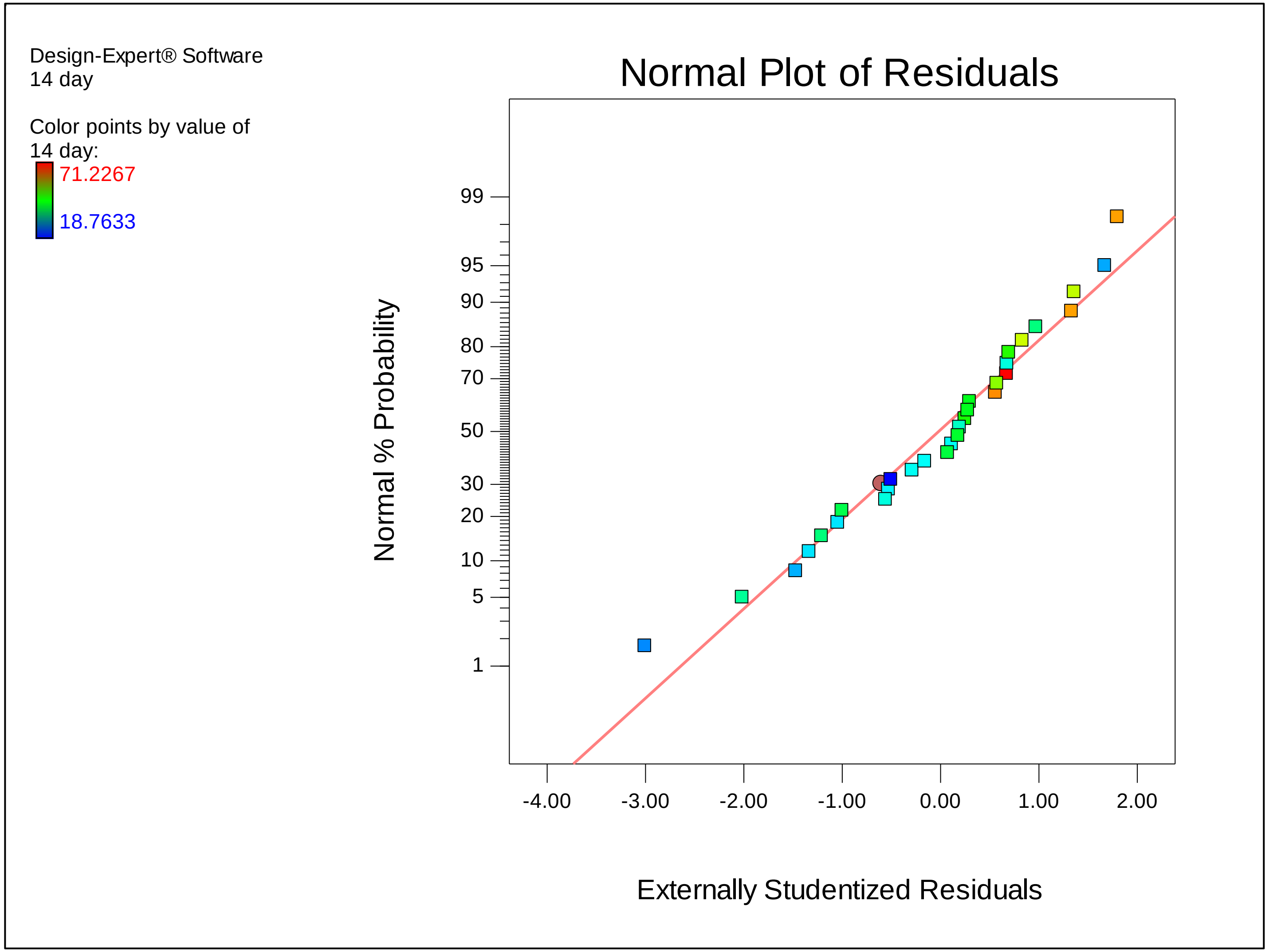


Figure 3.15: Residual Plot Diagram – 14 days

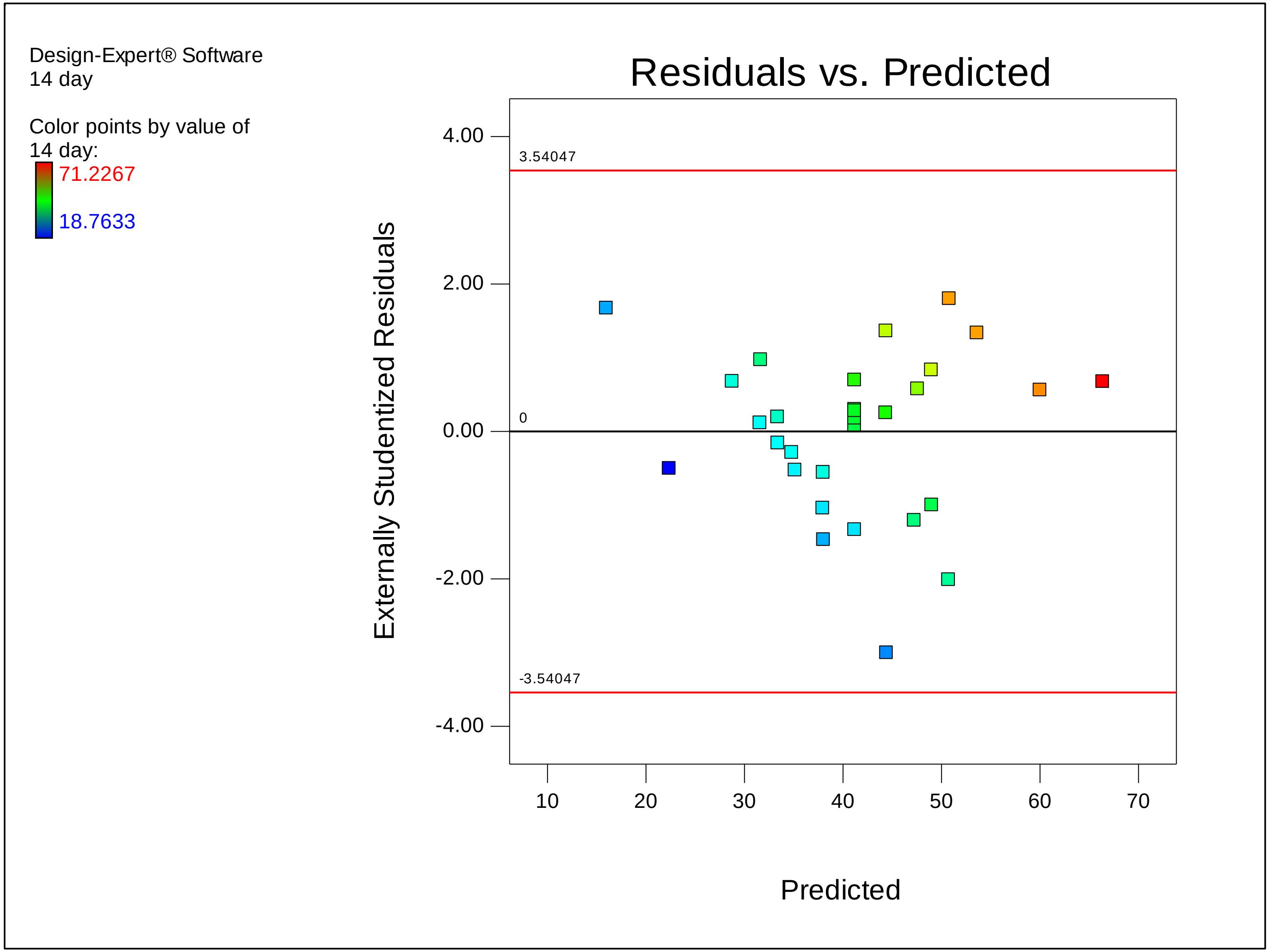


Figure 3.16: Residual vs Predicted Plot Diagram – 14 days

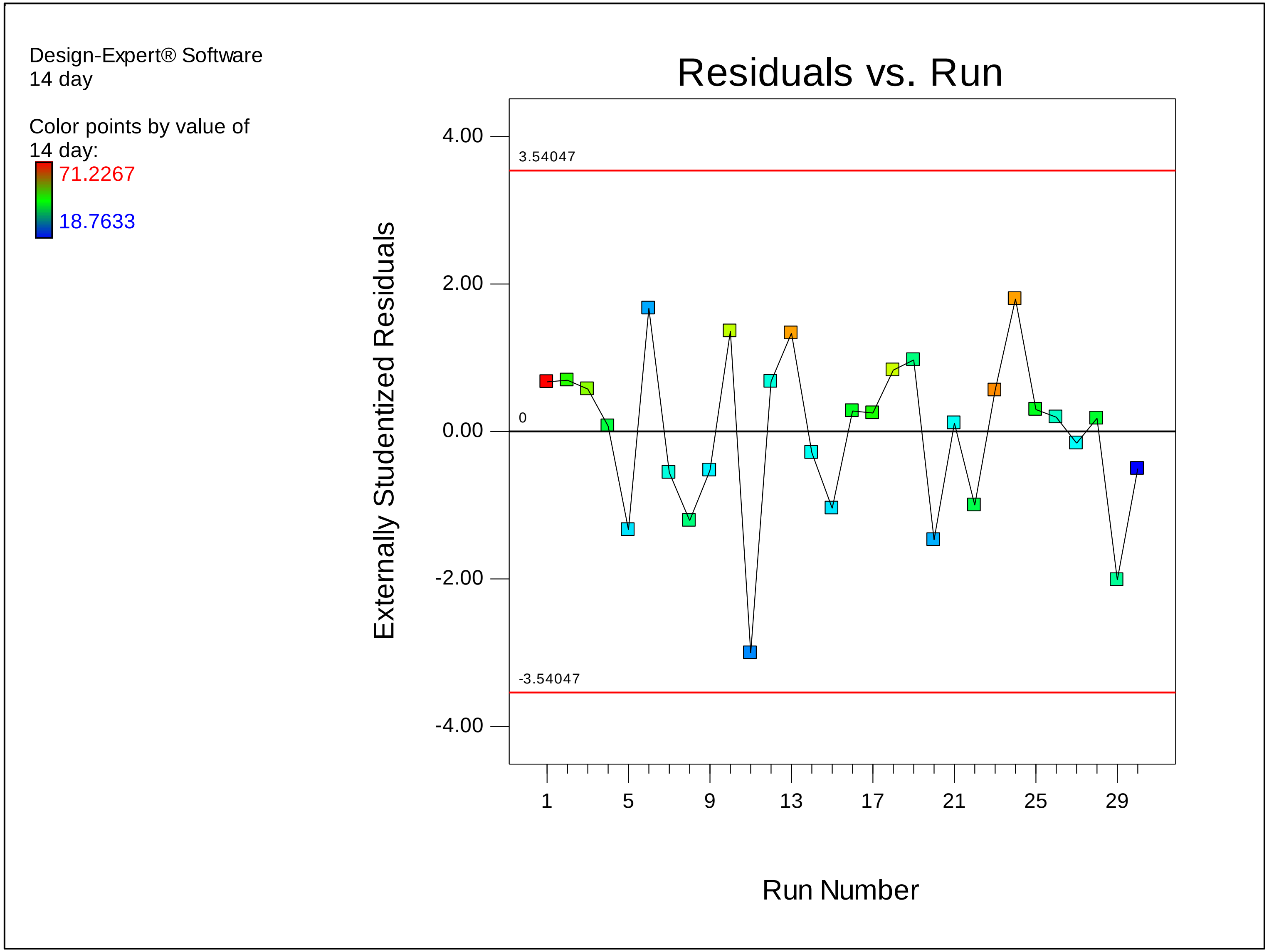


Figure 3.17: Residuals vs Run Plot Diagram – 14 days

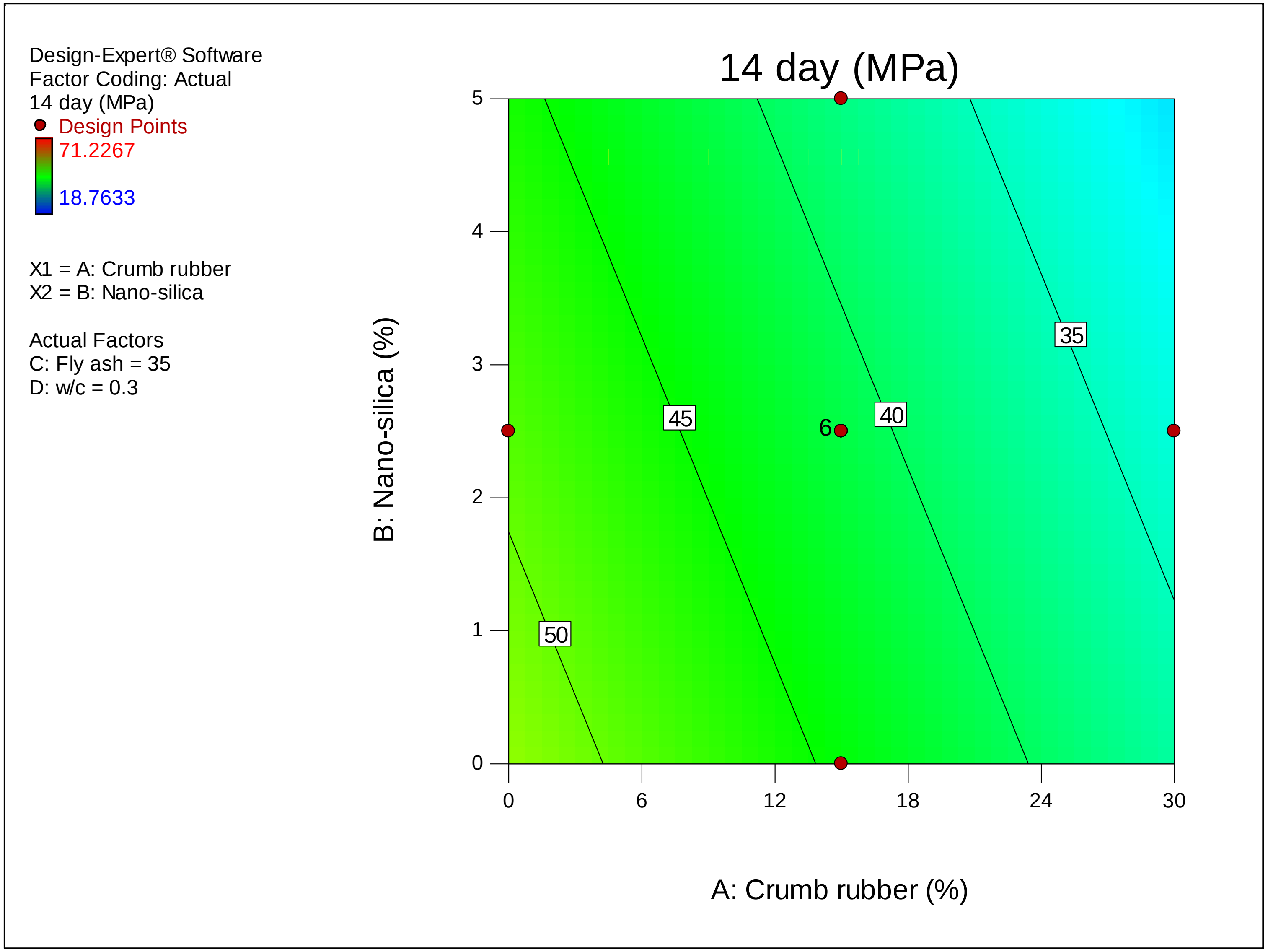


Figure 3.18: 14 day compressive strength Plot Diagram

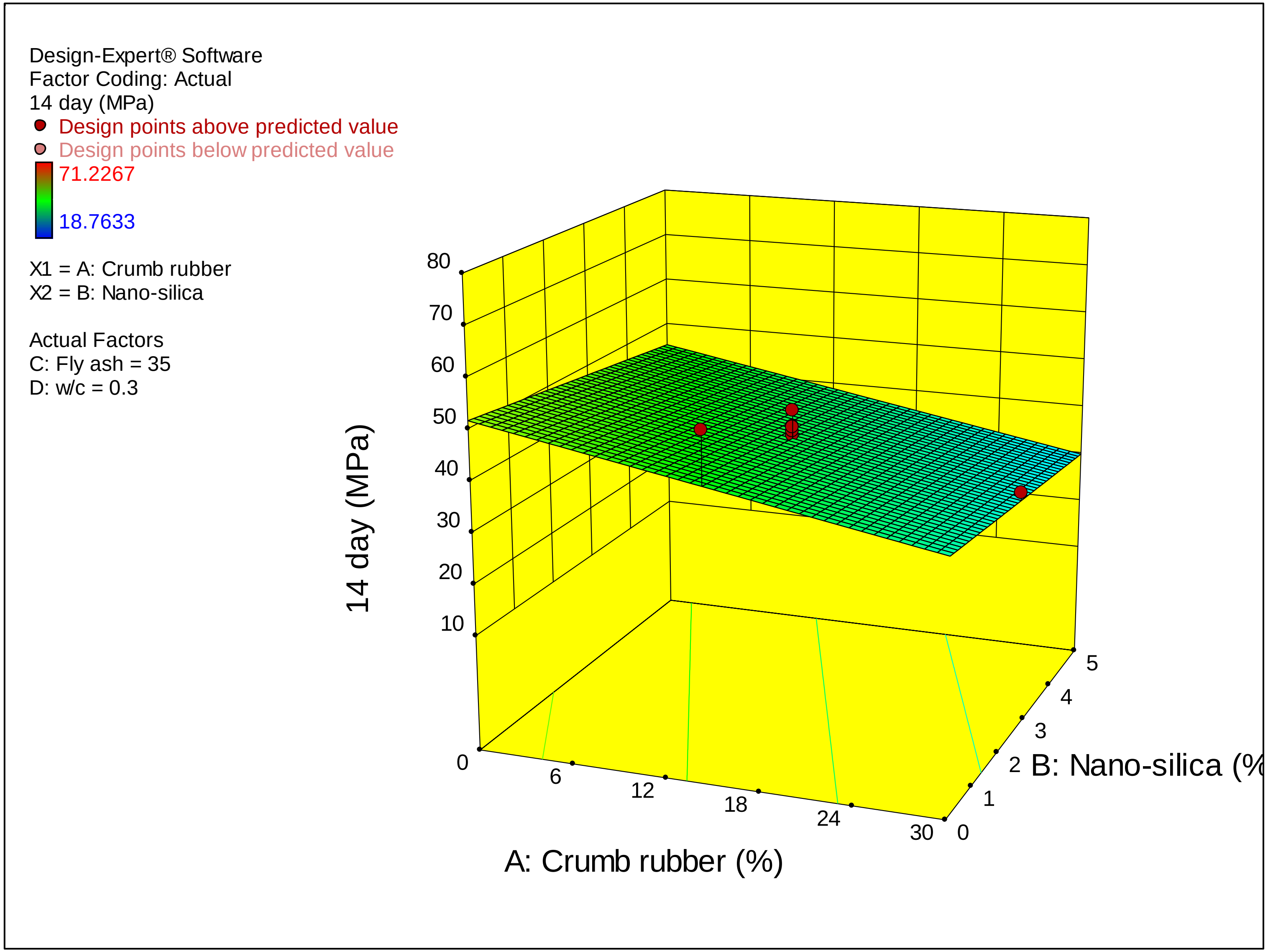


Figure 3.19: Crumb Rubber vs Nano silica Box-Cow Plot Diagram (Fly ash 35%) – 14 days

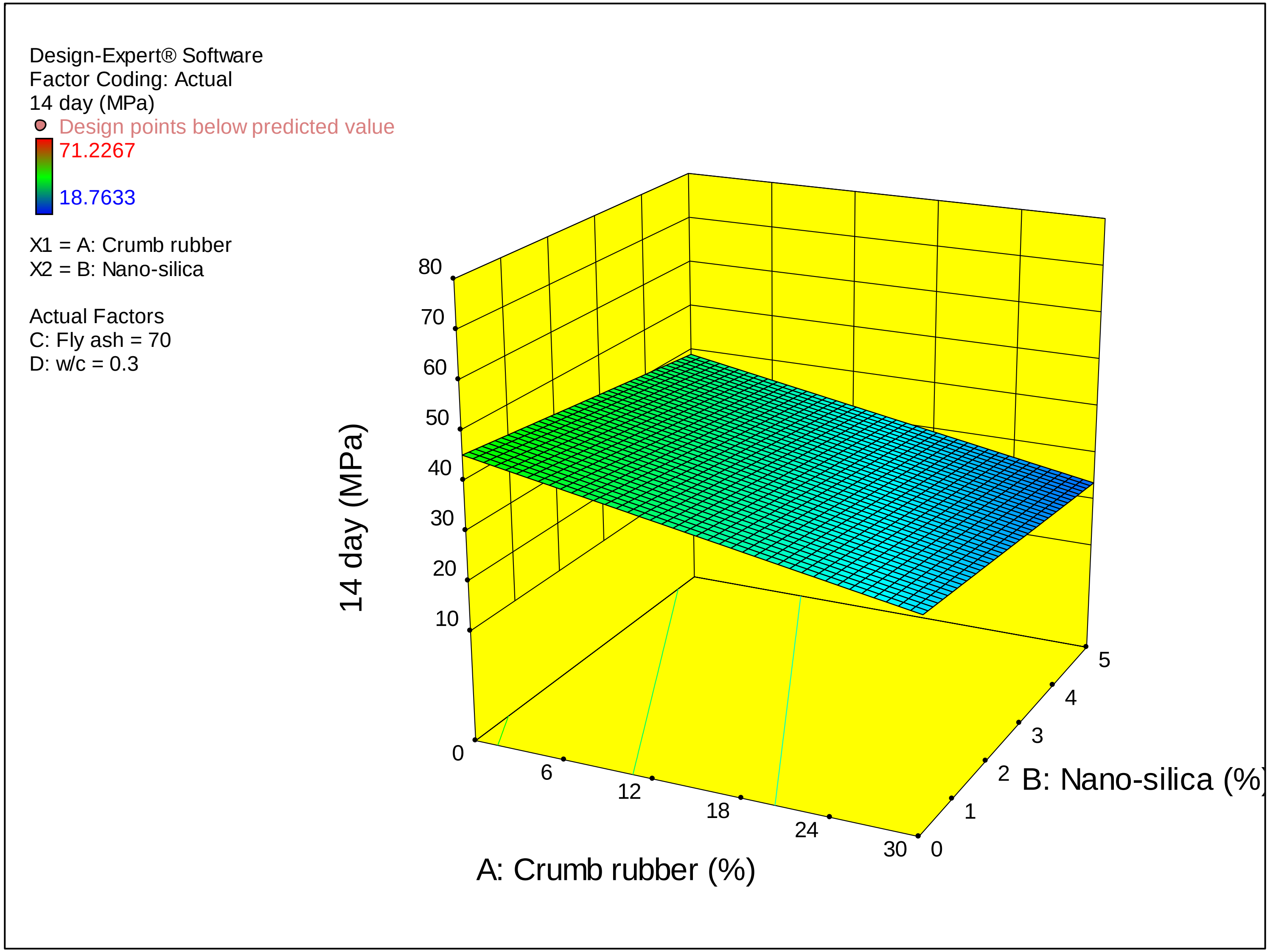


Figure 3.20: Crumb Rubber vs Nano silica Box-Cow Plot Diagram (Fly ash 70%) – 14 days

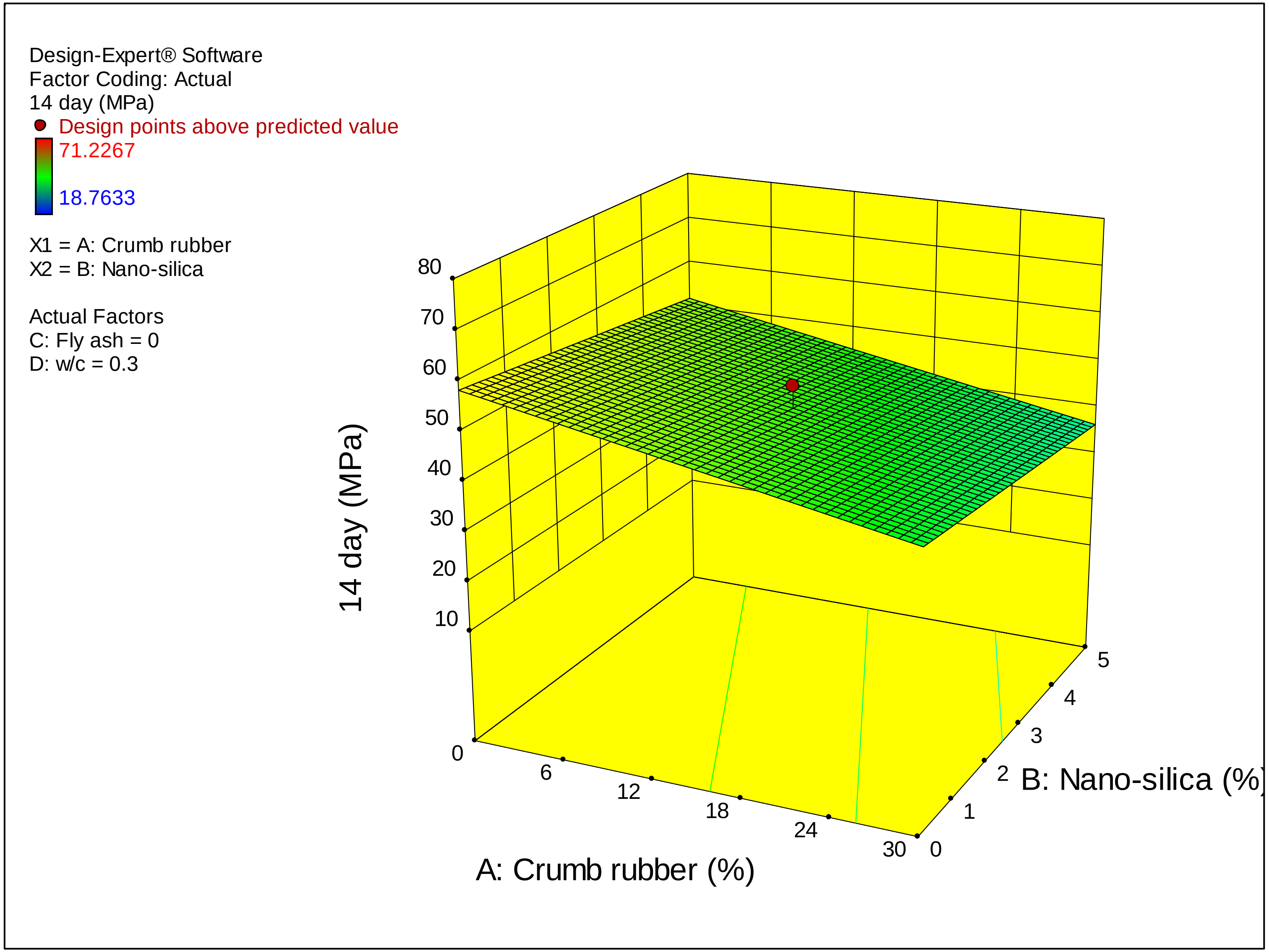


Figure 3.21: Crumb Rubber vs Nano silica Box-Cow Plot Diagram (Fly ash 0%) – 14 days

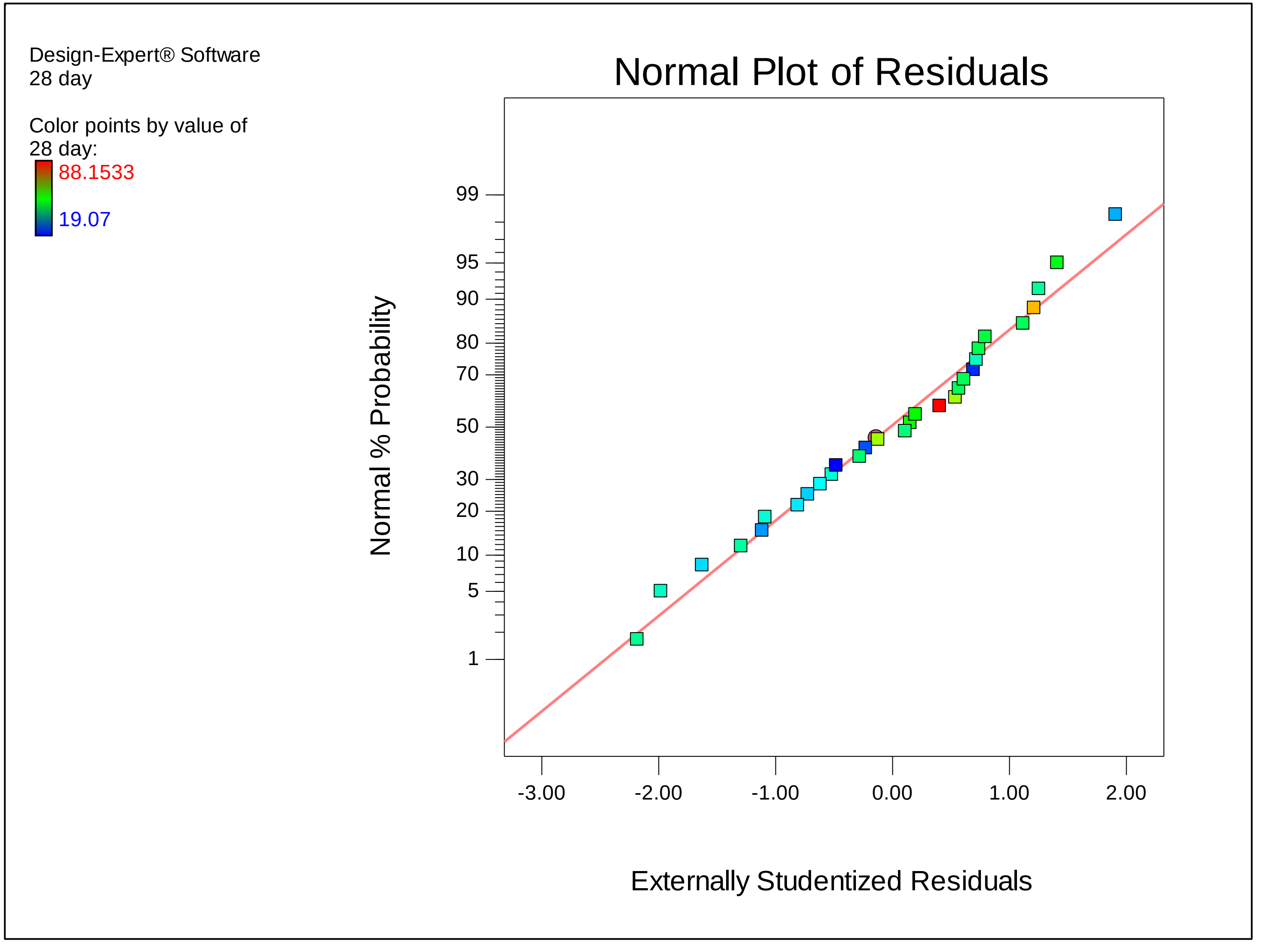


Figure 3.22: Normal Plot of Residuals Diagram – 28 days

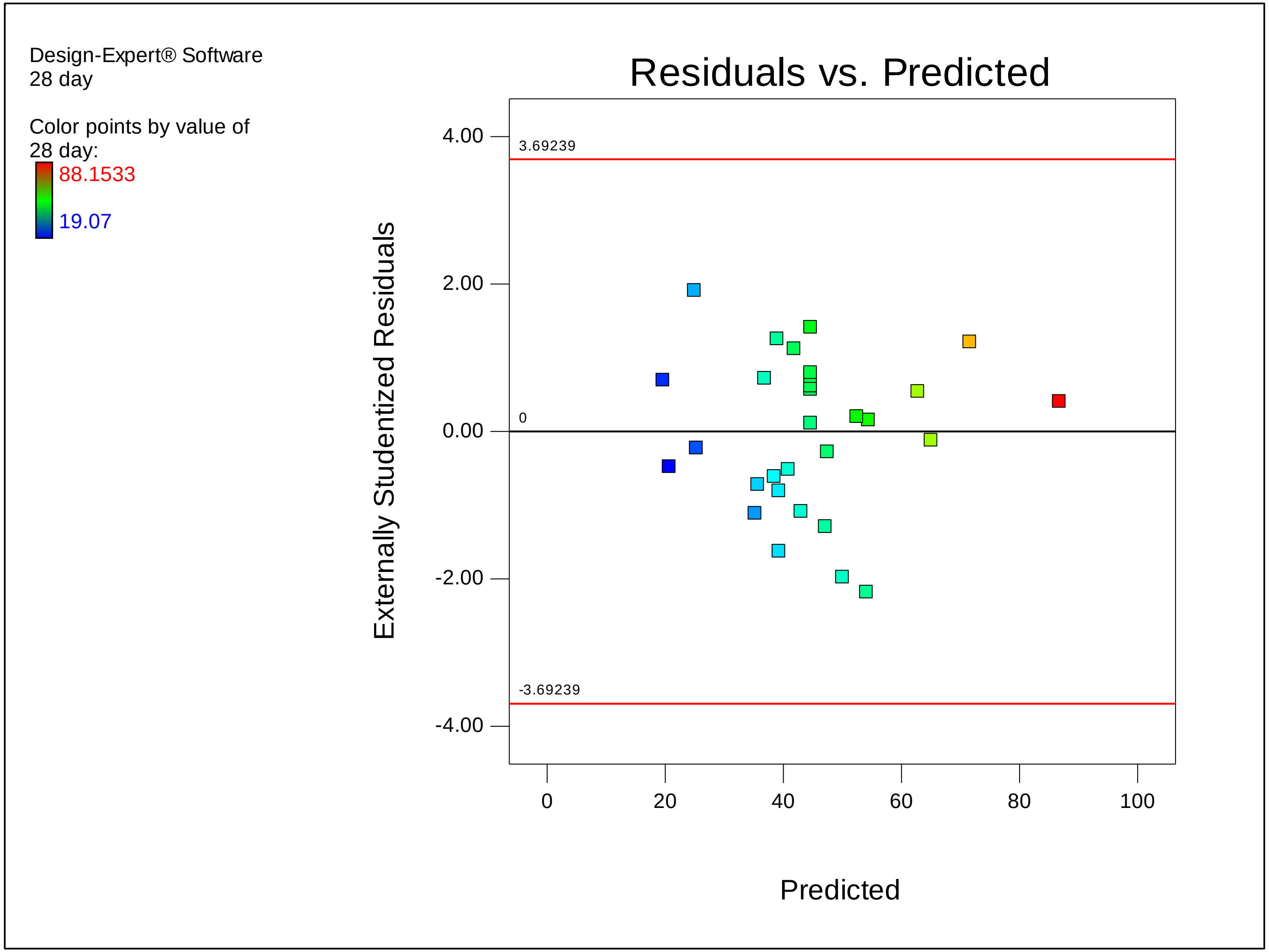


Figure 3.23: Residual vs Predicted Plot Diagram – 28 days

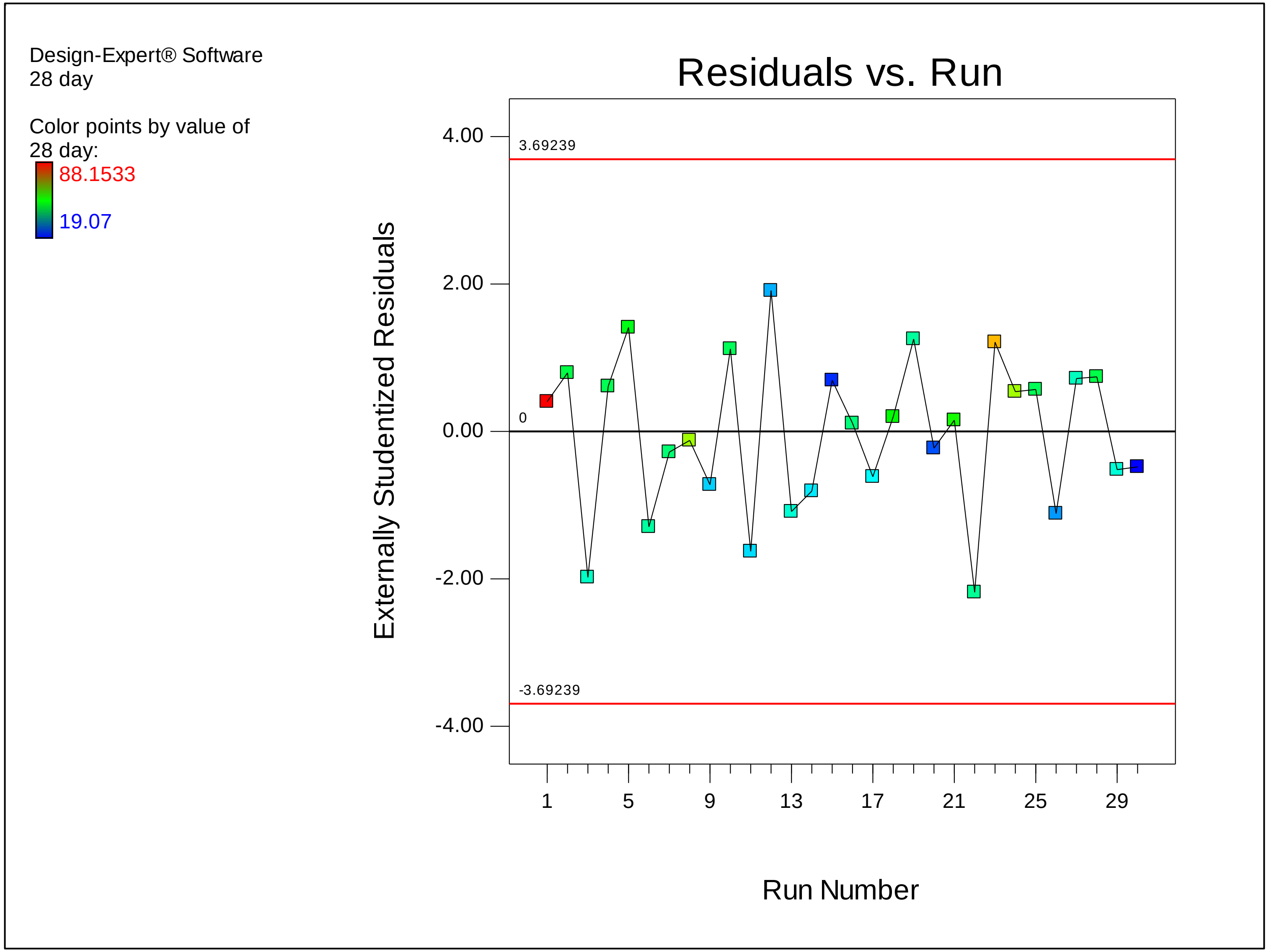


Figure 3.24: Residual vs Run Plot Diagram – 28 days

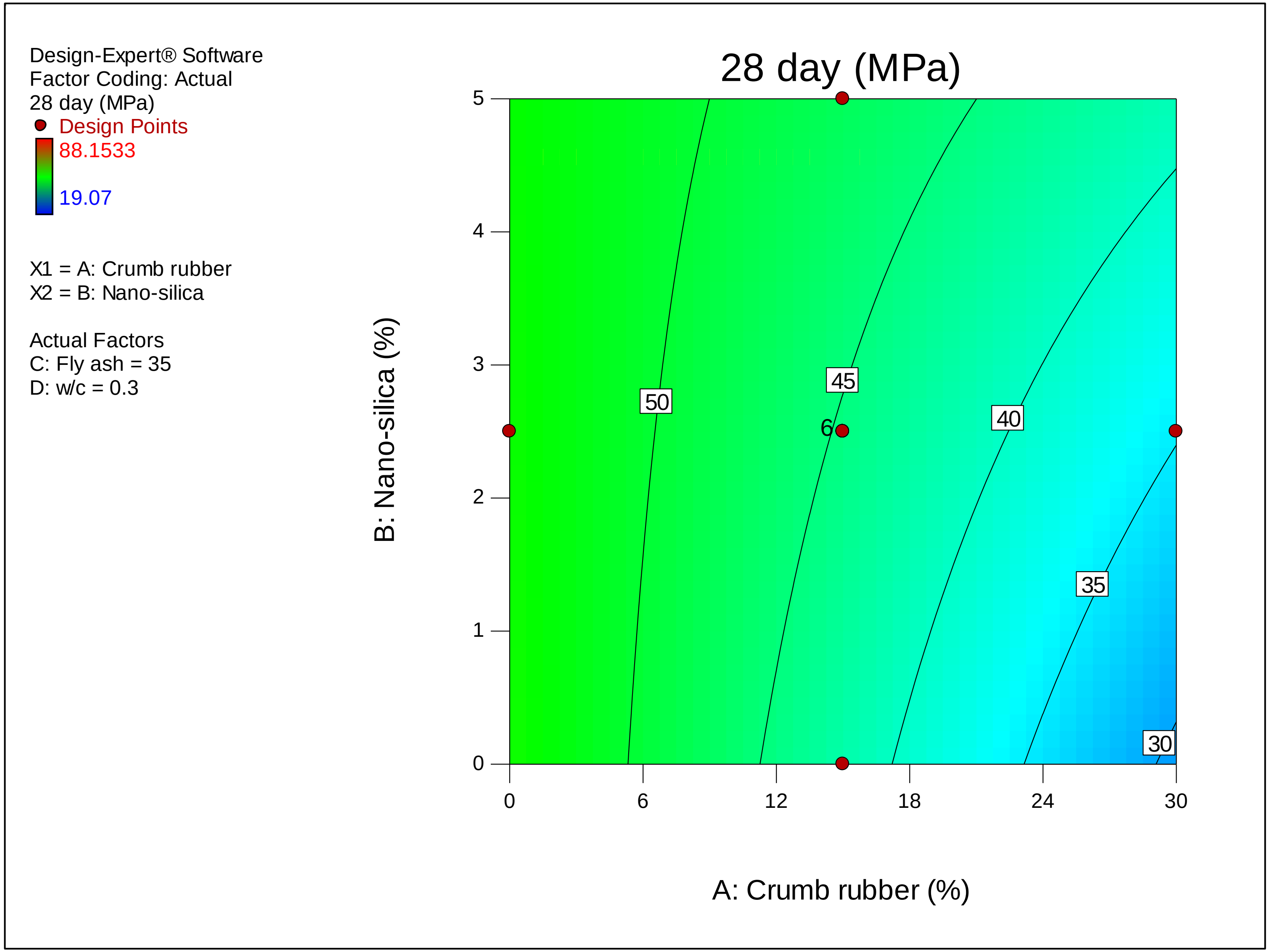


Figure 3.25: 28 day compressive strength Plot Diagram

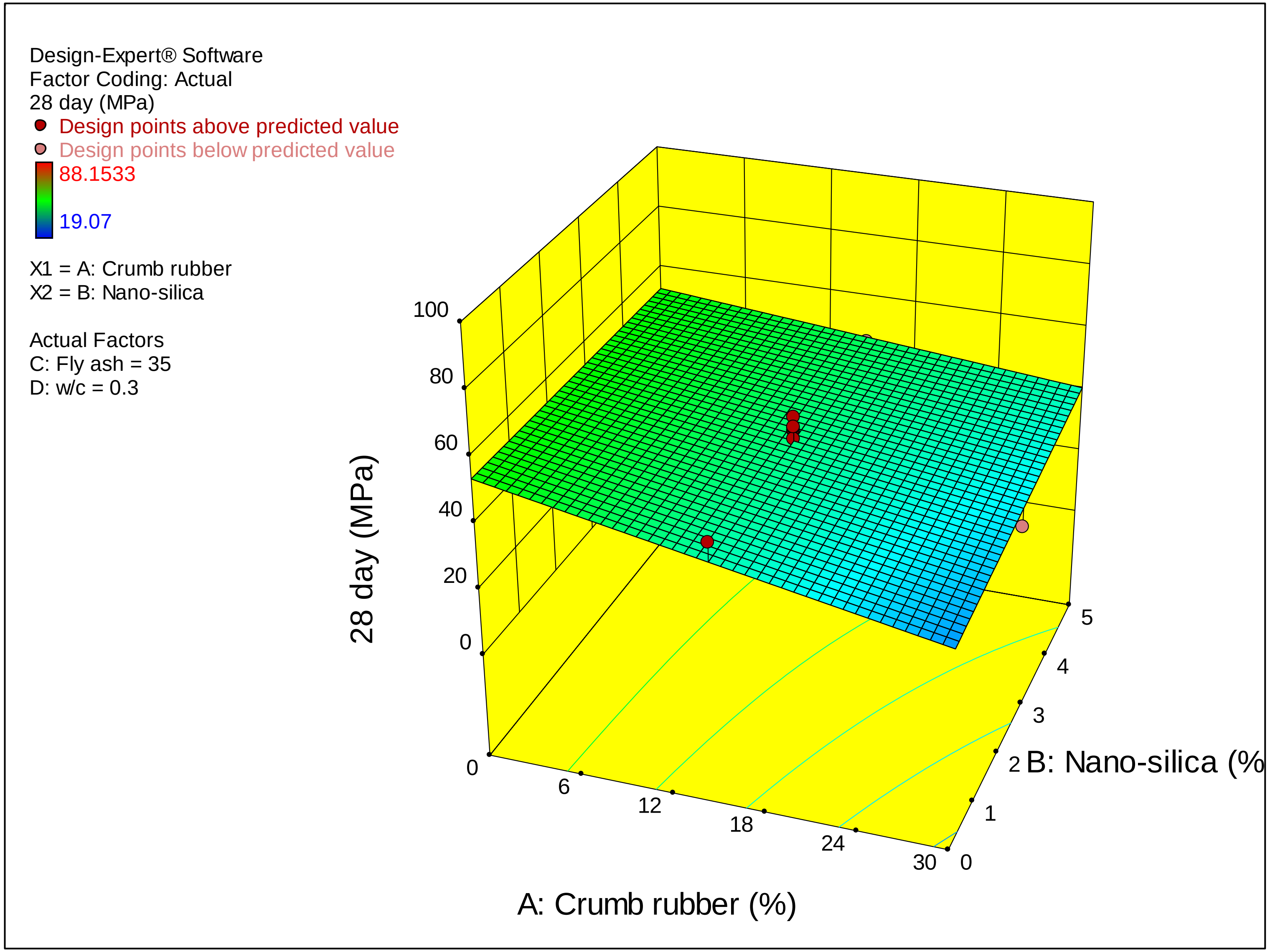


Figure 3.26: Crumb Rubber vs Nano silica Box-Cow Plot Diagram (Fly ash 35%) – 28 days

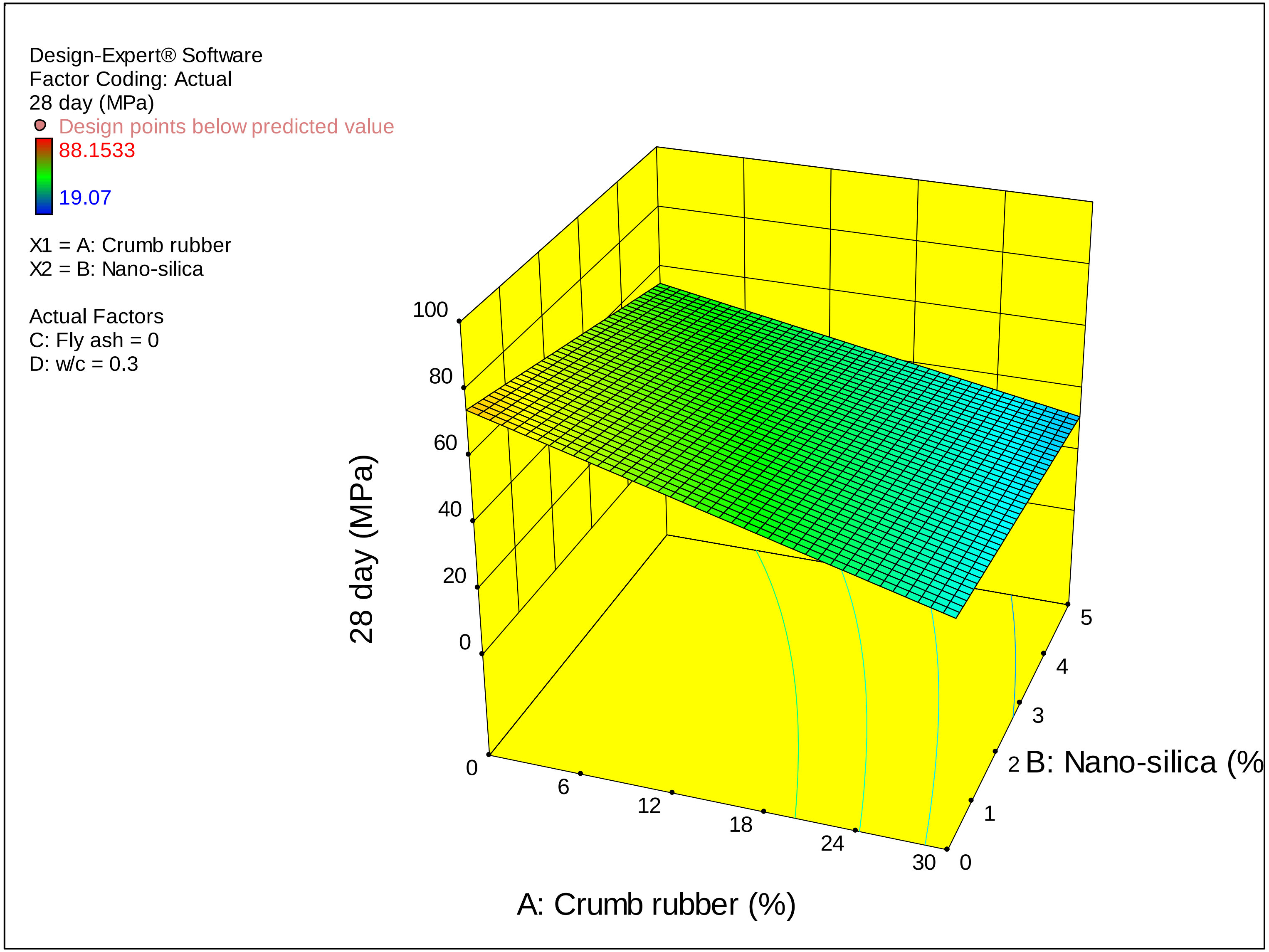


Figure 3.27: Crumb Rubber vs Nano silica Box-Cow Plot Diagram (Fly ash 0%) – 28 days

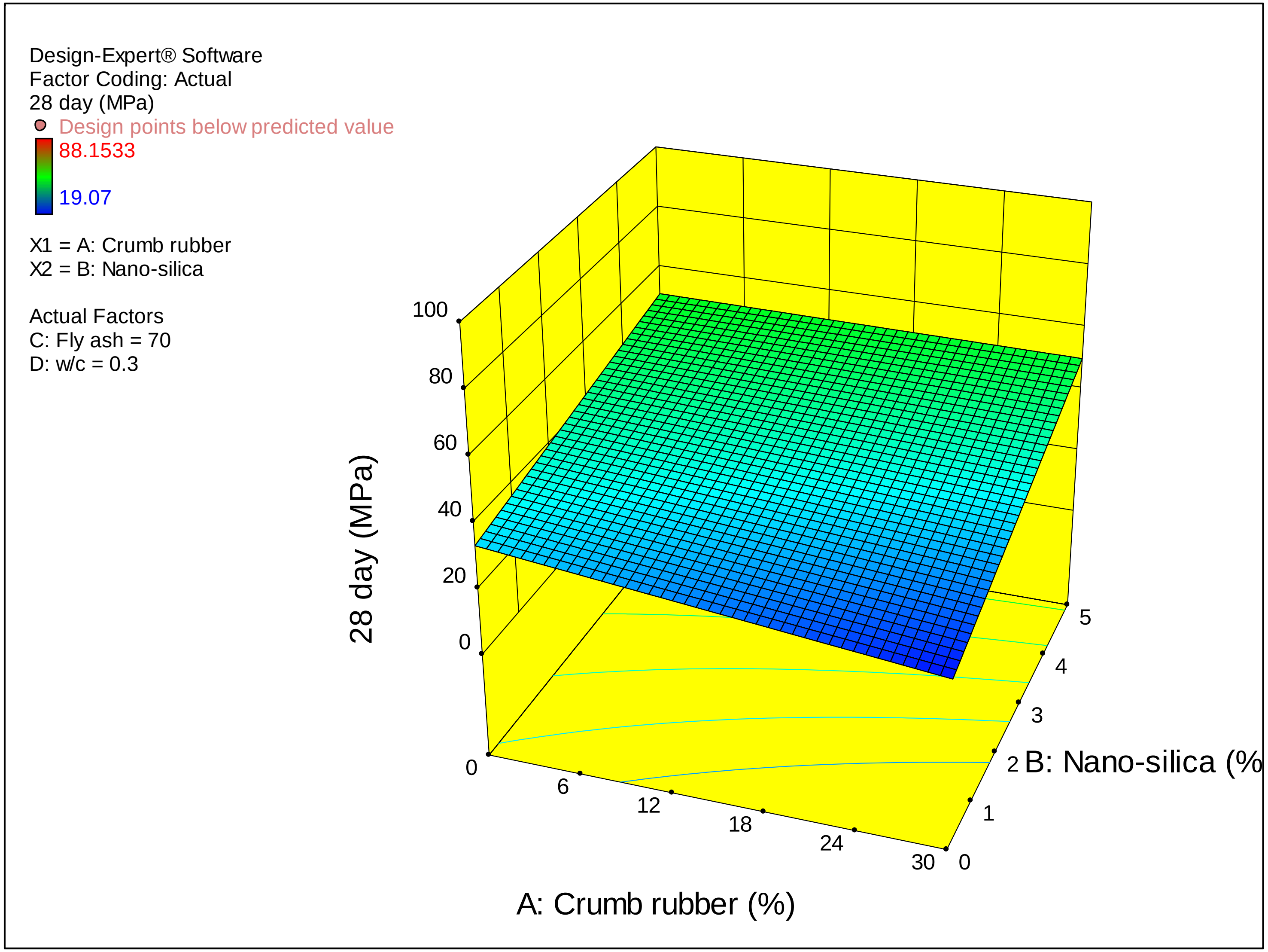


Figure 3.28: Crumb Rubber vs Nano silica Box-Cow Plot Diagram (Fly ash 70%) – 28 days

Hence, the analysis by the Response Surface Methodology using the results for the 14-day and 28-day compressive strength test has provided six different design models in which each model have to be mixed for the deformation properties to be tested.

M20

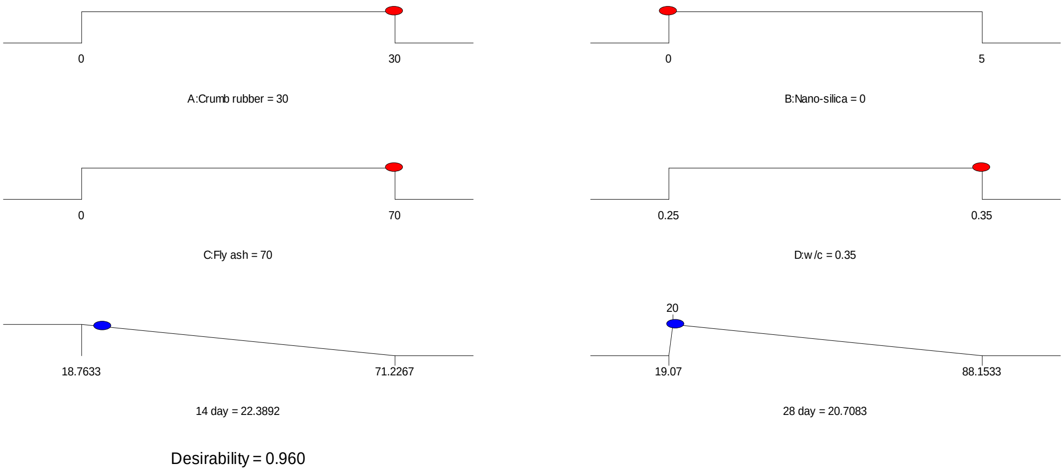


Figure 3.29: Design Model (M20)

M25

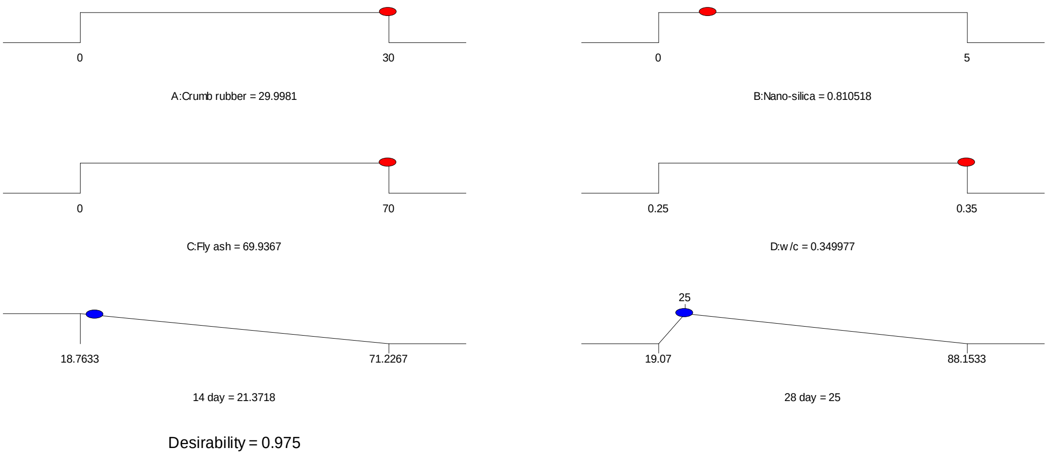


Figure 3.30: Design Model (M25)

M30

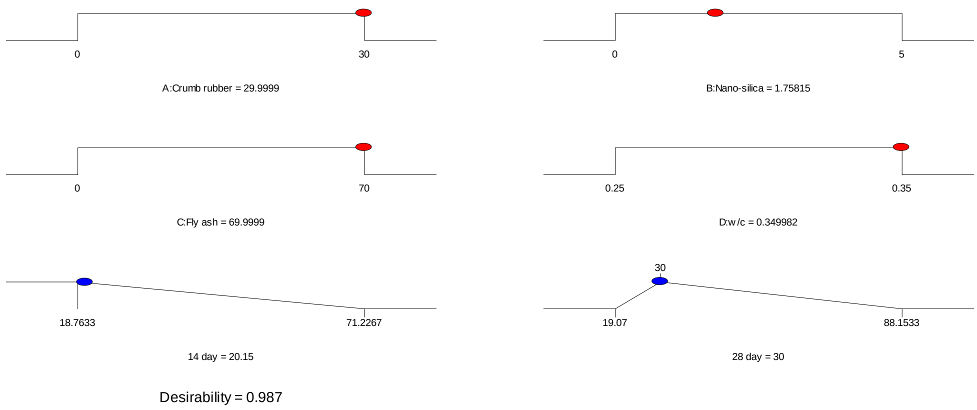


Figure 3.31: Design Model (M30)

M40

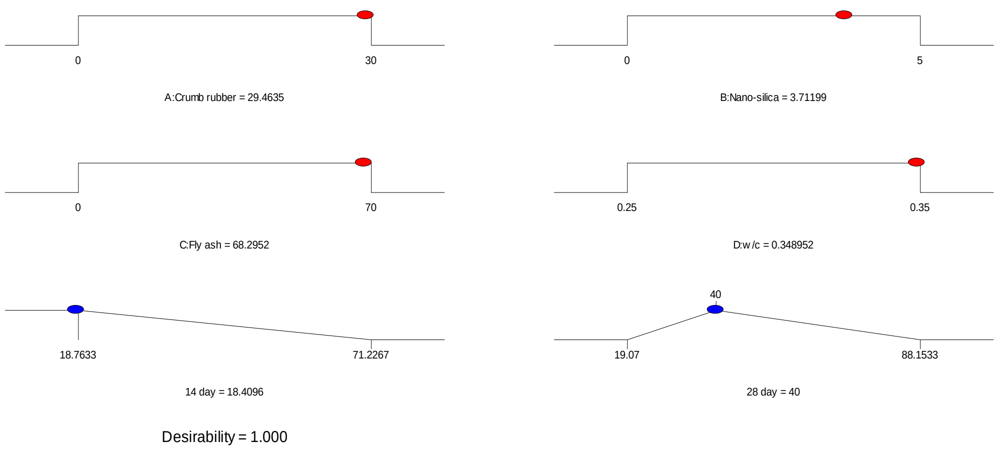


Figure 3.32: Design Model (M40)

M50

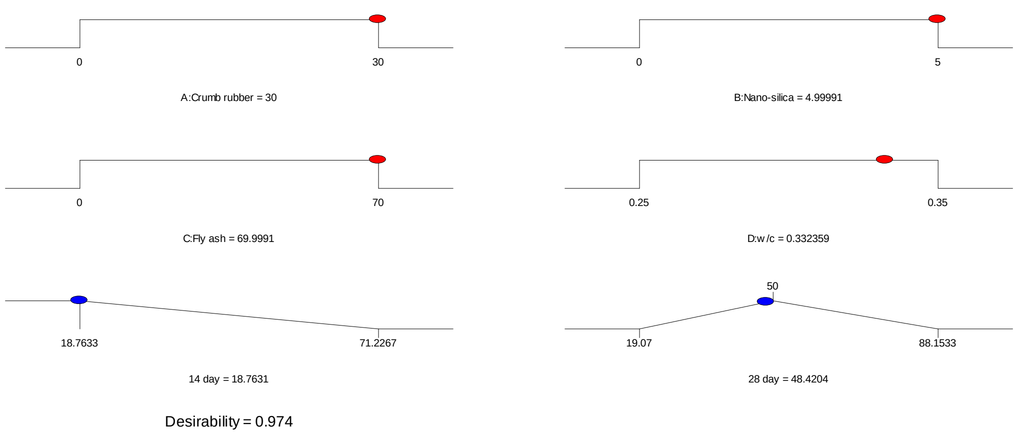


Figure 3.33: Design Model (M50)

M60

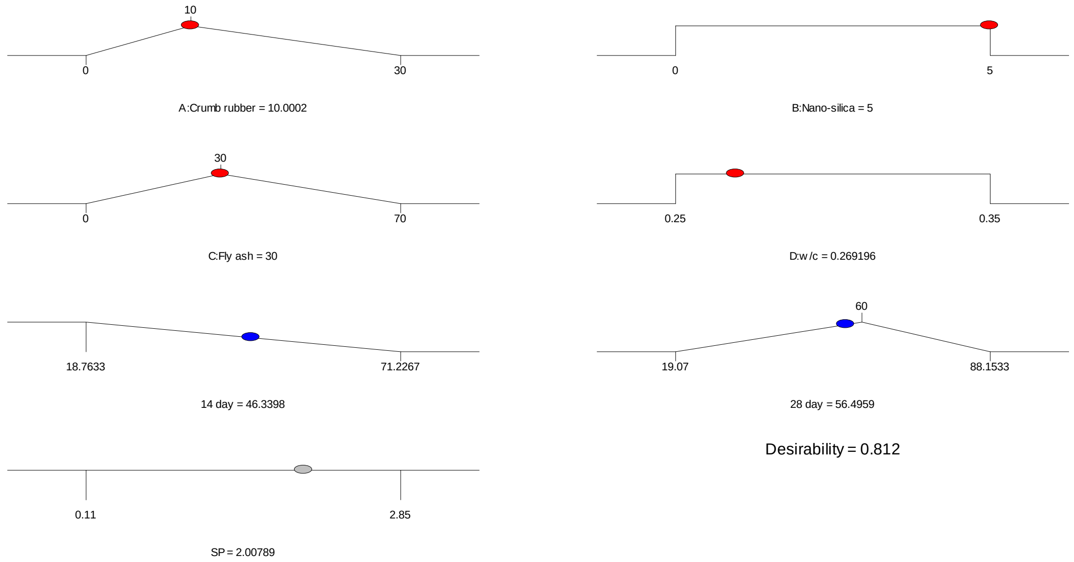


Figure 3.34: Design Model (M60)

The summarization of all the graph models above can be equated into a table form as shown below.

Table 3.4: Six Design Mixes generated from the Response Surface Methodology for Dry Shrinkage test & Modulus of Elasticity and Poisson's Ratio of Concrete Test

Run	CR %	NS %	FA %	w/c	SP %
1	30	0	70	0.35	0
2	29.9981	0.810518	69.9367	0.34997	0
3	29.9999	1.75815	70	0.349982	0.08
4	29.4635	3.71199	68.2952	0.348952	0.6
5	30	4.99991	69.9991	0.332359	1
6	10.0002	5	30	0.269196	2.1

Similarly, a manual calculation is required in order to determine the exact quantity of crumb rubber, Nano silica, fly ash, water-cement ratio, cement and sand required for each mix for all 6 design mixes to be mixed. In the following page, the Excel calculation can be viewed where the quantities of the materials needed for the mix for the deformation properties test can be seen.

Cement kg/m³	543
Coarse aggregate kg/m3	840
Fine aggregate kg/m3	670

Specific gravity	
Sand	2.6
Crumb rubber	0.95

at volume of (m3):	0.0212
Cement (kg)	11.5116
Coarse aggregate (kg)	17.808
Fine aggregate (kg)	14.204

Add 20% wastage (4 cylinder casting)	
at volume of (m3):	0.02544
Cement (kg)	13.8139
Coarse aggregate (kg)	21.3696
Fine aggregate (kg)	17.0448
Volume sand	6.556

Run	CR (m3)	CR (kg)	NS (kg)	FA (kg)	w/c	cement	sand (m3)	sand (kg)	SP (ml/g)
1	1.9668	1.86846	0	9.669744	4.83	4.14	4.59	11.93	0
2	1.966675	1.87	0.11	9.66	4.83	4.15	4.59	11.93	0
3	1.966793	1.87	0.24	9.669744	4.83	4.14	4.59	11.93	11.24543
4	1.931627	1.84	0.51	9.43	4.82	4.38	4.62	12.02	85.96015
5	1.9668	1.87	0.69	9.67	4.59	4.14	4.59	11.93	145.046
6	0.655613	0.62	0.69	4.14	3.72	9.67	5.90	15.34	304.5969

Figure 3.35: Excel Calculations to determine the proportion of each material in each mix – For 4 cylinders per mix

3.7 PROJECT ACTIVITIES

This section will discuss the first part of the research methodology for conducting the Compressive Strength test to deduce the best design mix for it to be tested for its deformation properties. The research begins by obtaining the data which is the simulation of 30 Rubbercrete mixtures which were generated by the application of Response Surface Methodology (RSM) at three levels of CR replacement by volume to fine aggregate (0%, 15%, 30%), three levels of Nano silica addition (0%, 2.5%, 5%) and three levels of Fly ash addition (0%, 35%, 70%).

After manual calculation done where the composition needed for each mix (in terms of a mix) is established, the raw materials are collected and the weight of each material in a single mix was then mixed as for how a normal concrete mix would be done.

The second part of the research methodology begins with obtaining the compressive strength results for the 30 design mix previously where the results are inputted in the Response Surface Methodology algorithm once again to deduce the best design mix for it to be tested for its deformation properties. Hence, six more mix designs were designed and the compositions of each mix were given. Subsequently, the Dry Shrinkage test as well as, Modulus of Elasticity and Poisson’s Ratio of Concrete Test for Rubbercrete, can be conducted based on the design mixes produced by the RSM.

3.7.1 MIXING OF CONCRETE

Figure 3.36: Mixing of concrete in concrete mixer

Following the design rubrics, the wet and dry materials are placed in the cement mixer and are mixed for about 10 minutes with the slow addition of water, Nano silica and superplasticizer. Once the concrete is formed, it is immediately transferred to the moulds.

3.7.2 SLUMP TEST

Figure 3.37: Slump Test

Concrete Slump test is to decide the workability or consistency of a concrete mix which is/was prepared at the laboratory right after a mix has been done. Concrete Slump test is also done to check the uniform nature of cement amid testing which is quite popular in construction activities. The slump test is the most straightforward workability test for concrete where it includes minimal effort and gives quick outcomes as it is tested directly after a concrete mix has been done. Because of this, it has been generally utilized for workability tests since 1922.

Elements which can affect the Concrete Slump test:

- Properties such as particle size distribution and moisture content.
- Admixtures amount dosage (Nano silica, fly ash and superplasticizers)
- Air content
- Concrete mixing procedure and transporting techniques
- Technique of slump testing
- The measure of free water in the concrete
- Time since blending of cement at the season of testing

3.7.3 CONCRETE MIX SET IN MOULDS

Figure 3.38: Concrete being set in moulds

PART 1; Compressive Test:

Once the slump test was conducted and is in the allowable limit of 75mm to 100mm height, the concrete mix is then transferred into a 100mm x 100mm x 100mm cube where it then left for at least 24 hours before the concrete cube is removed from the mould. The concrete cube mould is then placed in a curing tank for the curing process.

PART 2; Dry Shrinkage test & Modulus of Elasticity and Poisson's Ratio of Concrete Test:

Once the concrete mix has been done, the concrete is immediately placed in a 150mm x 300mm cylinder where it then left for at least 24 hours before the concrete cylinder is removed from the mould. The concrete cylinder mould is then placed in the curing tank for the curing process.

3.7.4 CURING PROCESS

Figure 3.39: Curing Process

Curing process aims to serve as a process of controlling the rate and degree of dampness loss from concrete amid concrete hydration. The curing process must be embraced for a sensible timeframe if the concrete is to accomplish its potential quality and sturdiness. Curing may likewise envelop the control of temperature since this influences the rate at which concrete hydrates.

Hence, according to Malaysian Concrete Standards EN 12390-2: Testing hardened concrete – Part 2: Making and curing specimens for test specimens, concrete achieves about 50% of its strength within the first 7 days when it undergoes its curing period. The compressive strength then proceeds to increase gradually and achieve its highest compressive strength on the 28th day of curing.

Figure 3.40: Thermometer Scale in Curing Room

3.8 PROJECT TESTING

After 14 and 28 days has passed, the concrete cube mould will then undergo a compression test where the sample will then be subjected to compressive loading stresses. The compressive strength test will be conducted and the results are taken note of (in N/mm^2) and the next concrete mix from another mix will be tested there forth. After all thirty mixes are done, and after determining the best design mix (with reference to the best compressive strength), then only will the other two tests will be conducted where the deformation properties of Rubbercrete will be investigated.

PART 1; Compressive Test:

The first test (as mentioned earlier) that will be conducted is the Compression Test which is conformed to the ASTM C39/39M standards where the specification will provide the standard procedure to measure the compressive strength of the concrete masonry units.

PART 2; Dry Shrinkage test & Modulus of Elasticity and Poisson's Ratio of Concrete Test:

The second test that will be conducted is the Shrinkage Test which is in accordance with the ASTM C490 standards where the specification provides an institutionalised method to decide the drying shrinkage of solid concrete units. Lastly, the third test that will be conducted is the Modulus of Elasticity and Poisson's Ratio of Concrete test which is in accordance with the ASTM C469 standards where the specifications provide the methods which will determine the stress-strain ratio value, the modus of elasticity value and Poisson's Ratio values.

3.8.1 Compressive Strength Test (ASTM C39/39M)

This test is conducted to determine the compressive strength of the concrete cube. The concrete mix must have undergone a 28-day curing period in order for this test to be conducted. The specimen must be first placed in the machine in the centre of the base plate where the load transmitted by the compression machine is applied on the opposite sides of the cube cast. The top part of the compressor is then lowered until it gently touches the top of the concrete cube mix. Then, a load of 140 kg/cm^2 per minute is applied gradually until the specimen fails. The maximum load is then recorded and the compressive strength is then calculated as shown in Eq 3.1-Eq 3.3;

Size of the cube =100mmx100mmx100mm (3.1)

Area of the specimen = 1000000mm^2 (3.2)

Maximum load the concrete cube takes before cracking = (A) N (3.3)

Figure 3.41: Compressive Strength Test

3.8.2 Dry Shrinkage Test (ASTM C490)

This test is conducted where three cylinders are cast and cured in air. Two sets of gauge points, separated by 150 mm separated, were put on each of the concrete cylinders. A gauge point guide was utilised towards the position of the gage point on the cylinder, and a Whittemore gauge was utilised to measure the adjustments in length between the gauge points as the concrete has shrunk. In a nutshell, shrinkage test;

- To help predict the cracking behaviour of concrete cylinders.
- Concrete is to be cast in cylindrical steel moulds with dimensions 150mm by 300mm.
- Initial weight and length were measured and recorded, and specimens are to be placed on storage racks for drying until testing dates.
- Two sets of gauge points, separated by 150 mm separated, were put on each of the concrete moulds.
- A gauge point guide was utilised and a Whittemore gauge was utilised to measure the adjustments in length between the gauge points as the concrete has shrunk.

Figure 3.42: Shrinkage Test

3.8.3 Modulus of Elasticity and Poisson’s Ratio of Concrete Test (ASTM C469)

This test provides the details of the stress-strain ratio and a ratio of lateral to longitudinal strain for hardened cylindrical concrete at whatever age and curing conditions that are assigned. This test is basically a compression test whereby a heap is load is applied with a Constant-Rate-of-Traverse (CRT) type machine until a predetermined stress is reached. The modulus of elasticity and Poisson’s Ratio esteem will be found inside the working stress range (0 to 40% of ultimate strength). From then, the data logger will sketch a graphical model of the Stress-Strain model and the test will be terminated after achieving at least 40% of the ultimate load. The parameters necessary to calculate the Modulus and Poisson’s Ratio is to be entered and the results are posted to the right of the graph. In short;

- This test provides the details of the stress-strain ratio and a ratio of lateral to longitudinal strain for hardened cylindrical concrete.
- This test is basically a compression test whereby a heap is load is applied with a Constant-Rate-of-Traverse (CRT) type machine until a predetermined stress is reached.
- The modulus of elasticity and Poisson’s Ratio esteem will be found inside the working stress range (0 to 40% of ultimate strength). From then, the data logger will sketch a graphical model of the Stress-Strain model and the test will be terminated after achieving at least 40% of the ultimate load.

Figure 3.43: CRT Type Machine

CHAPTER 4

RESULTS & DISCUSSION

4.1 COMPRESSIVE STRENGTH TEST

For the first part of the research which is the compressive strength test, all the 30 mixes are completed and had undergone the Compressive Strength test. The average 14 days and 28 days Compressive strength test are determined and the results are then inputted into the Response Surface Methodology to determine the best and the most optimum design mix for conducting the Dry Shrinkage test & Modulus of Elasticity and Poisson's Ratio of Concrete Test.

The complete Compressive strength test 14 day strength and 28 day strength can be seen in Table 4.1 and Table 4.2 below.

Table 4.1: Results of Mix 1 to Mix 15 of Compressive Strength Test

Mix Design	Compressive Strength (MPA)									
	14 Days (MPa)			Average (14 days) MPa	28 Days (MPa)			Average (28 days) MPa	Slump (mm)	SP Value (ml)
Mix 1	73.26	70.42	54.45	66.04	84.82	67.78	94.64	82.41	100	114.93
Mix 2	49.21	46.46	37.25	44.31	46.95	34.95	55.13	45.68	90	50.171
Mix 3	52.65	44.65	53.85	50.38	35.84	37.58	43.58	39	100	42.873
Mix 4	46.63	34.82	28.56	36.67	49.09	47.07	35.51	43.89	95	57.0125
Mix 5	27.52	53.74	32.23	37.83	25.56	52.09	54.29	43.98	89	51.0832
Mix 6	29.4	28.98	24.02	27.46	43.25	44.7	40.69	42.88	82	40.1368
Mix 7	32.34	30.91	37.49	33.58	34.6	48.13	38.59	40.44	93	129.98
Mix 8	28.84	41.97	36.32	35.71	64.36	69.81	59.75	64.64	98	119.95
Mix 9	27.14	33.06	33.89	31.36	34.17	31.71	33.88	33.25	85	12.77
Mix 10	58.42	56.26	23.63	46.1	41.52	33.83	51.59	42.31	85	17.78
Mix 11	25.1	31.43	21.15	25.89	34.17	38.88	29.2	34.08	80	74.8
Mix 12	32.5	35.3	33.1	33.63	29.66	15.4	33.21	26.09	100	55.188
Mix 13	68.19	62.3	58.35	62.94	31.99	49.08	37.17	39.41	90	14.14
Mix 14	31.2	36.91	29.48	32.53	45.02	42.41	41.42	42.95	77	21.8928
Mix 15	30.05	14.84	31.74	25.54	32.12	31.7	32.85	32.22	100	10.03

Table 4.2: Results of Mix 16 to Mix 30 of Compressive Strength Test

Mix Design	Compressive Strength (MPA)									
	14 Days			Average (14 days)	28 Days			Average (28 days)	Slump (mm)	SP Value (ml)
Mix 16	46.16	36.26	48.08	43.5	37.58	50.44	47.87	45.3	100	69.78
Mix 17	45.86	47.71	44.96	46.18	34.59	38.58	36.08	36.42	100	126.79
Mix 18	56.25	57.04	53.42	55.57	37.78	37.31	35.63	36.91	85	45.15
Mix 19	40.5	37.6	37.6	38.56	46.18	42.19	40.95	43.11	82	50.171
Mix 20	25.6	28.72	29.25	27.85	31.45	21.03	21.16	24.55	75	5.0171
Mix 21	34.14	33.14	30.01	32.43	53.37	56.96	54.57	54.97	80	51.083
Mix 22	43.03	40.38	40.15	41.18	41.93	38.74	50.24	43.64	100	27.82
Mix 23	30.86	56.52	75.62	54.33	70.34	75.38	81.19	75.64	100	83.01
Mix 24	61.98	58.88	68.85	63.23	64.63	41.45	69.35	58.47	100	11.86
Mix 25	41.84	42.65	46.48	43.66	46.71	43.4	53.35	47.82	90	51.083
Mix 26	36	33.62	35.18	34.93	27.23	32.36	28.71	29.43	81	30.1
Mix 27	34.82	14.44	31.61	26.95	40.26	43.23	38.56	40.69	80	29.19
Mix 28	42.16	42.34	43.55	42.68	48.41	46.88	50.93	48.74	85	25.99
Mix 29	36.97	39.36	35.44	37.25	33.16	43.43	40.74	39.11	100	34.2
Mix 30	18.7	17.03	20.56	18.76	12.39	20.17	17.04	16.53	75	9.122

As mentioned in the literature review, the reduction in compressive strength of the Rubbercrete compared to conventional concrete is caused by the weak bonding of the crumb rubber and cement matrix (due to the presence of the Interfacial Transition Zone). This Interfacial Transition Zone can be credited to the properties of the crumb rubber itself which is hydrophobic (which are nonpolar molecules that repel water). This hydrophobic nature is due to the zinc stearate application on tires during production (Youssf et al., 2014). This said nonpolar molecules which repel water traps air surrounding the crumb rubber particles which increases the general thickness of this zone known as the Interfacial Transition Zone. Hence, due to the increasing thickness of the Interfacial Transition Zone, the strength is naturally weaker (Mohammed et al., 2012).

The test that was conducted so far has been the compressive strength test where it was done with the aim of obtaining the compressive strength of each design mixes. The compressive strength increases especially with the addition of Nano silica into the mix. From a chemical properties perspective, Nano silica helps in improving the microstructure of the design mix by reacting with the gaseous state of $Ca(OH)_2$ which was released as a product of the hydration process of the cement paste. This, in turn, creates a gel-like substance (C-S-H gel) which will then play its role to occupy the voids within the cement matrix and also reacts with the Interfacial Transition Zone via densification. As for the physical role of Nano silica, the addition into the design mix not only fills up the voids but also generally produce a thicker and more opaque matrix.

Also as mentioned beforehand, the compressive strength of the Rubbercrete increases when the quantity of Nano silica increases. This is evident as the highest compressive Rubbercrete strength (Mix 21) which has the composition such as water, cement, aggregates with the addition of Nano silica and fly ash obtained a strength of 54.97 MPa after 28 days curing process compared to the second highest Rubbercrete mix (Mix 28) with a strength of 48.74 MPa. This can be explained by Mix 21 which uses 0.23kg of Nano silica whereas Mix 28 uses 0.11kg Nano silica.

Hence, it can be deduced that the compressive strength of the Rubbercrete increases when the quantity of Nano silica increases.

As an interpretation from the results obtained, the production of the C-S-H gel which is supposed to densify the Interfacial Transition Zone is said to be small (hence why the compressive test results are not similar to that of a conventional concrete). Also, the amorphousness of Nano silica is to be also considered where the particles of Nano silica lacks a crystalline structure and has no apparent shape. Hence, this is one of the reasons why the increment in strength is not up to par with using pure conventional concrete. However, it is undeniable that the increment in strength when using the addition of Nano silica does occur.

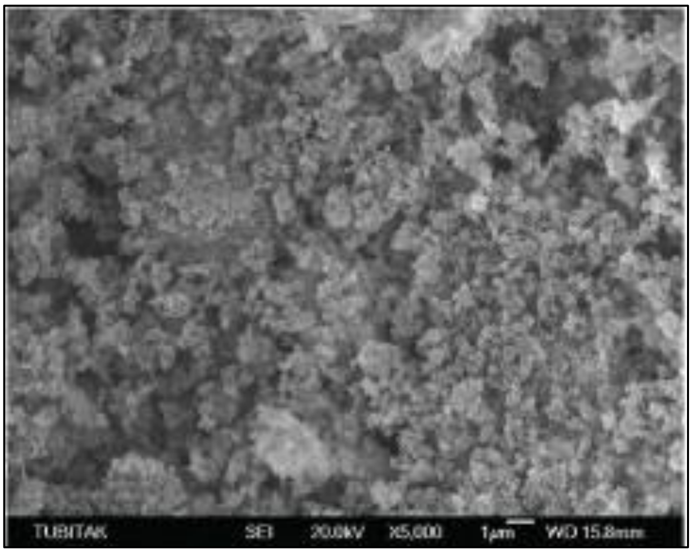


Figure 4.1: X-Ray of Nano silica particles

4.2 SHRINKAGE TEST

As mentioned previously, six more design mixes were designed by the Response Surface Methodology where the mix was casted and the second part of the research can be started where the Dry Shrinkage test & Modulus of Elasticity and Poisson's Ratio of Concrete Test can be determined.

The complete Shrinkage Test results 7 days and 14 days shrinkage can be seen in Table 4.3 – Table 4.5 below.

Table 4.3: Change in Length after 7 & 14 days in mm

	Length after Removal from Curing Tank (mm)	Length after 7 days (mm)	Length after 14 days (mm)
Mix 1-A	299.99	299.91	299.89
Mix 1-B	299.96	299.87	299.85
Mix 2-A	298.77	298.71	298.68
Mix 2-B	300.05	299.98	299.95
Mix 3-A	299.98	299.92	299.87
Mix 3-B	299.1	299.05	299.01
Mix 4-A	299.77	299.73	299.7
Mix 4-B	299.72	299.69	299.65
Mix 5-A	300.02	299.98	299.91
Mix 5-B	300.01	299.99	299.94
Mix 6-A	299.99	299.91	299.89
Mix 6-B	299.89	299.85	299.8

Table 4.4: Change in Length after 7 & 14 days in percentage (%)

	% in change after 7 days	% in change after 14 days
Mix 1-A	-0.032	-0.008
Mix 1-B	-0.036	-0.008
Mix 2-A	-0.024	-0.012
Mix 2-B	-0.028	-0.012
Mix 3-A	-0.024	-0.02
Mix 3-B	-0.02	-0.016
Mix 4-A	-0.016	-0.012
Mix 4-B	-0.012	-0.016
Mix 5-A	-0.016	-0.028
Mix 5-B	-0.008	-0.02
Mix 6-A	-0.032	-0.008
Mix 6-B	-0.016	-0.02

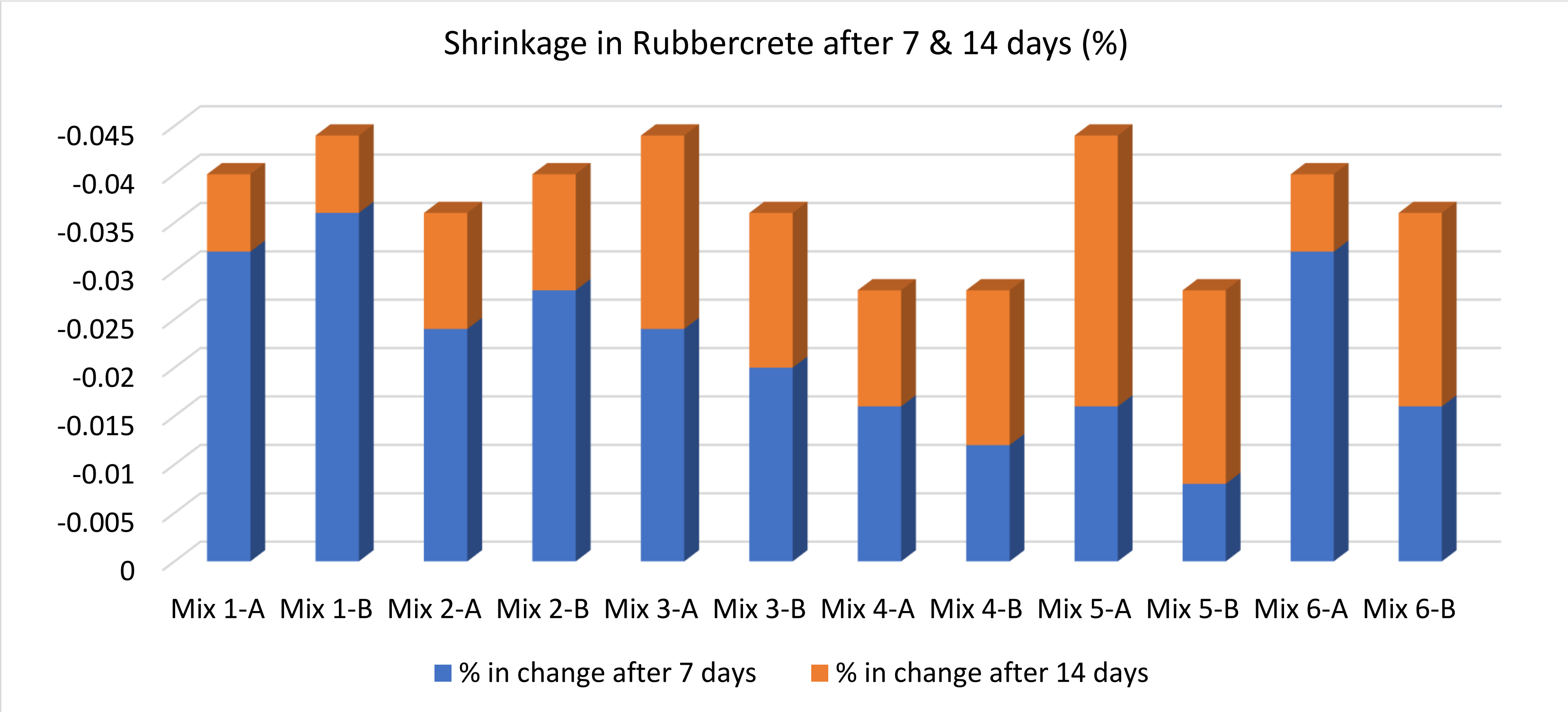


Figure 4.2: Graphical Visualization of change in length after 7 & 14 days in percentage (%)

According to the ASTM C157 – 08 Standard Test Method for Length Change of Concrete, the specified limit of change should be 500 microstrain (0.05%) at 28 days. As seen in the results above, all the mixes are within the permissible limit (<0.05% shrinkage loss). These can be credited due to several important factors.

Aggregate Sizing

Usually, concrete with high contents of aggregates displays shrinkage on a smaller scale. Speaking about aggregates, aggregates with a higher modulus of elasticity and with a lot of rough edges (not smooth) is much more resistant to the shrinkage deformation. Due to the proper gradation of the aggregates in this research, as evident by the sieve analysis of materials, every single mix is within the allowable shrinkage limit according to ASTM standards.

Water-cement ratio

The water-cement ratio of each mix design proposed by the RSM can heavily influence the shrinkage of concrete. The lower the water-cement ratio, the lower the shrinkage is, and vice versa. Water content when increased in concrete, increases the shrinkage potential, hence why it is recommended to have a low water-cement ratio.

Environmental Condition

A major factor which affects the total volume of shrinkage where the cylinders were dried in the air. The drying condition is affected by the atmosphere where the shrinkage increases with the decrease in levels of humidity. Since the cylinders are stored safely in a storing room where the humidity of air is low, there will be eventually traces of shrinkage. However, the environmental condition is just enough where the shrinkage levels are not over excessive.

Hence, the appropriate grading of the aggregates, as well as the accuracy of the design composition as proposed by the Response Surface Methodology, is justified.

4.3 MODULUS OF ELASTICITY AND POISSON'S RATIO OF CONCRETE TEST

Figure 4.3: Compressometer with dial gauge attached to cylindrical Rubbercrete

The Compressometer is utilized for assessing deformation and strain qualities of the cylindrical Rubbercrete which was casted while experiencing compressive testing. The Compressometer incorporates two cast aluminium-composite yokes, mounting and centre points along with stainless steel control rods. The Compressometer is accessible with two dial gauges with a scope of 5.08mm and least graduations of 0.001 mm which meets the standards of ASTM C469.

Figure 4.4: Modulus of Elasticity and Poisson’s Ratio Test being conducted while undergoing compression

Poisson’s Ratio is the proportion of transverse constriction strain to longitudinal augmentation strain toward extending power. Deformation of tensile strength is viewed as positive and distortion of compressive strength is viewed as negative. The definition of Poisson’s Ratio contains a short sign with the goal that typical materials have a positive proportion. Poisson's proportion is identified with versatile moduli K (likewise called B), the mass modulus; G as the shear modulus; and E, Young's modulus, by the accompanying (for isotropic solids, those for which properties are autonomous of course). The flexible moduli are measures of firmness. They are proportions of worry to strain. Stress is drive per unit territory, with the bearing of both the power and the zone determined.

The results of the Modulus of Elasticity and Poisson’s Ratio is as shown in Table 4.5 and the stress-strain graphs are seen in Figure 4.5 to Figure 4.7.

Table 4.5: Elastic Modulus and Poisson's Ratio Test Results

	Elastic Modulus (GPa)	Poisson Ratio (ϑ)
Mix 1	26.33	0.34678423
Mix 2	28.37	0.33217324
Mix 3	30.67	0.31923043
Mix 4	32.67	0.29234174
Mix 5	34.01	0.281293284
Mix 6	34.7302	0.27129213

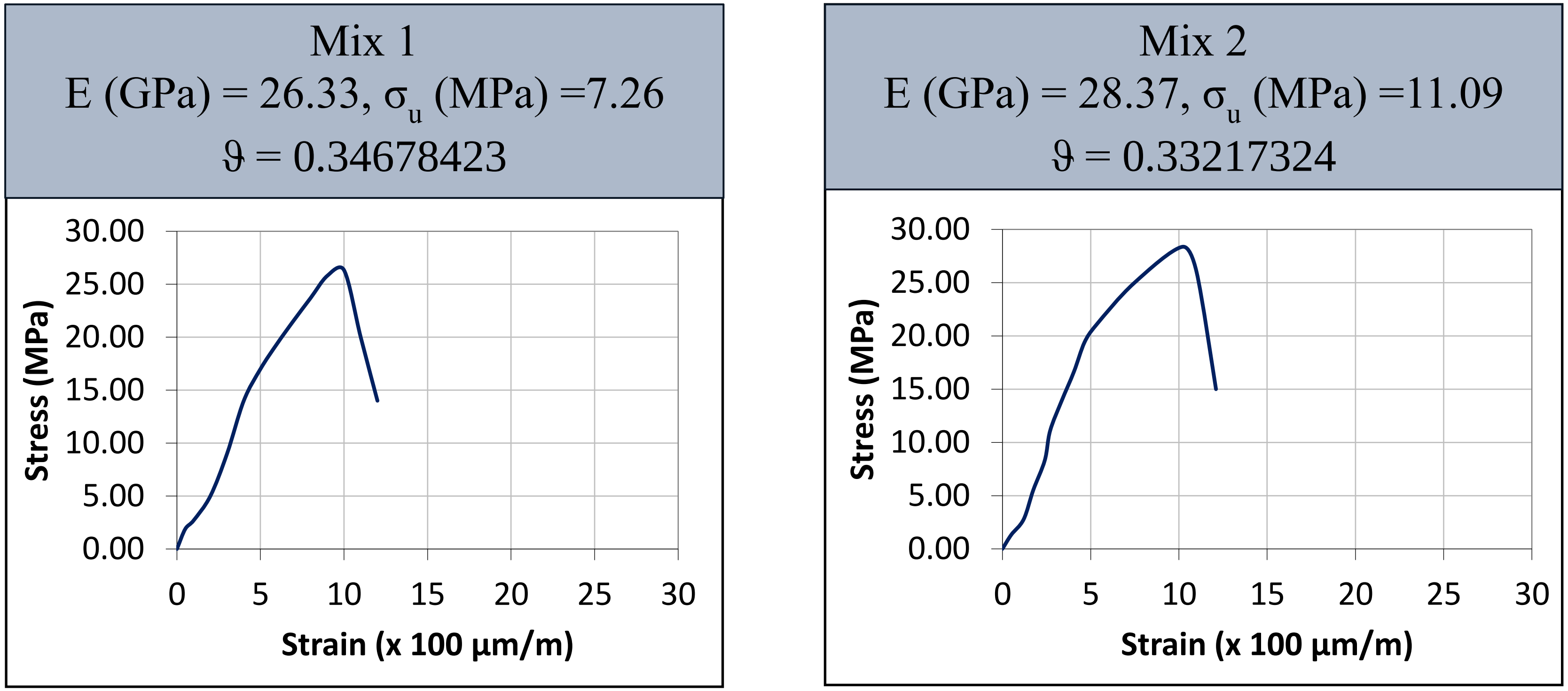
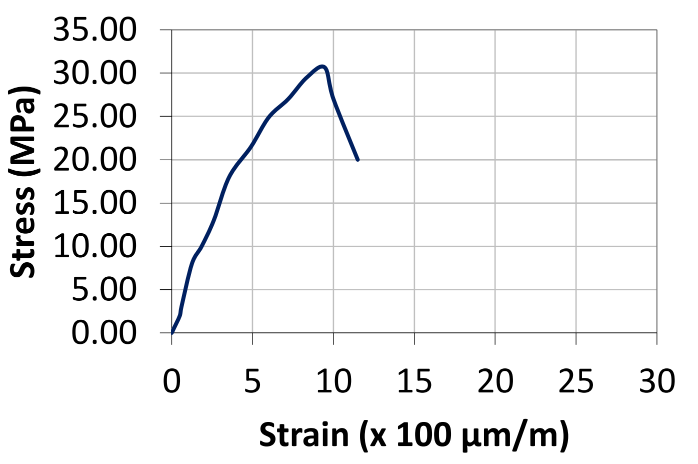


Figure 4.5: Stress-Strain Graphs for Mix 1 & Mix 2

Mix 3

E (GPa) =30.67, σ_u (MPa) =12.60

ϑ = 0.31923043



Mix 4

E (GPa) = 32.67, σ_u (MPa) = 15.72

ϑ = 0.29234174

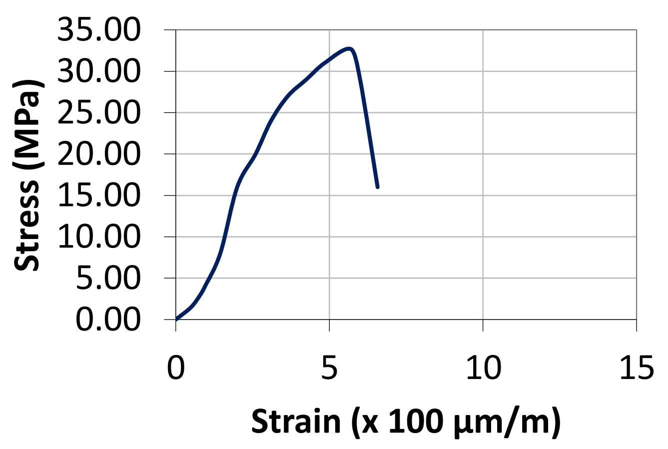
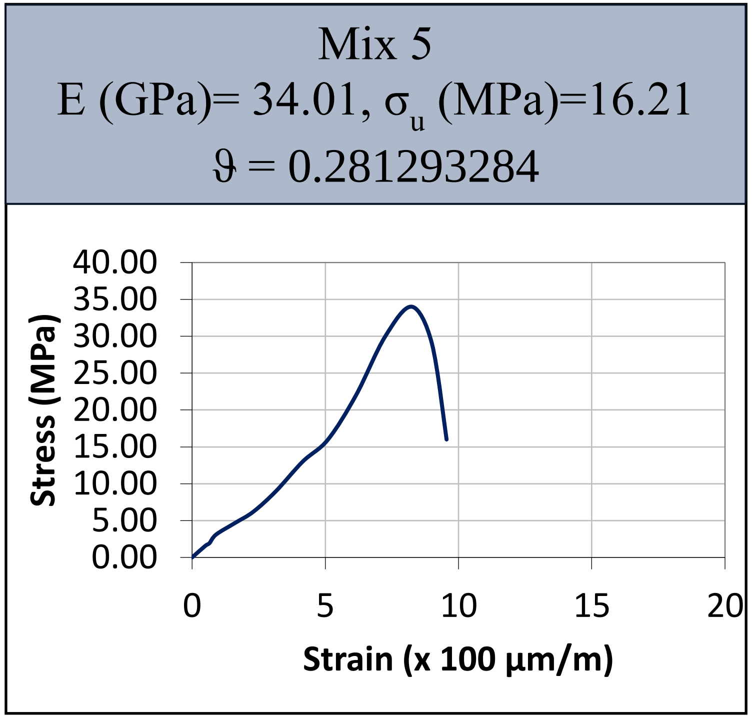


Figure 4.6: Stress-Strain Graphs for Mix 3 & Mix 4



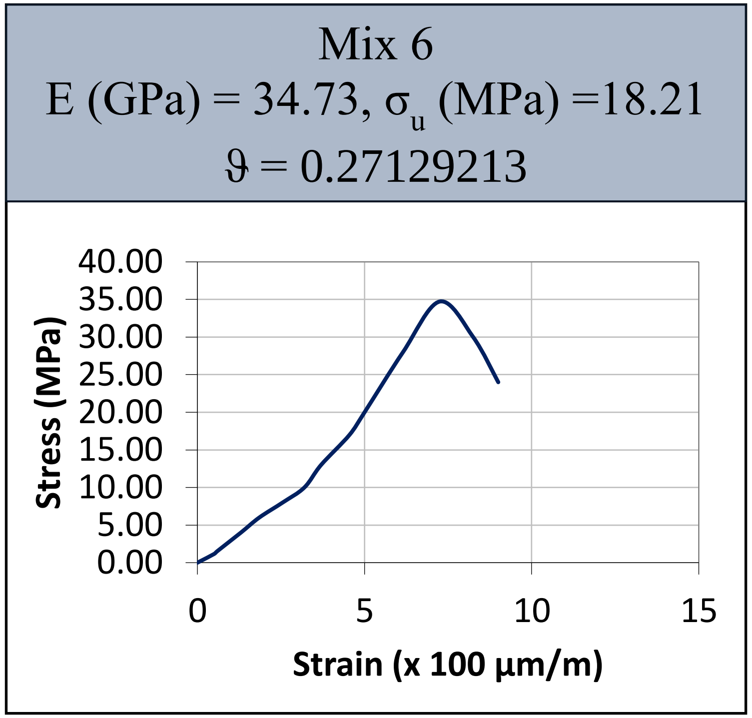


Figure 4.7: Stress-Strain Graphs for Mix 5 & Mix 6

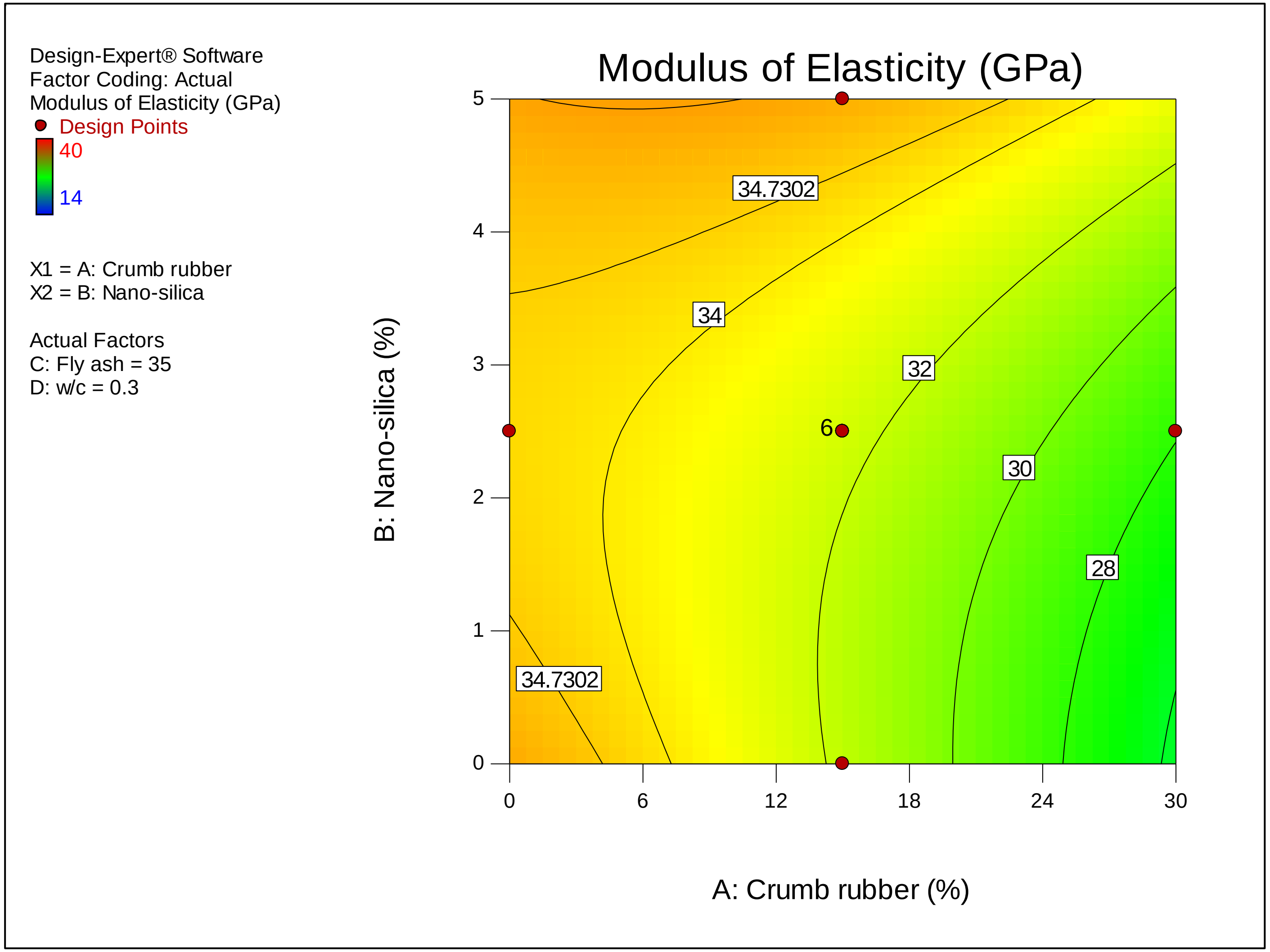


Figure 4.8: Modulus of Elasticity of Nano silica and crumb rubber (2D Contour Plot)

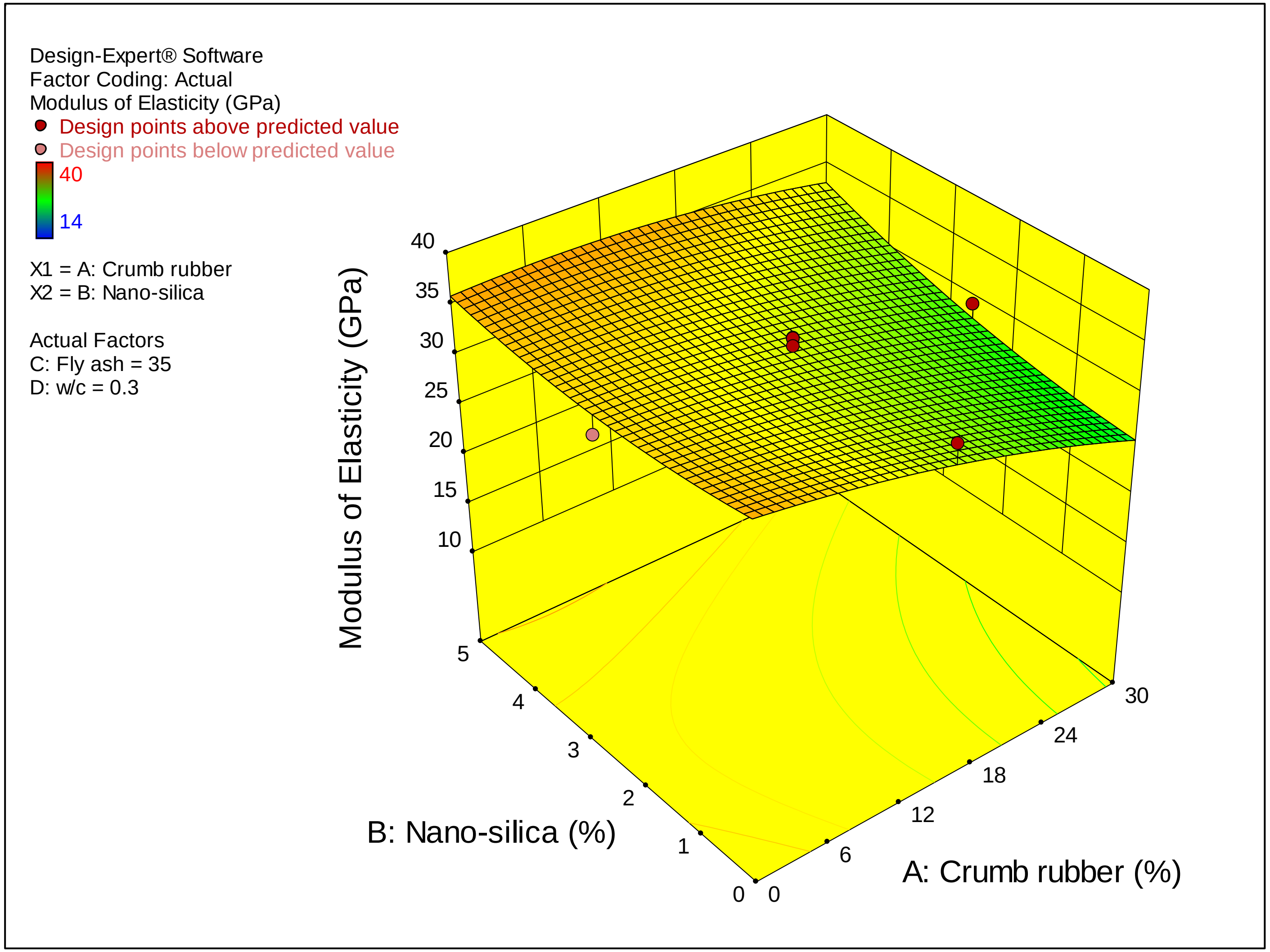


Figure 4.9: Modulus of Elasticity of Nano silica and crumb rubber (3D Surface Model)

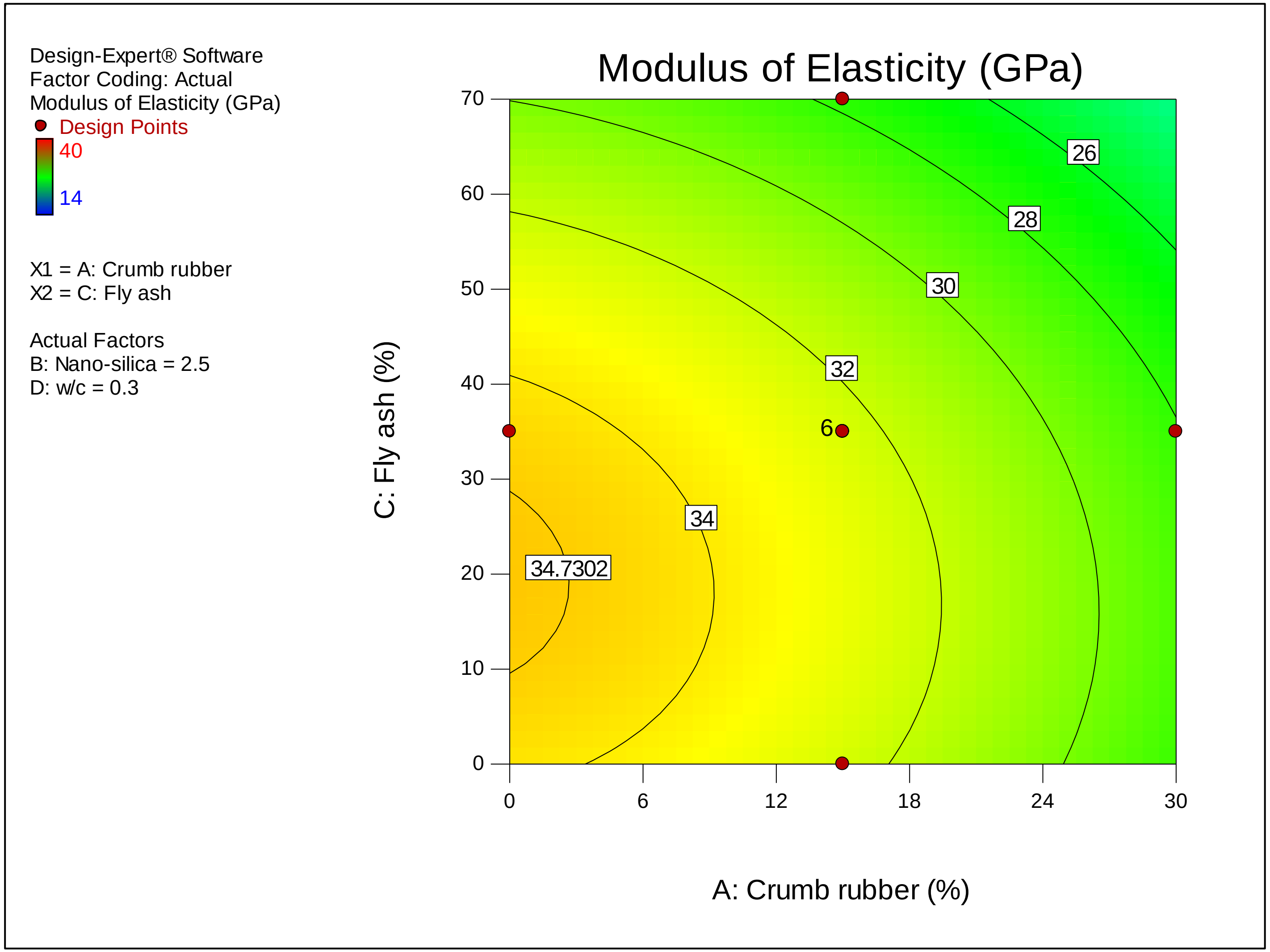


Figure 4.10: Modulus of Elasticity against Fly Ash and crumb rubber (2D Contour Plot)

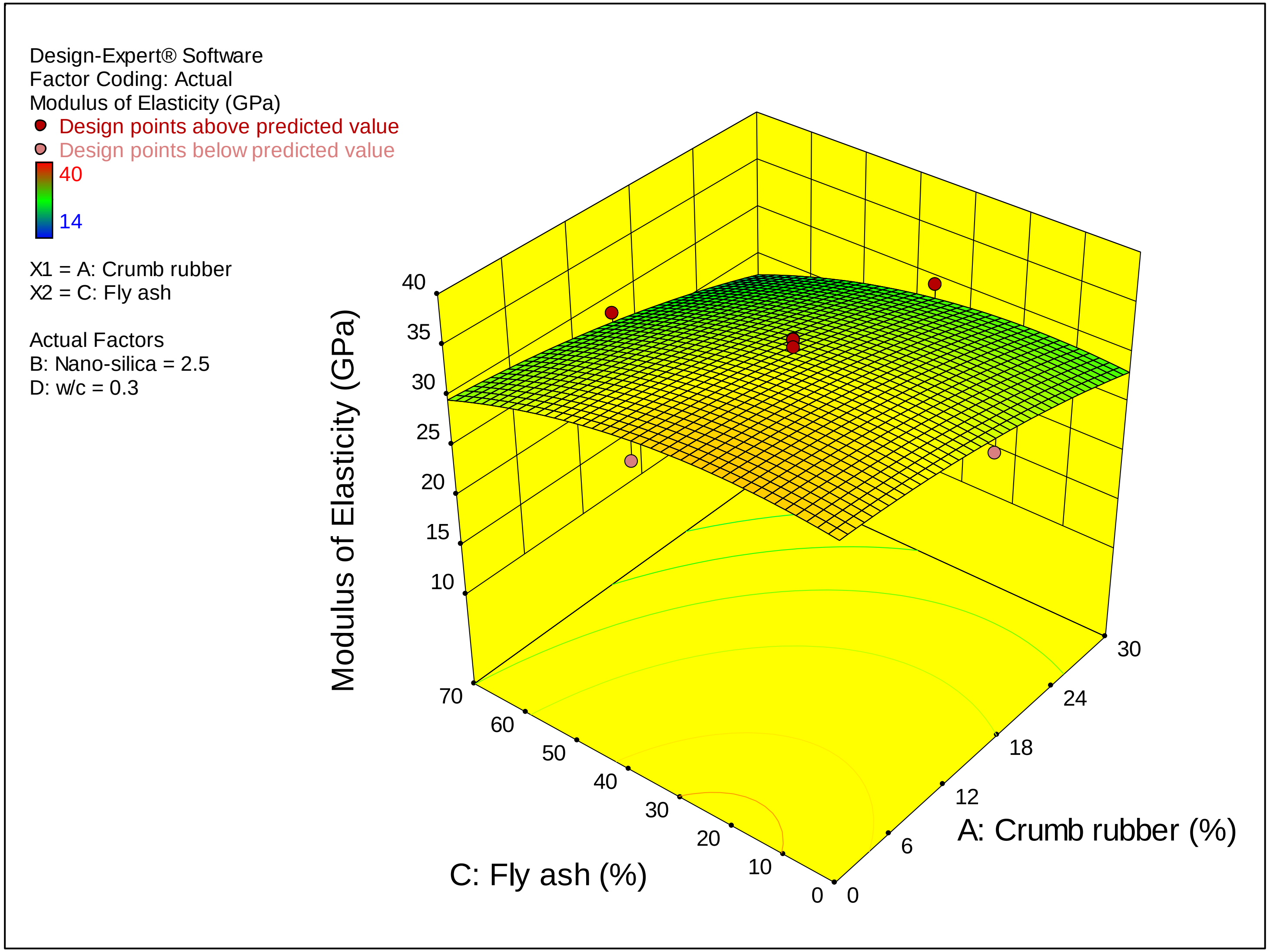


Figure 4.11: Modulus of Elasticity against Fly Ash and crumb rubber (3D Surface Model)

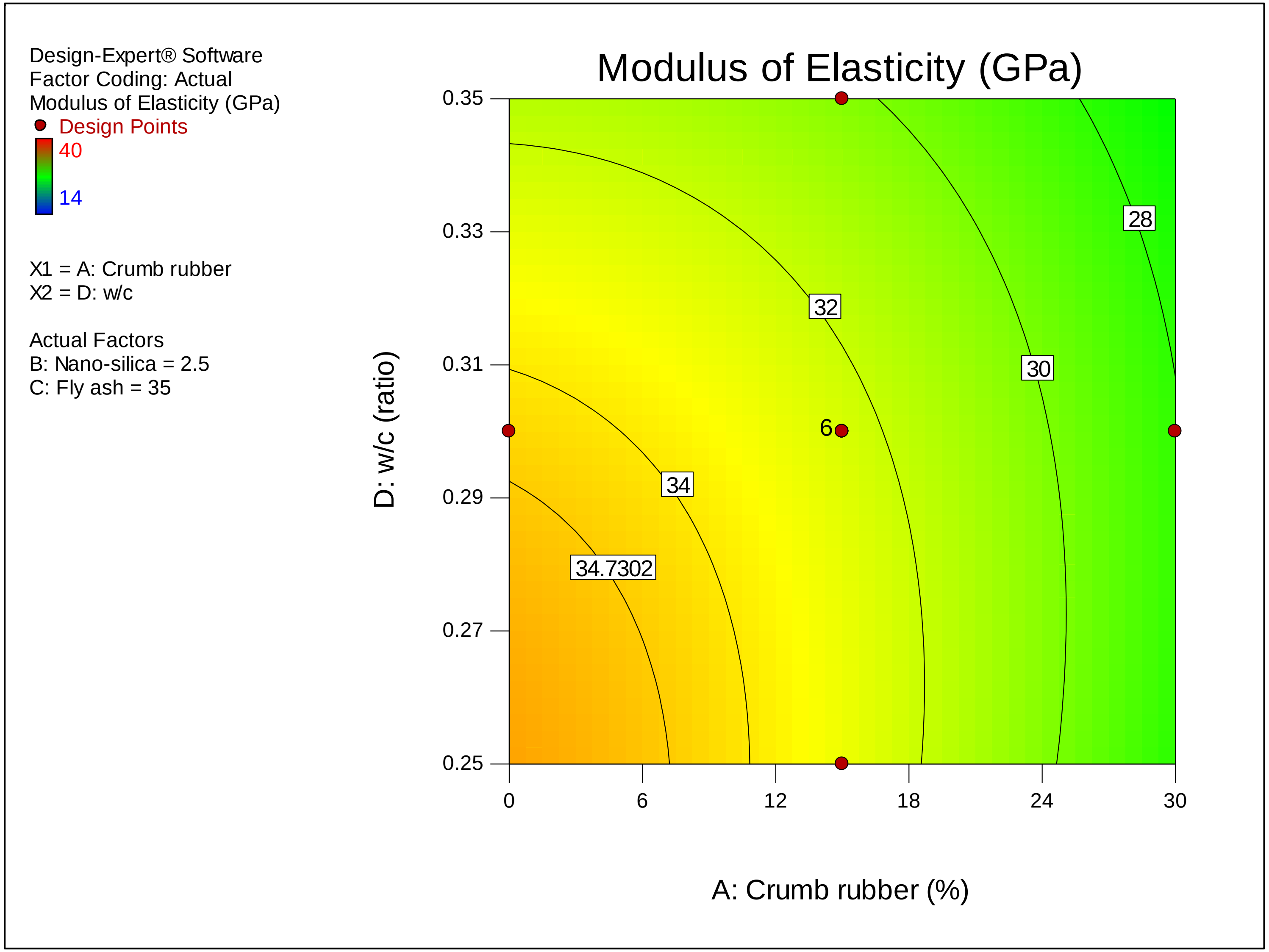


Figure 4.12: Modulus of Elasticity against w/c ratio and crumb rubber (2D Contour Plot)

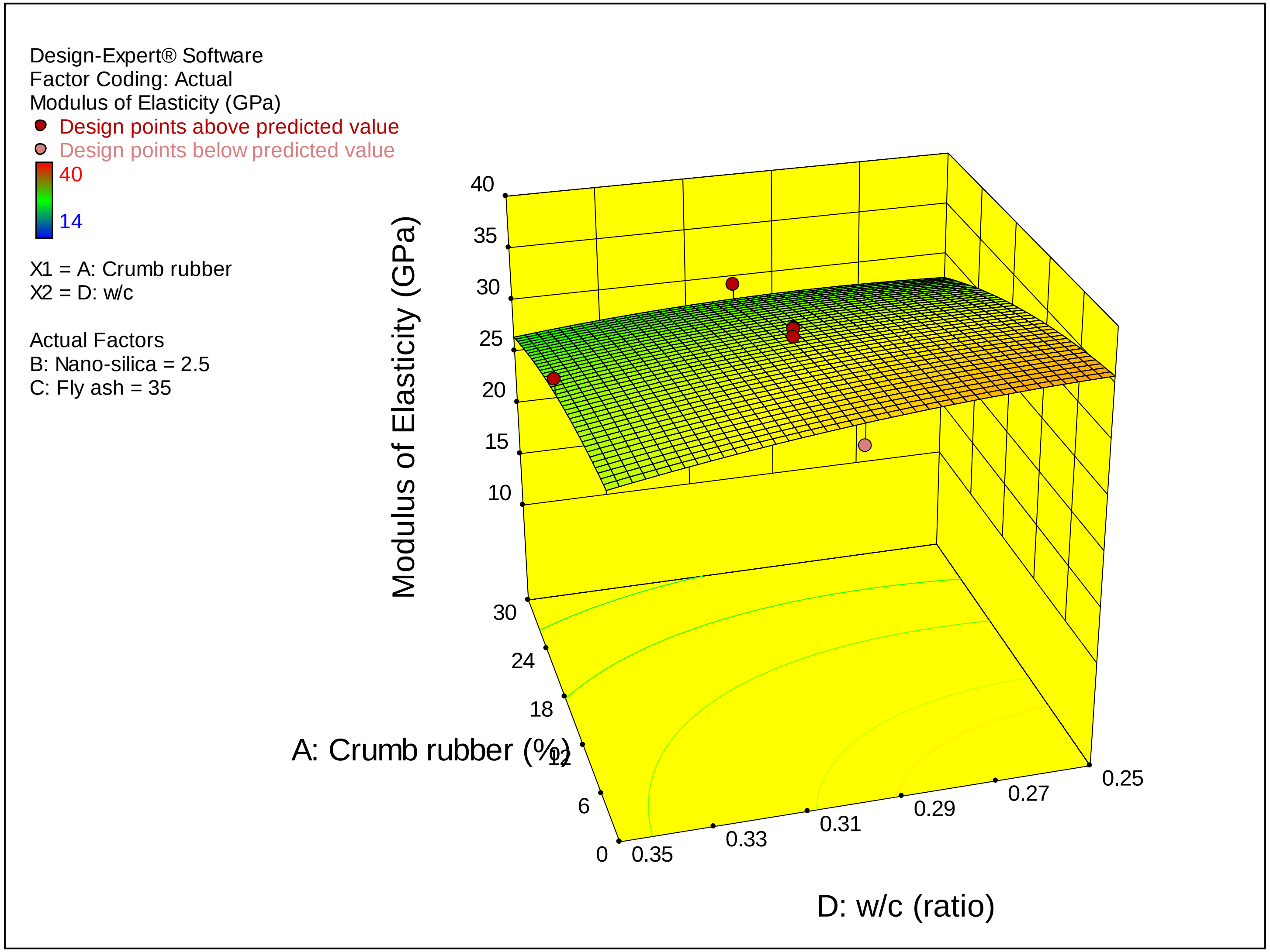


Figure 4.13: Modulus of Elasticity against w/c ratio and crumb rubber (3D Surface Model)

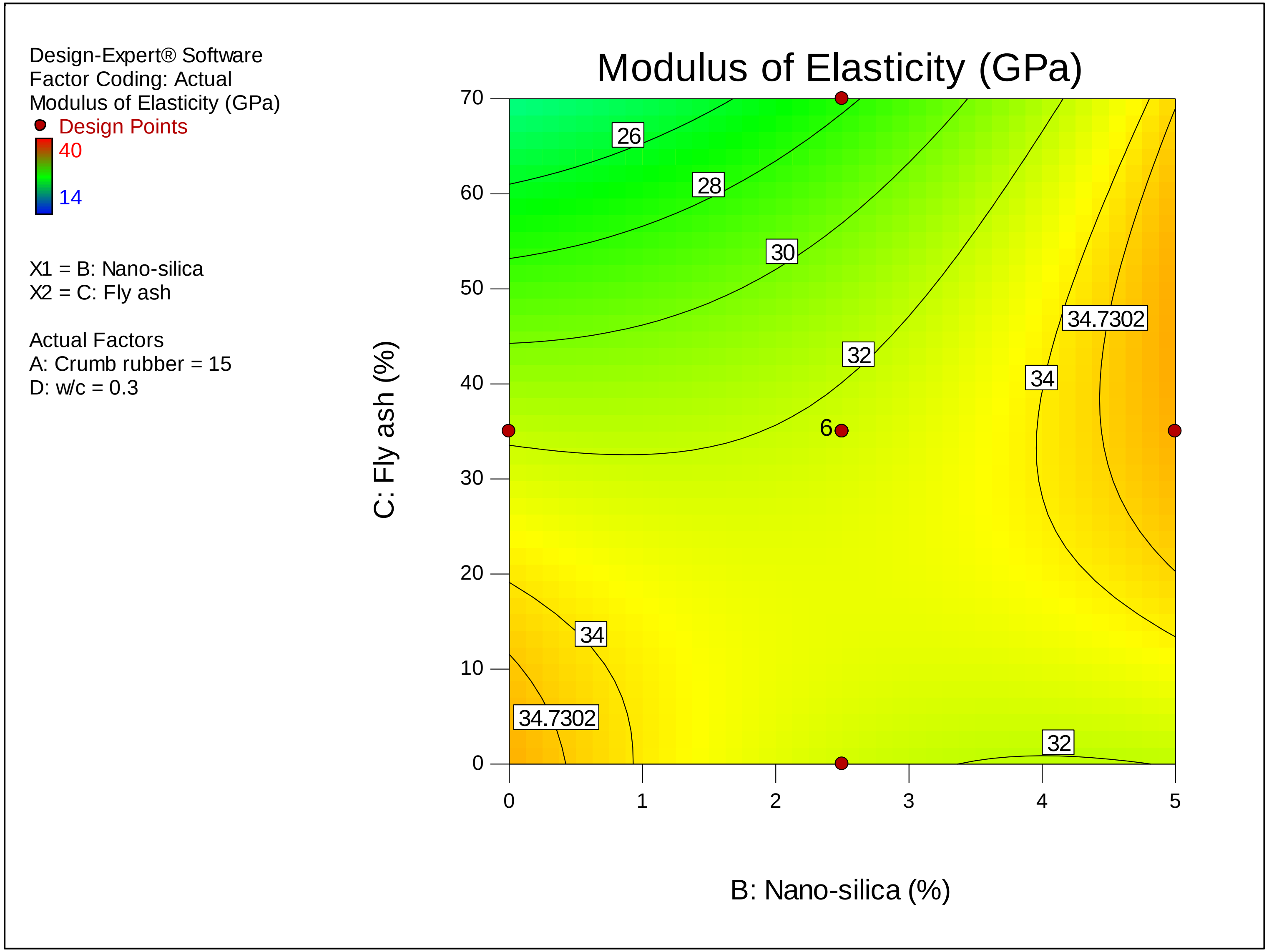


Figure 4.14: Modulus of Elasticity of Fly Ash and Nano silica (2D Contour Plot)

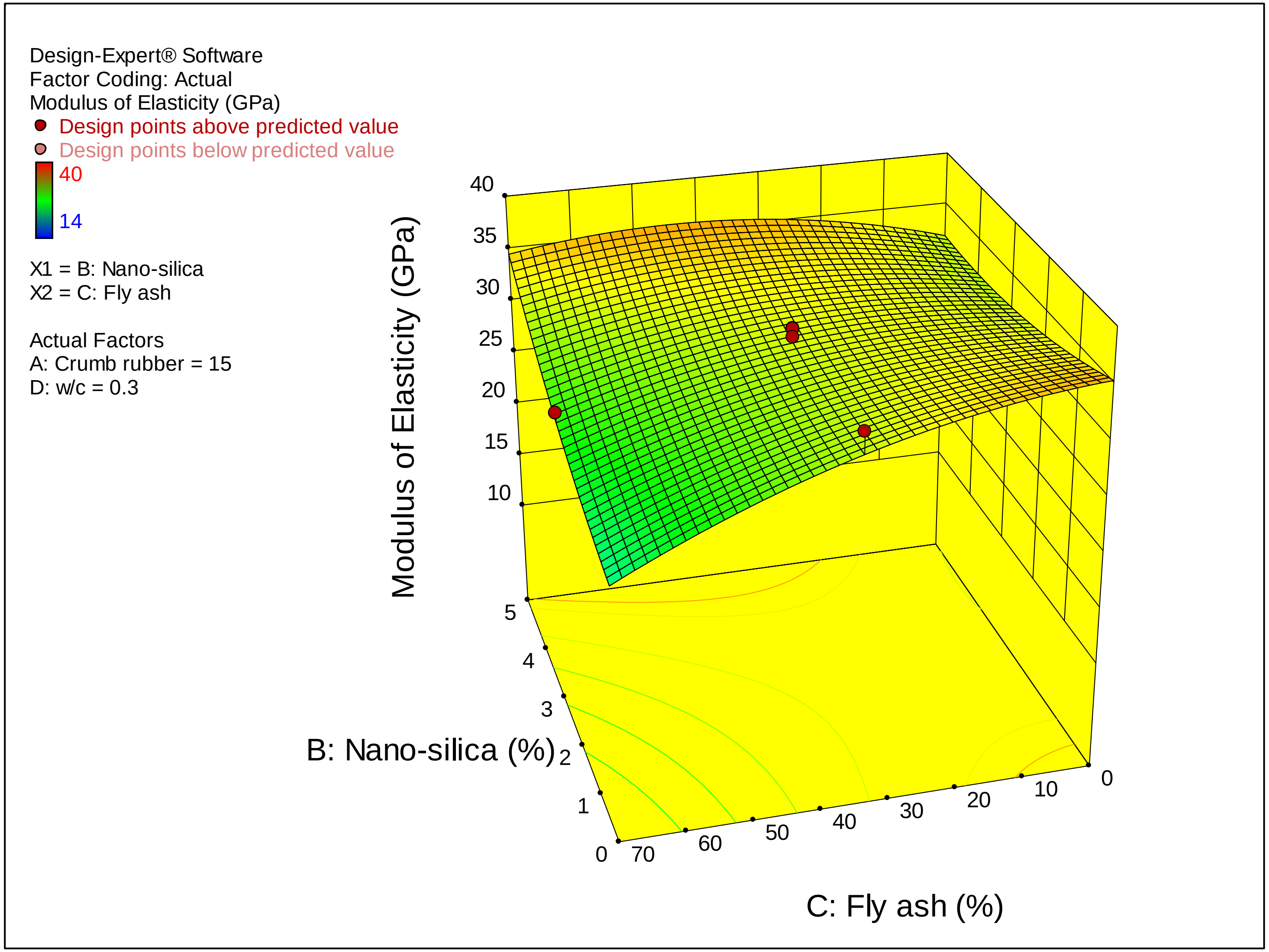


Figure 4.15: Modulus of Elasticity of Fly Ash and Nano silica (3D Surface Model)

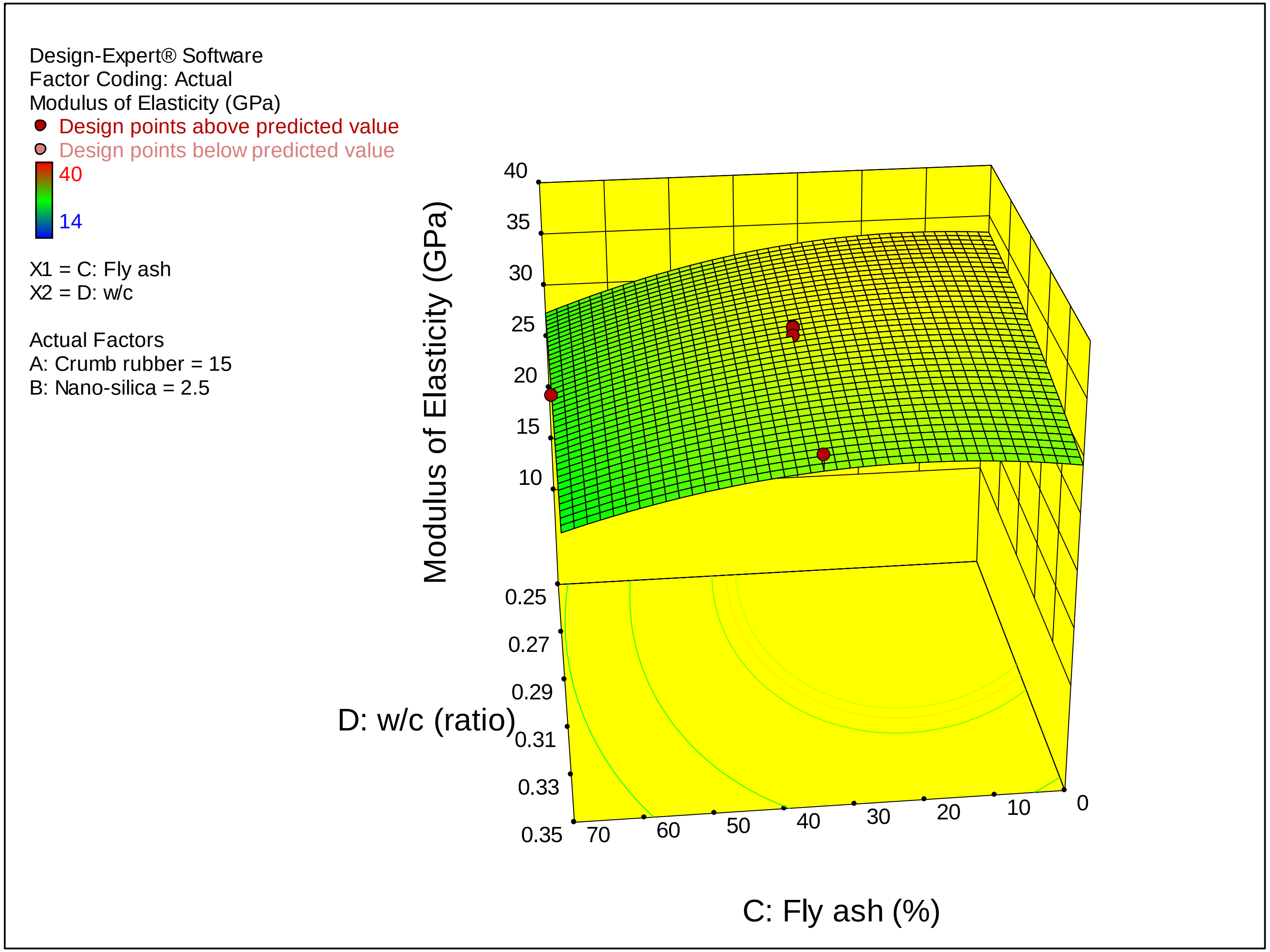


Figure 4.16: Modulus of Elasticity against Fly Ash and w/c ratio (2D Contour Plot)

From Figure 4.8 to Figure 4.16, several 2D Contour Plot and 3D Surface Model diagrams were produced from an analytical process of ANOVA (Analysis of Variance) from the Response Surface Methodology based on the Modulus of Elasticity results obtained during testing, which is to be compared with the other variables in this research, which are crumb rubber, Nano silica, fly ash as well as water-cement ratio. Hence, the diagrams were to show to the relationship between each other which eventually describes the percentage of modulus elasticity obtained from the testing.

Pelisser et al. (2011) have reported that the addition of crumb rubber into the concrete mixture to form Rubbercrete, has in fact lowered down the modulus elasticity of Rubbercrete. To add to that, Mohammed et al., (2011) and Gupta et al., (2015) have concurrently agreed that the addition of the crumb rubber particles has also decreased the overall general stiffness and strength of the Rubbercrete hence, increasing the flexible properties of the Rubbercrete. However, Figure 4.9 and Figure 4.15 shows a similarity, where the increment in Nano silica percentage also increases the percentage of Modulus of Elasticity. This is mainly due to the fact that Nano silica is considered as a pozzolanic material where it has the attributes of a filler-effect when reacted with the portlandite matrix. To be more elaborate, this filler effect attribute which the Nano silica has will fill in the pores left by the Interfacial Transition Zone (ITZ) which is hence, why it is known as a filler material, which is to fill in gaps. The filling in of the gap by the addition of Nano silica densifies the concrete thus strengthens the bond of the cement matrix and that of crumb rubber, thus increasing the modulus elasticity. This in return causes the reduction in absorption of impact from the Rubbercrete.

As far as the fly ash percentage is concerned, the modulus of elasticity percentage decreases when fly ash is increased. This is due to the fact that fly ash, unlike concrete, delays the time taken for the Rubbercrete to gain the maximum strength. Just like Nano silica, fly ash is also a pozzolanic material where fly ash reacts with the calcium hydroxide from the cement at a very slow pace during its hydration stage. Hence, due to the slow reaction time it takes to fully react with the calcium hydroxide, the early stages of the Rubbercrete will not show any significant improvement in strength or modulus of elasticity.

The water-cement ratio, on the other hand, plays a very important role in determining the Modulus of Elasticity of the Rubbercrete. As seen in the Shrinkage Test results it is determined that one of the factors for shrinkage is the water-cement ratio where the lower the water-cement ratio, the better it is for the Rubbercrete as the presence of water increases the shrinkage potential of the Rubbercrete. In relation to the Modulus of Elasticity, it is proven again as seen in Figure 4.13, that when the water-cement ratio decreases, the Modulus of Elasticity of the tested Rubbercrete increases. The number of air voids/Nano voids present in the Rubbercrete mix depends heavily on the total water-cement ratio. A phenomenon known as bleeding would occur in the concrete matrix where excessive water that was not used up during the hydration process of the concrete would instead leave the cement matrix and create new and more microscopic pores thus allowing air to be entrapped. These entrapped air in these microscopic pores in the Rubbercrete matrix will eventually weaken the bonding capability between the crumb rubber and cement paste. Hence, to reiterate the fact that, in the research above, results show that the decrease of water-cement ratio would eventually increase the Modulus of Elasticity of the Rubbercrete.

CHAPTER 5

CONCLUSION

To reiterate, this research studies the deformation properties of concrete containing crumb rubber from scrap tire as a partial replacement to fine aggregates. From the results, comparisons can be made and suggestive actions can be made to further improve our eccentricity towards achieving the objectives set for this study in pursuit of pushing towards the usage of Rubbercrete in the construction industry. The most notable one being that it is suitable and justified to use the Response Surface Methodology to design the experiments as every result are within the permissible limit for each tests without showing many erratic results.

The shrinkage test shows that every mix is within the allowable limit as following to the conformance of ASTM C157 – 08 Standard Test Method for Length Change of Concrete where every single factor which promotes shrinkage is reduced/eliminated. The cylindrical moulds were kept in a low humidity area and also the proper gradation of aggregates is done to be used for the casting of the mixes as aggregates with the higher modulus of elasticity and with a lot of rough edges (not smooth) is much more resistant to the shrinkage deformation.

As for the Modulus of Elasticity and Poisson's Ratio, from using the mix designs by the RSM, it can be concluded that by adding Nano silica into the concrete mixture, the general strength of the Rubbercrete mixture itself increases. Variables such as water-cement ratio have to be low in order to decrease the deformities properties of Rubbercrete as the presence of water increases the shrinkage possibility and decreases the modulus of elasticity of the Rubbercrete. Hence, the water-cement ratio variable should be decreased to obtain a "better" Rubbercrete.

Also, the modulus of elasticity percentage decreases when fly ash is increased due to the pozzolanic nature of the fly ash which delays the time for the Rubbercrete to obtain its maximum strength.

All in all, the results and highlights to be taken are;

1) The compressive strength of Rubbercrete using Nano silica as additives should be noticeably increased.
2) The inclusion of Nano silica in the concrete mix will densify the Interfacial Transition Zone and enhance pore systems of the concrete to allow better mixing matrix.
3) Properties such as durability are increased with the usage of Nano silica in the design mix of Rubbercrete.

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APPENDICES

APPENDIX 1-1: 14 Day Analysis by RSM

14 days Analysis

Response 1

ANOVA for Response Surface Linear model

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	3112.58	4	778.15	11.51	< 0.0001	significant
A-Crumb rubber	*1103.04*	*1*	*1103.04*	*16.32*	*0.0004*	
B-Nano silica	*182.96*	*1*	*182.96*	*2.71*	*0.1124*	
C-Fly ash	*733.23*	*1*	*733.23*	*10.85*	*0.0029*	
D-w/c	*1093.35*	*1*	*1093.35*	*16.18*	*0.0005*	
Residual	1689.58	25	67.58			
Lack of Fit	*1531.21*	*20*	*76.56*	*2.42*	*0.1664*	*not significant*
Pure Error	*158.37*	*5*	*31.67*			
Cor Total	4802.16	29				

The Model F-value of 11.51 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, C, D are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model. The "Lack of Fit F-value" of 2.42 implies the Lack of Fit is not significant relative to the pure error. There is a

16.64% chance that a "Lack of Fit F-value" this large could occur due to noise. Non-significant lack of fit is good -- we want the model to fit.

Std. Dev.	8.22	R-Squared	0.6482
Mean	41.21	Adj R-Squared	0.5919
C.V. %	19.95	Pred R-Squared	0.4225
PRESS	2773.07	Adeq Precision	15.013
-2 Log Likelihood	206.07	BIC	223.07
		AICc	218.57

The "Pred R-Squared" of 0.4225 is in reasonable agreement with the "Adj R-Squared" of 0.5919; i.e. the difference is less than 0.2. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 15.013 indicates an adequate signal. This model can be used to navigate the design space.

Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	41.21	1	1.50	38.11	44.30	
A-Crumb rubber	-7.83	1	1.94	-11.82	-3.84	1.00
B-Nano silica	-3.19	1	1.94	-7.18	0.80	1.00
C-Fly ash	-6.38	1	1.94	-10.37	-2.39	1.00
D-w/c	-7.79	1	1.94	-11.78	-3.80	1.00

Final Equation in Terms of Coded Factors:

14 day =

+41.21

-7.83 * A

-3.19 * B

-6.38 * C

-7.79 * D

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

Final Equation in Terms of Actual Factors:

14 day =

+105.36626

-0.52188 * Crumb rubber

-1.27526 * Nano silica

-0.18235 * Fly ash

-155.87407 * w/c

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the centre of the design space. Proceed to Diagnostic Plots (the next icon in progression).

Point to be taken note of;

1) Normal probability plot of the standardized residuals to check for normality of residuals.
2) Standardized residuals versus predicted values to check for constant error.
3) Externally standardized Residuals to look for outliers, i.e., influential values.
4) Box-Cox plot for power transformations.

If all the model statistics and diagnostic plots are OK, finish up with the Model Graphs icon.

APPENDICE 1-2: 28 Day Analysis by RSM

28 days Analysis

Response 2 28 day

ANOVA for Response Surface 2FI model

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	5879.69	10	587.97	19.40	< 0.0001	significant
A-Crumb rubber	*1601.59*	*1*	*1601.59*	*52.84*	*< 0.0001*	
B-Nano silica	*143.24*	*1*	*143.24*	*4.73*	*0.0426*	
C-Fly ash	*523.08*	*1*	*523.08*	*17.26*	*0.0005*	
D-w/c	*1099.39*	*1*	*1099.39*	*36.27*	*< 0.0001*	
AB	*163.07*	*1*	*163.07*	*5.38*	*0.0317*	
AC	*506.48*	*1*	*506.48*	*16.71*	*0.0006*	
AD	*352.63*	*1*	*352.63*	*11.63*	*0.0029*	
BC	*1381.24*	*1*	*1381.24*	*45.57*	*< 0.0001*	
BD	*70.08*	*1*	*70.08*	*2.31*	*0.1448*	
CD	*38.90*	*1*	*38.90*	*1.28*	*0.2714*	
Residual	575.95	19	30.31			
Lack of Fit	*551.54*	*14*	*39.40*	*8.07*	*0.0154*	*significant*
Pure Error	*24.41*	*5*	*4.88*			
Cor Total	6455.64	29				

The Model F-value of 19.40 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise.
Values of "Prob > F" less than 0.0500 indicate model terms are significant.
In this case A, B, C, D, AB, AC, AD, BC are significant model terms.
Values greater than 0.1000 indicate the model terms are not significant.

If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.
The "Lack of Fit F-value" of 8.07 implies the Lack of Fit is significant. There is only a 1.54% chance that a "Lack of Fit F-value" this large could occur due to noise. Significant lack of fit is bad -- we want the model to fit.

Std. Dev.	5.51	R-Squared	0.9108
Mean	44.68	Adj R-Squared	0.8638
C.V. %	12.32	Pred R-Squared	0.7473
PRESS	1631.07	Adeq Precision	20.133
-2 Log Likelihood	173.78	BIC	211.19
		AICc	210.45

The "Pred R-Squared" of 0.7473 is in reasonable agreement with the "Adj R-Squared" of 0.8638; i.e. the difference is less than 0.2. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 20.133 indicates an adequate signal. This model can be used to navigate the design space.

Factor	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	44.68	1	1.01	42.57	46.78	
A-Crumb rubber	-9.43	1	1.30	-12.15	-6.72	1.00
B-Nano silica	2.82	1	1.30	0.10	5.54	1.00
C-Fly ash	-5.39	1	1.30	-8.11	-2.67	1.00
D-w/c	-7.82	1	1.30	-10.53	-5.10	1.00
AB	3.19	1	1.38	0.31	6.07	1.00
AC	5.63	1	1.38	2.75	8.51	1.00
AD	4.69	1	1.38	1.81	7.58	1.00
BC	9.29	1	1.38	6.41	12.17	1.00
BD	-2.09	1	1.38	-4.97	0.79	1.00
CD	1.56	1	1.38	-1.32	4.44	1.00

Final Equation in Terms of Coded Factors:

28 day	=
+44.68	
-9.43	* A
+2.82	* B
-5.39	* C
-7.82	* D
+3.19	* AB
+5.63	* AC
+4.69	* AD
+9.29	* BC
-2.09	* BD
+1.56	* CD

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

Final Equation in Terms of Actual Factors:

28 day	=
+146.64748	
-3.09460	* Crumb rubber
+1.15787	* Nano silica
-0.84752	* Fly ash
-239.52037	* w/c
+0.085133	* Crumb rubber * Nano silica
+0.010717	* Crumb rubber * Fly ash
+6.25944	* Crumb rubber * w/c
+0.10619	* Nano silica * Fly ash
-16.74333	* Nano silica * w/c
+0.89095	* Fly ash * w/c

The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the centre of the design space.
Proceed to Diagnostic Plots (the next icon in progression).

Point to be taken note of;

1) Normal probability plot of the standardized residuals to check for normality of residuals.
2) Standardized residuals versus predicted values to check for constant error.
3) Externally Studentized Residuals to look for outliers, i.e., influential values.
4) Box-Cox plot for power transformations.
If all the model statistics and diagnostic plots are OK, finish up with the Model Graphs icon.

APPENDICE 1-3: Modulus of Elasticity Analysis from RSM

Modulus of Elasticity =

+29.94660

-0.47302 * Crumb rubber

-3.23768 * Nano-silica

-0.13967 * Fly ash

+122.39788 * w/c

+0.047617 * Crumb rubber * Nano-silica

-4.60714E-004 * Crumb rubber * Fly ash

+1.03417 * Crumb rubber * w/c

+0.041693 * Nano-silica * Fly ash

+2.64500 * Nano-silica * w/c

+0.36179 * Fly ash * w/c

-5.01598E-003 * Crumb rubber^2

+0.21142 * Nano-silica^2

-1.90906E-003 * Fly ash^2

-307.43860 * w/c^2