FACULTY OF TEXTILE ENGINEERING TUL

Dissertation Thesis

Investigating the Effects of Alkaline Aging on Jute Fibers and Their Reinforcement Capabilities in Modified Cement Composites

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Dedication

I dedicate this thesis to my late parents

Acknowledgment

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Anotace

Tato disertační práce je rozdělena na do dvou hlavních částí. První část se zabývá degradaci (zjemňování) technických jutových vláken v alkalických podmínkách. Různé koncentrace alkálií a doby působení byly systematicky přezkoumány za účelem posouzení jejich vlivu na pevnost vláken. Výsledky ukazují, že vlákna ošetřená NaOH výrazně snížila pevnost v tahu v průběhu času. Hydroxid sodný byl podle analýzy metodou "Response Surface Methodology" (RSM) nejagresivnějším alalkálií použitou v tomto experimentu.

Druhá část studie hodnotí účinky popílku (FA), Laponitu (LAP) a Bentonitu (BENT) na mechanické vlastnosti cementové směsy. Popílek zlepšil pevnost při tříbodovém ohybu, ale snížil pevnost v tlaku a houževnatost. Naproti tomu Laponit měl negativní vliv na všechny vlastnosti, ale 1 % Laponitu vykázalo maximální hodnotu u všech funkcí. Bentonit zlepšil jak pevnost při tříbodovém ohybu, tak pevnost v tlaku. Statistické regresní modely a modely „Ordered Weighted Averaging "(OWA) naznačily, že směs s 5 % popílku a 1 % Laponitu je optimální pro stavební účely, vyvažující bezpečnost a výkon. Nejlepší výsledky z hlediska tříbodového ohybu, pevnosti v tlaku a houževnatosti byly pozorovány u cementových směsí obsahujících 5 % popílku a 1 % Laponitu, zesílených různými množstvími jutových vláken.

Klíčová slova: Stárnutí materiálu, Jutové vlákno, Alkalické ošetření, Mechanické vlastnosti, Metoda Response Surface, Cementová směs, Popílek, Laponit, Bentonit, Ordered Weighted Averaging, Hodnocení dopadu na životní prostředí.

Annotation

This thesis is divided into two main parts. The first part investigates the degradation (refining) of jute technical fibers under alkaline conditions. Various types of alkali concentrations, and treatment times were systematically reviewed to assess their effects on fiber strength. Results indicate that fibers treated with NaOH significantly reduced the tensile strength over time. Sodium hydroxide was found to be the most aggressive alkali according to Response Surface Methodology (RSM) analysis.

The second part of the study evaluates the effects of fly ash (FA), Laponite (LAP), and Bentonite (BENT) on the mechanical properties of cement paste. Fly ash improved 3-point bending stress but reduced compressive strength and toughness. Conversely, laponite negatively affected all properties, but 1% of Laponite showed a maximum value for all the functions. while Bentonite enhanced both 3-point bending stress and compressive strength. Statistical regression and Ordered Weighted Averaging (OWA) models indicated that a mixture of 5% fly ash and 1% Laponite was optimal for construction purposes, balancing safety and performance. The best performance in terms of 3-point

bending, compressive strength, and toughness was observed in cement mixtures containing 5% fly ash and 1% Laponite, reinforced with different amounts of jute fibers.
Keywords: Aging behavior, Jute fiber, Alkali treatment, Mechanical properties, Response Surface Methodology, Cement mixture, Fly ash, Laponite, Bentonite, Ordered Weighted Averaging, Environmental Impact Assessment.

Anmerkung

Diese Dissertation ist in zwei Hauptteile gegliedert. Der erste Teil untersucht den Abbau (Raffination) von technischen Jutefasern unter alkalischen Bedingungen. Verschiedene Konzentrationen von Alkalien und Behandlungszeiten wurden systematisch überprüft, um ihre Auswirkungen auf die Faserstärke zu bewerten. Die Ergebnisse zeigen, dass mit NaOH behandelte Fasern die Zugfestigkeit im Laufe der Zeit signifikant reduzierten. Natriumhydroxid wurde gemäß der Analyse der "Response Surface Methodology" (RSM) als das aggressivste Alkalium befunden.

Der zweite Teil der Studie bewertet die Auswirkungen von Flugasche (FA), Laponit (LAP) und Bentonit (BENT) auf die mechanischen Eigenschaften von Zementpaste. Flugasche verbesserte die 3-Punkt-Biegefestigkeit, verringerte jedoch die Druckfestigkeit und Zähigkeit. Laponit hingegen wirkte sich negativ auf alle Eigenschaften aus, aber 1 % Laponit zeigte für alle Funktionen einen Höchstwert. Bentonit verbesserte sowohl die 3-Punkt-Biegefestigkeit als auch die Druckfestigkeit. Statistische Regressionsmodelle und Modelle des „Ordered Weighted Averaging" (OWA) zeigten, dass eine Mischung aus 5 % Flugasche und 1 % Laponit für Bauzwecke optimal war, wobei Sicherheit und Leistung ausgeglichen wurden. Die besten Ergebnisse in Bezug auf die 3-Punkt-Biegefestigkeit, Druckfestigkeit und Zähigkeit wurden bei Zementmischungen beobachtet, die 5 % Flugasche und 1 % Laponit enthielten und mit unterschiedlichen Mengen an Jutefasern verstärkt waren.
Schlüsselwörter: Alterungsverhalten, Jutefaser, Alkalibehandlung, Mechanische Eigenschaften, Response Surface Methodology, Zementmischung, Flugasche, Laponit, Bentonit, Ordered Weighted Averaging, Umweltverträglichkeitsprüfung.

Abbreviations

ANOVA	Analysis of Variance
ASR	Alkali-Silica Reaction
BENT	Bentonite
CSHC	Calcium Silicates Hydrates
DSC	Differential Scanning Calorimetry
EDS	Energy-dispersive X-ray Spectroscopy
EIA	The Environmental Impact Assessment
EU	European Union
FA	Fly Ash
FBC	Fluidized Bed Combustion
GHG	Green House Gases
HAD	Historical Data Analysis
LAP	Laponite
LOI	Limiting Oxygen Index
OFAT	One-Factor-at-A-Time
OWA	Ordered Weighted Averaging
RSM	Response Surface Methodology
SCMs	Supplementary Cementitious Materials
SEM	Scanning Electron Microscope
TGA	Thermogravimetric Analysis
US	United States

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Chapter 1

1 Introduction

1.1 An overview of the current state of the problem

Industrialization and growth are another important factors that have raised many concerns over the increasing degradation of the environment over the years across the globe. As the world population is increasing and with the coming up of industries, there is a need to expand construction facilities. In the same way, through emerging construction activities, more pressure is being placed on natural resources; the construction industry is among the major negative contributors to the environment through utilizing a large percentage of raw natural resources and releasing a high amount of greenhouse gases [1]. Many countries are increasingly getting concerned with the disclosure of information concerning energy consumption, materials, water, and waste produced by the construction and building industry which has made it reach an influential status on the political agenda of most countries. The European Union (EU) has specifically pointed out various studies that prove that the construction industry alone is responsible for consuming 42% of the EU's total final energy consumption, more than 50% of all the extracted or mined materials, 30% of water usage and resultant waste as well as contributing to 35% of the total Green House gases (GHG) emissions [2].

Cement concrete being the widely used construction material is not without a few drawbacks at least within the context of this research; it is a brittle material that cracks easily, possesses low tensile strength, and endures early failure due to freeze-thaw cycles and chemical attack. According to estimations, concrete production itself contributes to the contribution of global CO_2 emissions that range from 5% to 8%. Out of these, 95% of carbon dioxide emissions are associated with the production of cement which is the key material used for concrete production [3]. It has been established that the process of manufacturing Portland cement leads to emissions almost similar to carbon dioxide for every individual cement produced. Furthermore, apart from being a major source of CO_2 release in concrete production, the process also consumes a lot of raw materials, depleting natural resources and polluting our environment. For instance, in making Portland cement, it is often observed that the raw material consumption is approximately double the amount of cement produced [4]. In addition, the global cement industry produces about 30 million tons of solid waste

commonly referred to as cement kiln dust per year [5]. Hence, pursuing the efficient use of other materials that at least partially or totally act as cement is extremely significant to minimize the influence of cementitious materials. Under this condition, there are a range of materials such as Waste and Clays replacing cement which should be further explored [6]. The materials used most widely in cement substitution include waste materials such as fly ash, slag and silica fume [7]. These materials include fly ash having originated from coal combustion or cinders and or scoria resulting from metallurgical processes such as smelting. For example, approximately 50% is currently being dumped as waste in the United States and 7. 1 per cent in the EU countries, 30 per cent in China and 75 per cent in India [8]. By using these waste materials in cement mixtures one gets to reduce the use of cement required for the construction as well as offer a sustainable, functional way to dispose the waste products and yet going a long way in preserving natural resources. The other possibility for the use of clays in concrete is that they can act as cement replacement material. Calcined clay or metakaolin has additional properties, namely the pozzolanic properties, which enable the clay to react with calcium hydroxide thus producing more cementitious compounds [9]. These clays can be used partially in substitution of cement, enhancing the strength and serviceability of concrete made therefrom. In addition to this, clays are abundant and renewable sources of material, compared to cement, making them attractive to use [10], [11]. As mentioned above concrete has relatively low tensile strength, tensile strength as a material that has resistance to a force applied perpendicular to its bottom surface. Earlier used materials for the reinforcement of concrete include steel; however, due to the advancement of fibre technology the modern construction world has more fibres including polypropylene, glass, carbon, basalt, jute and many more [12]. These fibres improve strength, durability, and toughness of constructions materials [13]. Natural fiber, which has always been appreciated in the textile industry, is now widely incorporated in construction, particularly cementitious composites [14]. That is, these fibres can span cracks and halt their progressive extension once introduced into concrete or asphalt matrix and enhance the tensile strength and fatigue properties of the material [15]. Moreover, the use of fibres increases the features of material overall reliability, also the substantial decrease of the shrinkage coefficient, and the fire resistance features [16]. Apart from enhancing the efficiency of structures, they help enhance the sustainability of the building industry. Developing natural and recycled fibres or using natural fibre blends can reduce the carbon footprint [17]. With advancing technology fibers' importance is expected to revolutionize

construction and make structures to be stronger, more environmentally friendly, and efficient.

Cementitious composites are highly alkaline [18] which can cause different levels of degradation in fibres with varying polymeric compositions. Therefore, it is essential to investigate the performance of various fibres when added to concrete. Some fibres are chemically inert, making them more stable compared to others [19]. Thus, understanding the durability and life-cycle performance of fibres in cementitious composites remains a significant technical challenge [20][21].

1.2 Research Objectives

The overall aim of this study is explore the behaviour of deterioration of jute fibres in alkaline solutions, part replacement of cement with waste and clay materials in cement paste, and utilization of partial cement reinforcement with jute fibre. The study aims to address the following key research questions:

Aging behavior of jute fibers in alkaline environments

Natural cellulosic fibers are in alkalis stronger? For this purpose, we were intended to:

- Conduct preliminary laboratory formulations of jute-derived fibres in an alkaline environment and ascertain their weight loss and tensile strength retaining capabilities in a One-Factor-at-A-Time (OFAT) research design. Carry out the thermal properties and stability of the formulated samples using Differential Scanning Calorimetry (DSC), Thermogravimetric Analysis (TGA) as well as Scanning Electron Microscope (SEM) to characterize the obtained samples.
- Perform Historical Data Analysis (HAD)-Response Surface Methodology (RSM) protocol for maximization of carrying out the sensitivity analysis and the mathematical modeling of significant factors affecting tensile performance.

Partial replacement of cement by waste and clay materials in cement paste mixture

- Preparing cement paste samples by blending varying proportions of Fly Ash (FA), Bentonite (BENT), Laponite (LAP) and assessing the impact on characteristics such as 3-point bending stress, compression stress, and toughness through the One-Factor-at-A-Time (OFAT) method.
- Statistical regression assessment of FA, BENT, and LAP correlated by all functions.

- The Environmental Impact Assessment (EIA) in terms of the concentration of the toxic compounds of the additive compounds.
- The sustainability assessment of the prepared mixtures concerning the green concrete will be made with the help of the Ordered Weighted Averaging (OWA) method.
- Estimating particle size distribution of the ingredients used in the cement mixtures.
- Preparation of cement mixtures with partial replacement of cement by fly ash and laponite and its reinforcement with various percentages of jute fiber.

1.3 Scope of the Study

The current research is intended to analyze the effect of aging with alkaline solutions, including different concentration levels and exposure periods of NaOH, KOH, and $Ca(OH)_2$ solutions on fibre jute properties and mechanical features. It also explores the influence of Supplementary Cementitious Materials (SCMs) on the mechanical characteristics and durability of jute fibre reinforced cement paste keeping into consideration the characteristic such as compressive strengths, flexural strength, and toughness. Furthermore, in order to study the fundamental information of the morphological and composition changes occurred within the cementitious matrix this study will employ analysis using scanning electron microscopy (SEM) and particle size distribution studies.

1.4 Organization of the Thesis

This thesis is organized into several chapters, each addressing specific aspects of the research objectives outlined above:

Chapter 1: Introduction (current chapter) provides an overview of the background, significance, objectives, and scope of the study.

Chapter 2: Literature Review aims to offer analysis of the literature previously published for the research that concerns fibre reinforced concrete, impacts of the alkali solution on the deterioration of the fibre used and role of SCMs in cement matrix.

Chapter 3: Experimental Methodology describes the various experiments that have been performed in this study in order to understand the aging characteristic and mechanical characteristics of treated jute fibre with an Alkaline environment and cement paste mixtures containing partially replaced material.

Chapter 4: Results and Discussion gives the findings of the experiments and discusses their implications concerning the research objectives

Chapter 5: This section concludes the study by highlighting the major findings, their significance, and the direction to be taken in the future on the issue being investigated.

Chapter 2

2 Literature Review

2.1 Partial Replacement of Cement in Cementitious Materials

The construction Industry is one of the largest industries all-over the world and going on with the increase in human population and Structural development. It is worth to emphasize that this industry is heavily rely on natural resources with the predicted virgin aggregates production within the next 13 years estimated at around 60 billion tons worldwide [22]. According to the sources, the construction industry and building materials around the world have been projected to grow at the rate of 4.2 % from 2018 to 2023, attaining an estimated value of $ 10.5 trillion By 2023 [23]. As construction demands are increasing with time, its impact on the environment is alarming; it is therefore very relevant to look for materials that help reduce impacts on the environment. As it stands today, most constructions are done using conventional materials that are not environmentally friendly to cater to the growing needs of the developing society [24]. Concrete plays the largest role as a construction material, with an annual production rate exceeding 4 million tons [25]. It is worth noting that construction activities in the world produce around 1 billion tonnes of masonry and concrete waste [26]. The major energy consumption is in the process of production of cement clinker, which ranges between 20 - 40% percent of the total energy in the cement industry [27]. Cement production is one particular industrial process through which a huge amount of CO_2 is emitted and accounts for about 5% – 7% of global CO_2 emissions while CO_2 estimated contributes 65% of global greenhouse gases [28][29][30]. Interestingly, to create one tonne of cement, 0.8 tonnes of CO_2 is released to the atmosphere [31]. Concrete is a material that does not possess the elasticity to support tensile forces, which is why it requires reinforcement. In this regard, conventional deformed steel bars are the ones in use. Yet of high importance is the fact that steel production is an energy demanding process that contributes to enormous carbon emissions. In 2016 there was production of 1,202 million tonnes of steel. According to the steel production statistics, around 2.3 tonnes of CO_2 emission is released for every tonne of steel produced [32]. This situation shows how important it is to create and use materials that are satisfactorily both in terms of sustainability and expenditure. In the United Nations sustainable development goals, there is a proclivity for the sustainable industrialization and establishment of safe resilient sustainable cities and

communities highlighted in goals nine and eleven respectively. In these goals, it becomes clear that there is a need to identify better solutions to this problem that are environmentally friendly and made of sustainable products [33]. Among the solutions, one is the use of waste and other materials in the creation of concrete. Disposal of industrial by-products is becoming voluminous, expensive, and complex due to the high costs of treatment involved, landfill operating costs, and scarcity of available disposal sites. Therefore, they encourage the use of industrial by-products in construction as it serves as a good option [34]. The outcome of the properties of concrete is the work of waste materials from industries, including fly ash, which has been investigated by previous researchers extensively [35][36]. Using these materials as a replacement or partial replacement for cement in cementitious materials helps solve the waste disposal problem and reduces the energy demand needed for cement production, thereby decreasing carbon emissions. Investing in such materials is crucial for addressing both environmental sustainability and the mechanical properties required for construction. The following sections will discuss the overall properties of fly ash, laponite, and bentonite.

2.1.2 Fly ash and its use in Composites

Fly ash is obtained in thermal power plants during the generation of electricity and is a by-product generated by coal combustion in plants [37][38]. The global production of fly ash is reported around 800 Metric tons (Mt) per year and the leading fly ash generating regions are China, India, the United States (US), and the European Union (EU) [39]. Particles of fly ash are spheroidal in shape with solid spheres, cenospheres, irregular shapes of waste and unburnt carbonospheres. Fluidized Bed Combustion (FBC) ash is predominantly composed of particles with an irregular shape with spherical particles a rarity. This is because while many of the minerals may be present in the coal in soluble forms, they do not melt but only soften at the relatively low boiler temperatures of 850 to 900 °C. Most of the irregular waste particles consist of unburnt carbon; anhydrite, and calcite [40]. The color of fly ash is normally grey-like and is reliant on the quantity of unburned coal which is responsible for its color from dark to dull to black [41]. Moreover, the type of coal significantly influences the physical and chemical properties of fly ash and coal type, air pollution control device's effectiveness and burning conditions shape the final chemical composition of the fly ash [42][43]. Table 2.1 indicates the chemical composition range of coal.

Table 2. 1 Fly ash chemical composition from different types of coal [39]

Coal type	Component (wt%)								
	Na2O	MgO	Al2O3	SiO2	K2O	CaO	SO3	Fe2O3	LOI
Sub-bituminous	0-2	1-6	20-30	40-60	0-4	5-30	0-2	4-10	0-3
Lignite	0-6	3-10	10-25	15-45	0-4	15-40	0-10	4-15	0-5
Bituminous	0-4	0-5	5-35	20-60	0-3	1-12	0-4	10-40	0-15
Anthracite	0-1	1-4	18-36	28-57	0-4	1-27	0-9	3-16	1-8

Fly ash is divided into two types, class C and class F respectively subject to the type of coal used and fly ash composition in terms of mineral content. While class C deals with lignite and sub-bituminous coals, class F is associated with anthracite and bituminous coals [44][45]. Table 2.2 outlines the classification of fly ash based on the characteristics listed previously.

Table 2. 2 Classification of fly ash based on chemical and mineralogical composition [44][45]

	Class C	**Class F**
Type of Coal	lignite, sub-bituminous	anthracite, bituminous
Total of SiO_2, Al_2O_3 and Fe_2O_3	<50%	>70%
CaO	20% – 30%	<5%

The two classifications of fly ash have markedly dissimilar characteristics and therefore have a variety of uses. If fly ash has a calcium oxide content greater than 20%, it is known as cementitious material and cementitious and pozzolanic if its CaO content ranges from 10% to 20% [44][46]. Some related characteristics such as the specific gravity of fly ash, specific surface area, and bulk density are presented in Table 2.3[41][40].

Table 2. 3 Physical properties of fly ash [41][40]

Physical Properties of Fly ash		
Specific Surface Area (m^2/kg)	**Specific Gravity**	**Bulk Density (Kg/m^3)**
170-1000	2.1-3.0	540-860

Fly ash is reporting a growing use in distinct areas like cement manufacturing, ceramics, paints, agriculture, and construction [47]. The shape, size, and chemical characteristics of

the fly ash influence its behaviour in a fly ash cement system, which in turn defines its appropriateness as a cement material substitute [48]. Many researchers have focused on exploring the effects of low-calcium fly ash in concrete [46]. When low-calcium fly ash is used, it contains some common active siliceous and aluminous materials that can be utilized as pozzolans to be blended with ordinary Portland cement to produce strengthened products. In turn, the incorporation of high calcium fly ash in concrete production is done in a very conservative manner because this material contains high levels of free CaO and sulfur that can be detrimental to the volume stability and durability of concrete. However, when suitably incorporated proportion of high calcium fly ash, it can give early strength as well as enhanced quality of concrete [49][46]. Fly ash makes concrete have better workability, needs less water for mixing, has less bleeding from the fresh concrete, and can produce better strengths and low permeability when specified correctly [40][50]. Fly ash concrete that contains less calcium is more resistant to sulfate attack as compared to concrete containing high calcium fly ash [51]. However, the ability to generalize the sulfate resistance of any type of fly ash is problematic. In the research outcomes, it has been found that fly ash concretes extend less when the content of alkali ions in the pore solution is lower because it affects the potentially reactive aggregates [52].

Fly ash has been found suitable to be used as a partial substitute for cement at a percentage of approximately 15–20 % cement replacement for cementitious materials [53]. When using fly ash in cement concrete, its quality is reduced when more than 20% of cement is replaced by this material, which is due to the reduction in the rate of the hydration process which initially reduces the strength gain [54]. Although in the long run, fly ash is known to improve the strength and durability of concrete structures. This is because it reacts with and consumes, $Ca(OH)_2$ formed in the course of cement hydration and forms secondary hydration products like; C-S-H [55]. The published data show that fly ash has a rather complex crystalline structure and fulfils the necessary requirements in terms of physical and chemical properties to be used in the hydration process of fly ash-cement systems [56]. In a previous study, the 28-day compressive strength was measured and it showed that there was a degradation in the strength of concrete with 30% cement and 40% cement replacement by fly ash and the achieved concrete strength was 84%, and, 63% of the average value of the control samples respectively. But at 90 days, the cement paste showed a similar compressive strength of concrete with a fly ash replacement level of 30% as with that of the control samples [57].

Earlier, Malhotra and Mehta suggested increasing at least 50% of cement by weight with fly ash, and using low water and cement content ratio [58]. Though there are advantages tied to this type of concrete, there are several factors that have limited its use particularly in the construction sites and they include, slower gain in strength and stiffness as well as setting time and constructional factors [38]. But the concretes with high-volume fly ash have delayed setting times and low early-age strengths [59]. Fly ash which is commonly used as a cement replacement has been faced with these challenges when utilized up to 80% by mass in concrete as described by researchers: some of these include the usage of superior material, Chemical admixtures, Fine limestone powder or internal curing [38]. Fly ash has low reactivity and its benefits, at least for concrete strength, are obtained at relatively later ages because of slow rates of pozzolanic reactions. The problem of low early-age strength has, however, been a major drawback in the use of this cement, and to overcome this, techniques of chemical activation with alkali or sulfate have been used [60][61][62].

2.1.2 Laponite and its Applications

Phyllosilicates are referred to as clay minerals; they are naturally formed through the process of chemical weathering on other silicate minerals. Based on their layer type, net layer charge magnitude, and type of interlayer species, clay minerals are categorized into seven groups: Serpentine-laolin, talc-pyrophyllite, montmorillonite, vermiculite, mica and chlorite interstratification [63]. As for the specific applications of clay minerals, they include building and construction materials, ceramics, paper production, extraction of petroleum and gas, and pharmaceuticals, among others, attributed to the special characteristics they possess, including high surface area per unit mass, ion-exchange capacity, ability to swell on contact with water, and layer structures. Furthermore, they have applications as adsorbents, catalysts, catalytic supporters, ion exchanger, decolorizing mater [64][65].

The synthetic clays resembling hectorite are called laponite which were only given this name in the 1960s, although they are currently defined as the synthetic hectorite nanoparticles for the paint industry. Laponite belongs to the smectite group of phyllosilicates, characterized by 2:1 crystal structures of layered units as shown in Fig. 2.1 [66]. Laponite clay has a disk-like structure with a thickness of 1 nm and an average diameter of 25±2 nm [67].

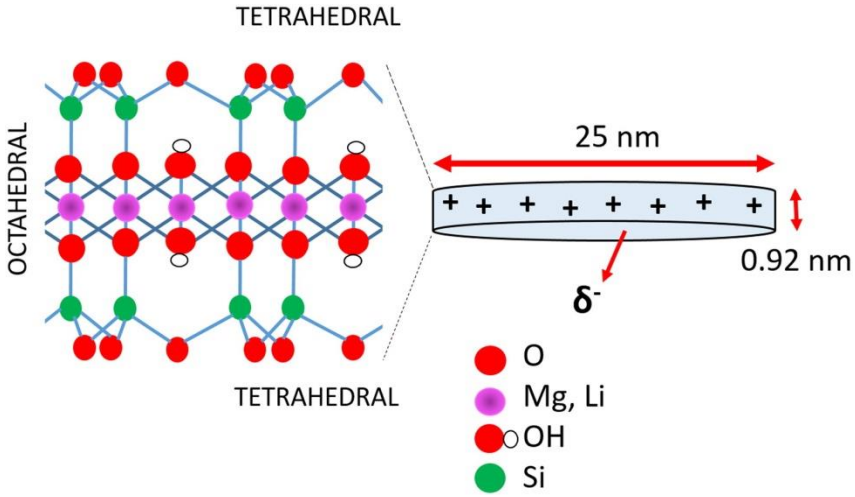


Figure 2. 1 Schematic diagram showing laponite nanocrystal geometry and chemical structure [66]

Laponites in aqueous solution can easily be separated apart into layers, and the aspect ratio of synthetic hectorite can be organized by the synthesis conditions and as a result, the edge area for synthesis covers a high proportion of the total surface area [68].

Laponite is widely used in personal care products, the polymer industry, surface coatings, and agriculture [69]. Recently, there has been significant interest in using clays as nanofillers in combination with various polymeric matrices [70]. Polymer nanocomposites exhibit markedly improved mechanical properties, but the effects of filler size and the role of the high specific interfacial area are still not fully understood [71]. Studies have shown that even with low clay contents, stiffness reinforcement is evident, and with increasing concentrations, the effects become more pronounced. However, clay contents in polymer nanocomposites are typically limited to 5-10 wt% due to challenges with proper dispersion and the high melt viscosity of nanocomposites and their precursors [72]. Laponite clay has a crystalline layered structure with weak bonds between layers, making it suitable for forming organic/clay nanocomposites. Laponite clay can be broken down into submicron-sized disk-like particles with an aspect ratio of approximately 10:1. These particles consist of stacks of nanometer-thick layers with very high stiffness [64].

Toyota's group has found a substantial enhancement in the modulus and strength of Nylon-6/clay nanocomposites and suggested that the overall values of Nylon-6 in a mixture with clay are superior to the pure Nylon [73]. The mechanical properties of epoxy/clay nanocomposites showed a higher value of modulus and strength compared to that of epoxy [74]. Laponite has been reported to degrade when it comes in contact

with aqueous solution particularly when the pH of the solution is low and this causes the release of many products such as aqueous silica, sodium ions, magnesium ions, and lithium ions into the medium [75].

2.1.3 Bentonite

Bentonite is a fine-grained, bent-to-fluid volcanic clay rock formed from hydrothermal siliceous ash sediments in fresh or salt water millions of years ago. The first complete specimen was found near the Fort Benton site in Wyoming which is why the name given to the clay is so. Bentonite is a term used that defines it as the smectite-rich clay and comprises most of the smectite, particularly the montmorillonite. The deposits of bentonite are found globally and extend from USA, Europe, North Africa, and Asia including Japan and China [76][77]. More recently, bentonite has been depicted as calcined clay that has no connection with laolin and is a cost effective supplementary cementitious material [78]. Bentonite is a very soft, plastic clay composed mainly of montmorillonite, a 2:1 type of mineral clay belonging to the phyllosilicate group and is composed of fine particles. Montmorillonite comprises of two tetrahedrals linked identically by an octahedral one; namely $Al(OH)_6$ and the second one is a tetrahedral layer SiO_4 [79]. It is thus mainly determined by its structure, which in this case refers to a hydroxyl-aluminosilicate compound. The structure in clay can be described as the arrangement of silica tetrahedral layer and alumino octahedral sheet [80].

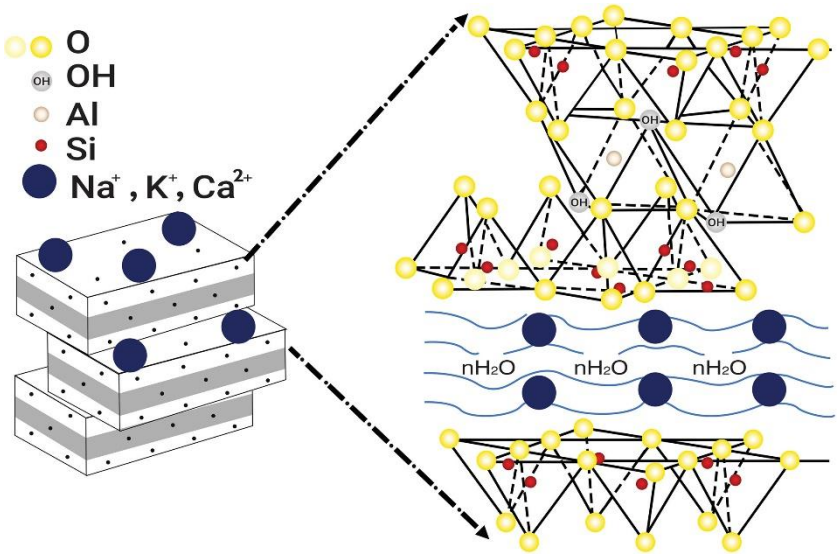


Figure 2. 2 Structure of bentonite clay [80]

Commercially available bentonites are termed as natural sodium bentonites and are of non-swelling type. An alkaline activation process is carried out to produce this material, where Ca^{2+} and Na^{+} ions must be replaced [81]. Bentonite clay has a specific gravity of 2.82 and a surface area of 2.53 cm^2/g [82].

Many studies have shown that raw bentonite concrete has lower early-stage compressive strength, but its strength at later stages is quite impressive [83]. Research by Masood et al. found that adding bentonite clay to concrete improved its density and microstructure [84]. In one study, cement was partially replaced with bentonite up to 21%, and at 56 and 90 days, the bentonite-added mixes exhibited much better strength compared to mixes without bentonite [83]. However, it has also been reported that increasing the proportion of bentonite clay as a partial cement replacement reduces the compressive strength of concrete [85]. Despite this, another study found that cement mixes containing up to 21% bentonite showed improved compressive strength at 56 and 90 days [83]. The flexural strength of cementitious composites with bentonite clay as a partial cement replacement shows almost no improvement and higher doses of bentonite can reduce the strength [86][87][88].

2.1.4 Environmental Impact (EIA) and Sustainability Assessment (SA)

In the present research, the created samples are first evaluated based on the toxic degrees of their elements, considering immunological and epidemiological effects (Table 2.4). The EIA analysis in this study is implemented in MATLAB 2019b (Table 2.5).

Table 2. 4 The toxicology of prepared sample scoring and their chemical formulas. (very speculative)

Additive	Formula	Elements	Toxic level	Reference
FA	Si(6), Al(1), Na(2), H_2O(339)	Si, Al, Na, H, O	Al=5, Si=3, Na=2, H2O=0, Li=4, Mg=4	[89], [90]
LAP	$Na0.7Si_8Mg5.5Li0.3O20(OH)_4$	Na, Si, Li, O, H		[90], [91]
BENT	$(Na,Ca)0.33(Al,Mg)2Si_4O_{10}(OH)_2•nH_2O$	Na, Si, Al, Mg, Ca, O, H		[67], [90]

Table 2. 5 The stages of EIA in this research.

No.	Stage	Descriptions
1	Calculation of Environmental Impact Scores	To assess the environmental impact of different mixtures, environmental impact scores are assigned to each chemical element present in the mixture. The following equation is used to calculate the environmental impact score (EIS) for a given element: EIS = ∑ (C_i * S_i)

		C_i: Represents the percentage of the element in the mixture, S_i: Represents the environmental impact score assigned to that element. How is evaluated it is not true generally.
2	Sample Description and Calculation of Environmental Impact	For each sample, the environmental impact is calculated based on the chemical composition using the previously defined equation: EIS_sample_i = (C_Al * S_Al) + (C_Si * S_Si) + (C_Na * S_Na) C_Al, C_Si, and C_Na represents the percentages of Aluminum, Silicon, and Sodium in the sample, respectively. S_Al, S_Si, and S_Na represents the environmental impact scores assigned to Aluminum, Silicon, and Sodium, respectively. How is evaluated it is not true generally.
3	Calculation of Total Environmental Impact	To obtain an overall measure of environmental impact for each sample, the individual environmental impact scores of Aluminums, Silicon, and Sodium are summed up: Total_EI_sample_i = EIS_sample_i The Total_EI_sample_i represents the total environmental impact score for sample i.
4	Visualisation and Analysis	The obtained environmental impact scores are visualised using a bar graph. Each sample is represented on the x-axis, while the corresponding total environmental impact score is displayed on the y-axis. The bar graph provides a comparative analysis of the environmental impacts of different samples.

2.2 Aging of Natural Fibers and Their Use in Cementitious Composites

Concrete, primarily composed of cement, is the most widely used material in construction activities. It is estimated that concrete is used at a rate of one ton per person on Earth [92]. However, concrete is known to be a brittle material with low tensile strain and strength capacities [93]. Its low toughness and susceptibility to cracking limit its applications. The propagation of cracks further deteriorates its mechanical properties, compromising the safety of structures [94][95]. Figure 2.3 illustrates the development of cracks in concrete structures. Consequently, concrete can only be used in non-critical sections with small gravity loads [96]. For critical infrastructure development, concrete requires reinforcement

to be effective. Typically, this is achieved by embedding deformed steel bars or welded wire fabric into freshly cast concrete [97].

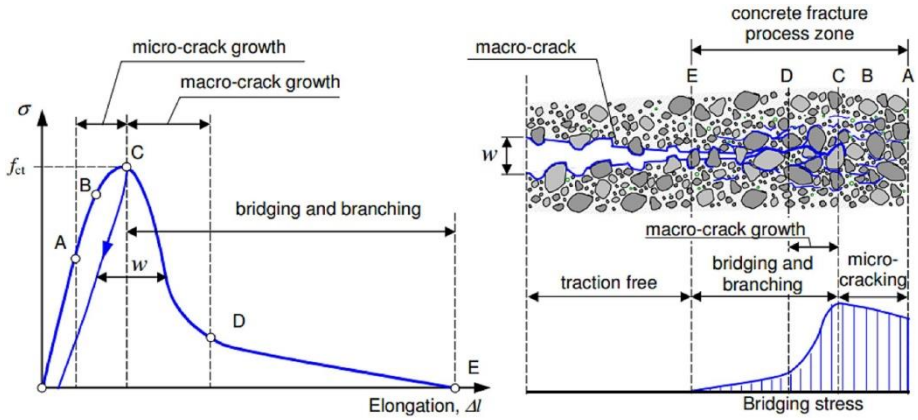


Figure 2. 3 The process of formation of cracks in concrete based on the progression of time [98]

The following are the issues related to this type of reinforcement: their costs are relatively high as compared to other rebars, they are prone to corrosion, and are quite dense. Also, steel production has been widely known to call for large quantities of energy and therefore lowers the well-being of our environment. Industrialized production of iron and steel is one of the most energy and carbon intensive ones across the globe and the manufacturing processes are still coal-dependent and contribute immensely to the emission of CO_2 [99]. The manufacturing industry across the globe is currently emitting up to 40 percent of the overall global emissions as estimated by the IEA, with the iron and steel sector manufacturing industry representing the highest emissions of over 27 percent of carbon emissions from manufacturing industries globally [100][101].

Keeping in view the problems mentioned above, there is a need to apply the concept of reducing, reusing, and recycling in the construction industry and material fabrication [102] to cater to the growing environmental challenges in a more sustainable way [103]. Therefore, the construction industry's interest in innovative sustainable solutions from recycling and reusing processes with minimum energy intake and reduced carbon emissions has been increasing day by day [104]. In this sense, fibers are getting their way as a promising alternative to steel reinforcement [105]. Cementitious materials incorporated with certain types of fibers have shown an improvement in many properties of the material, including toughness, energy absorption capacity, post-cracking residual strength, decreased shrinkage potential, and enhanced durability [106]. Previously, many types of short fibers, like asbestos, steel, glass, and polymeric, have been employed as reinforcing elements in cement-based composites. These fibers, besides their advantages, have shown some disadvantages,

such as detrimental health effects associated with asbestos, high costs associated with steel and polymeric fibers, as well as a notable environmental footprint [107][108].

In cementitious composites, some alkalis that are contained in the materials take on a major role during the process of cement hydration. During cement hydration, it releases calcium ions and hydroxide ions to form a paste with the name of calcium hydroxide, commonly referred to as Portlandite. This is due to the high of alkalinity of the cement paste that is an essential factor for density of the Calcium Silicates Hydrates (CSH) gel [109]. The elements such as sodium and potassium, can dissolve in cementitious mixtures to form NaOH and KOH [110], [111]. Some of these alkalis can prompt to hydrate at a faster pace, hence improving early-age strength. Nevertheless, the use of high concentrations of NaOH and KOH may cause some negative effects, like the Alkali-Silica Reaction (ASR), which is the reaction of some reactive silica in the aggregates with these chemical reagents. The gel formed due to ASR, when exposed to moisture swells forcing more pressure internally, leading to cracks and overall weakening of the concrete [112]. Therefore, it is important to study the effects of alkaline environment on the properties of the fibres. The present thesis focuses on two important issues described earlier namely replacing cement with waste and clay materials and studying the behaviour of natural fibres in alkaline environments from the perspective of their use in cementitious materials.

2.2.1 Jute Fiber and its Use in Cementitious Composites

Jute is an abundant, biodegradable, and natural fiber and because of these attributes, it can be a worthy green option for synthetic fiber reinforcement and also offers unique advantages when incorporated into cementitious composites. The use of jute in conjunction with cementitious composites is certainly the focus of the current modernization of the construction industry in terms of utilizing a sustainable approach to using renewable materials in the creation of construction elements that possess high durability and sustainability. Furthermore, it has several important applications [113], [114]. Jute is an important bast fiber which is largely formed of cellulose and other non-cellulose fragments. The non-cellulose parts are lignin, pectin, and hemicellulose [115]. Because of this, jute fiber has several characteristics that make its use in concrete complex and require careful consideration, especially in the way the fiber reacts in an alkaline environment and the fact that concrete is an alkaline material [116]. Under such conditions, it is a common phenomenon that jute fibers tend to undergo degradation because of hydrolytic action on hemicellulose and lignin present in the fiber [117]. It may therefore cause the reduction of

the mechanical properties of the technical jute fiber, generating dust or the elementary fibers and in the long run, it leads to the weakness and loss of elasticity. Moreover, due to the inherent nature of the technical jute fiber, the alkaline environment of the cementitious matrix can cause swelling and disintegration of the fiber [118], as a result, the utilisation of technical jute fiber, when used as the reinforcement in cementitious composites, requires special pre-treatment [119].

To tackle this issue, researchers have examined and executed various treatments, such as the application of alkali-resistant coatings or modifications to the fiber structure, to boost the durability and stability of technical jute fibres in alkaline environments, thus ensuring their longevity and efficacy in composite applications. On the other hand, while dealing with alkalis such as NaOH, KOH, and $Ca(OH)_2$, their concentrations and reactions must be carefully handled to ensure that the cementitious composites exhibit the desired performance and durability. Natural fibers have gained more interest because of their mechanical properties and low cost as well as the growing demand for environmental concerns [120]. Cellulosic fibers used in the fabrication of fiber-reinforced cementitious composites require little energy to process [121]. One of the uses of cellulosic fibres in the construction and building industry is aimed at reinforcing cementitious composites while replacing traditional reinforcing materials thus reducing the dependence on traditional materials to reduce carbon emissions, decrease waste generation, and improve the sustainability of construction materials. These fibres provide a promising approach to meeting environmental challenges and contributing to the environmentally friendly practices in the construction materials. A study conducted by Shireesha revealed that about 26% of plant fibres were used in the construction sector, the second highest after the textile industry [122]. Cementitious composites having short and long cellulosic fibres affect positively the flexural strength of the matrix [120]. In a study conducted by Onuaguluchi et al., the optimal bending strength of cellulosic fibers in a cementitious composite was found to be 8-10% [123]. Ramakrishna and Sundararajan revealed that the toughness of cement mortar reinforced with cellulosic fibers increased 3-18 times that of the samples without reinforcement [124]. In a recent study, jute fiber was pretreated by combining hot alkali solution soaking and chloroprene latex impregnation and was employed in the cementitious composite as a reinforcement. The results revealed that the mechanical properties including flexural strength, and splitting tensile strength increased considerably whereas the compressive strength remained unsatisfactory [125].

Cellulosic fibers, like jute, show improved durability in alkaline environments when modified with alkali and polymer, forming a protective coating. This reduces fiber mineralization, preserving tensile strength. Therefore, applying the treated fibers in alkaline environments can be useful for many structural and non-structural applications in some industries such as buildings [119]. Cellulose activation typically involves alkali treatment, commonly with sodium hydroxide due to its availability and cost-effectiveness. Mercerization using NaOH causes cellulose fibers to swell, morphologically change, and dissolve residual hemicelluloses, albeit with risks of oxidative degradation. Control over activation hinges on alkali concentration and temperature, with diluted solutions widening micropores and higher concentrations splitting fibrillar aggregates. Concentrated solutions lead to increased swelling and partial cellulose transformation [126]. Alkaline mercerization causes morphological alterations in cellulosic fibers. Morphological changes in cellulose fibers are first caused by swelling and then by longitudinal fibers. Shrinkage produces circular structures after elliptic structures first [126]. Changing of morphological structure into a circular one can be useful for increasing the mechanical properties of some types of concrete [127].

2.2.2 RSM modelling

This study adopts RSM (Response Surface method) modelling as statistical data analysis approach that involves creating a mathematical model to predict how the response changes based on variations in input variables. The methodology also facilitated the identification of the most influential factors and their interactions, which would be pivotal in steering the tensile strength to desired levels. The general second-order polynomial equation applied in RSM for this three-factor system is expressed as [128]:

$$y=\beta_0+\beta_1x_1+\beta_2x_2+\beta_3x_3+\beta_{12}x_1x_2+\beta_{13}x_1x_3+\beta_{23}x_2x_3+\beta_{11}x_1^2+\beta_{22}x_2^2+\beta_{33}x_3^2 \quad \text{Eq. (2.1)}$$

x_1: Time

x_2: Alkali type (coded numerically for different types)

x_3: Alkali concentration

y: represents the predicted response (tensile strength).

β_0 is the constant term.

β_1, β_2, and β_3 are the linear coefficients.

β_{12}, β_{13}, and β_{23} are the interaction coefficients.

β_{11}, β_{22}, and β_{33} are the quadratic coefficients.

In this research, Design Expert 7.0.0 is applied to implementing the RSM analysis.

Chapter 3

3 Materials and Methods

This chapter details the materials and methodologies employed in preparing this thesis. The first part focuses on the aging of jute fibers in an alkaline environment. This section outlines the preparation of jute fibers in various alkali solutions with different concentrations and treatment durations. Post-treatment, jute fibers were assessed for weight loss, tensile strength, and thermal properties. The aim is to evaluate the durability of jute fibers in cementitious composites for future applications.The second part of the thesis is related to the replacement of cement with inorganic additives including waste materials and clays and the reinforcement of cement based mixtures with jute fibers. For this purpose, fly ash, laponite and bentonite were used as partial replacement of cement with varying percentages. Based on the outcomes, new cement mixtures were prepared with partial replacement of cement by fly ash (5%) and laponite (1%). The cement mixtures were reinforced with jute fibers with varying percentages. Samples made were tested against 3-point bending stress, compressive strength and toughness properties. Particle size distribution of the ingredients used for preparing cement mixtures were also realized to understand their behavior in the cement mixtures. The purpose of this part is related to the economy of cement in cement based composites and the adoptability of jute fibers as reinforcement in the cement based composites.

3.1 Aging of Jute Fiber in Alkaline Environment

3.1.1 Materials and Instruments Used

This section describes the materials and methodology for treating jute fibers in an alkaline environment and assessing their properties. Tables 3.1 and 3.2 list the materials used in this study and the instruments for measuring certain properties. The materials were sourced from different suppliers, and the instruments were available at the Department of Material Engineering, Technical University of Liberec.

Table 3. 1 Materials used for aging of jute fibers.

Material	Company
NaOH	Lach-Ner, Czech Republic
KOH	Lach-Ner, Czech Republic

$Ca(OH)_2$	Lach-Ner, Czech Republic
Jute Fiber	Saifan, S.R.O, Czech Republic

Table 3. 2 The applied instruments during this study.

Instrument	Company	Model
Universal Tensile Testing Machine (UTM)	Labor Tech	LAP TEST 2.010
Thermogravimetric Analyser (TGA)	Mettler Toledo	TGA/SDTA851e
Differential Scanning Calorimeter (DSC)	Mettler Toledo	DSC 3^+ Star Systém
Scanning Electron Microscope (SEM)	TESCAN	TESCAN VEGA3

3.1.2 Research Methodology

The steps involved in this study are illustrated in Fig. 3.1, showing the aging process of jute fibers in an alkaline medium in three steps: sample preparation and characterization, optimization using Historical Data Analysis Response Surface Methodology (HDA-RSM), and prediction system execution. The experimental and numerical assessments were conducted sequentially, focusing on data preparation, categorization, and modeling. Preparation involved selecting chemicals and substrates, followed by precise preparation of alkali solutions. Samples underwent controlled treatment for 7, 14, and 28 days, with careful monitoring. Rigorous sampling protocols ensured accurate analysis, promising insightful outcomes. The analysis included weight loss assessment for material degradation, tensile strength testing for mechanical integrity, and DSC and TGA for thermal properties. These methods collectively revealed the treatment impact on sample characteristics, enabling comprehensive evaluation. RSM was employed to systematically explore the parameter space for optimizing treatment conditions. Sensitivity analysis identified critical factors influencing outcomes, and guiding focus. Statistical assessment ensured the robustness and reliability of results. Through RSM, optimal factors were pinpointed, maximizing desired responses efficiently.

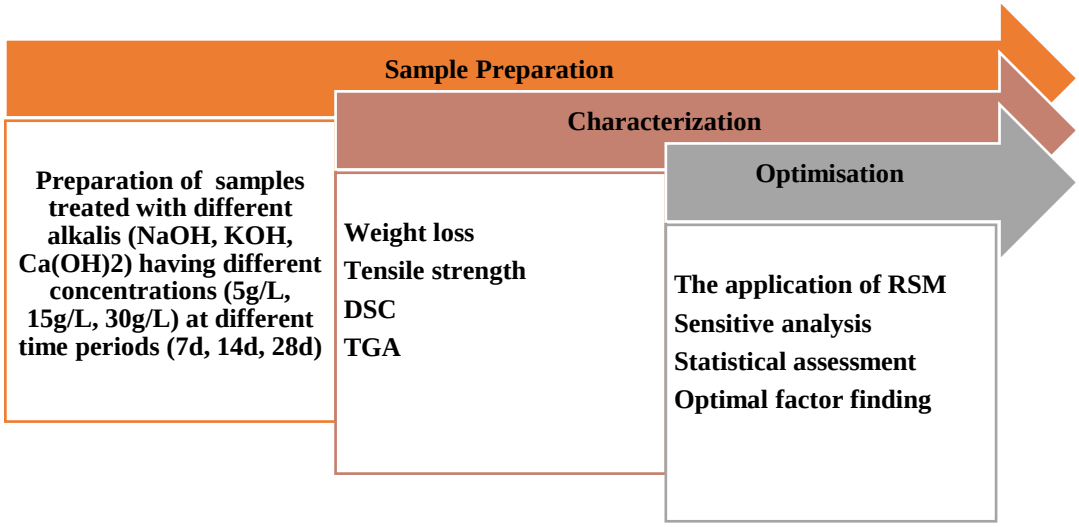


Figure 3. 1 The research roadmap of the present study including sample preparation, characterization, and optimization process.

A preparatory step involved was to obtain twenty threads of jute fiber, each with measurement of fifty centimeters. For preparation of alkali solution, the distilled water was used. Afterward, a 200ml container was used to soak the jute fiber in the prepared solution. The samples were then stored for 7, 14, and 28 days at 23 ^{o}C temperature. The samples were kept in the treatment for some time and after that, the samples were washed thoroughly with distilled water and then air-dried.

The stages of experimental sample preparation and data gathering in this study are shown in Fig. 3.2. In the experimental stages (Fig. 3.2), jute fibres along with solutions having different concentrations (5g/L, 15 g/L and 30 g/L) of NaOH, KOH and $Ca(OH)_2$ were prepared as described earlier. Therefore, it is important to emphasize that there is room for variance in the tests depending on three main factors: the kind of alkali, the alkali concentration, and the length of exposure. It's also important to remember that, to maintain uniformity across experimental conditions, all tests were carried out at room temperature. Furthermore, because of the significance of these factors, careful control and modification were used to clarify their individual and combined effects on the results of the experiment.

Fig. 3.3 presents that after sample preparation, three characterisations including TGA, SEM, and DSC are first carried out on the samples to observe the behaviour of jute technical fibres under varying thermal conditions followed by conducting the tensile strength test for each sample by the LAP TEST 2.010 instrument. The collected data are then evaluated to ind the impact of the process performance on the increasing of quality of samples. All experimental practices of this study are done based on ČSN EN ISO 2062 [129], ČSN EN ISO 5079 (*Textiles - Fibres - Determination of strength and ductility of individual fibres at break,*

2021), ČSN EN ISO 11358-1 [131], ČSN EN ISO 11357-1 [132], and ISO/TS 21383:2021 [133].

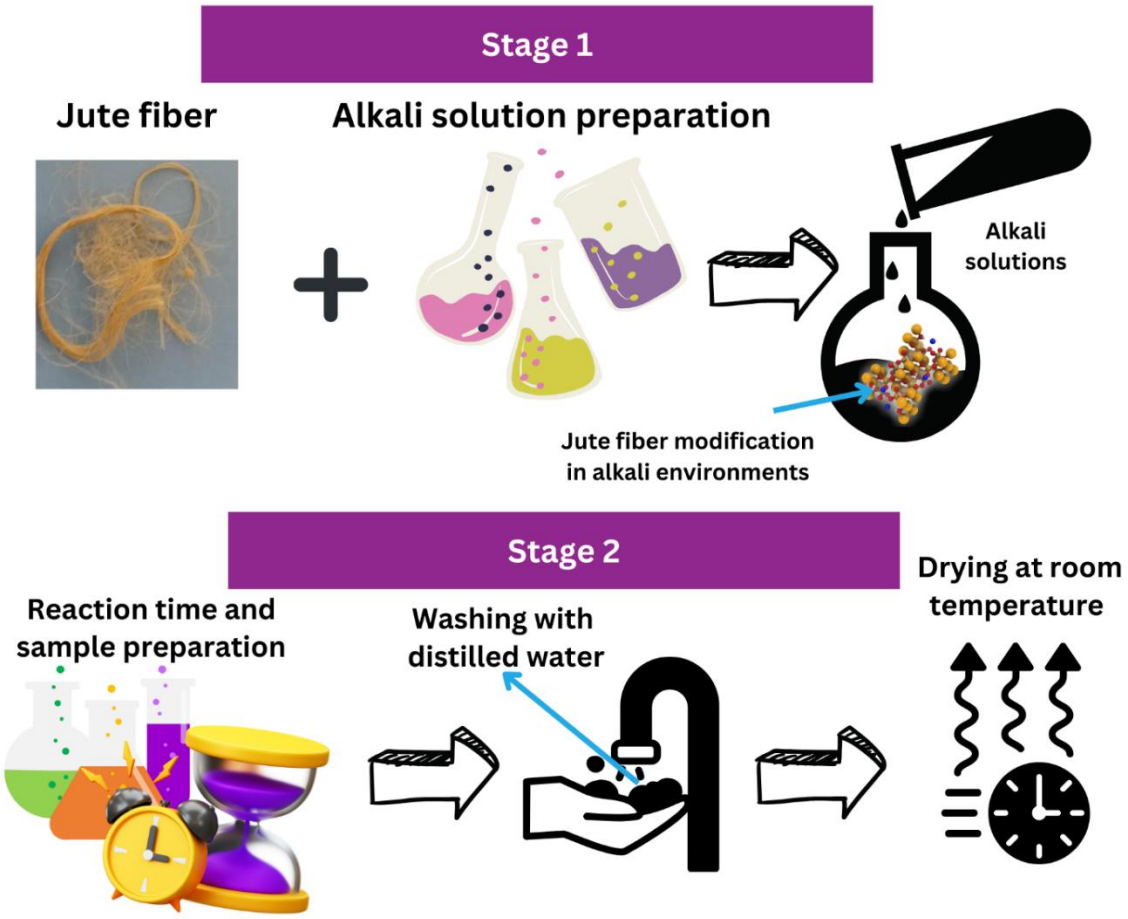


Figure 3. 2 The schematic plan of sample preparations in this study

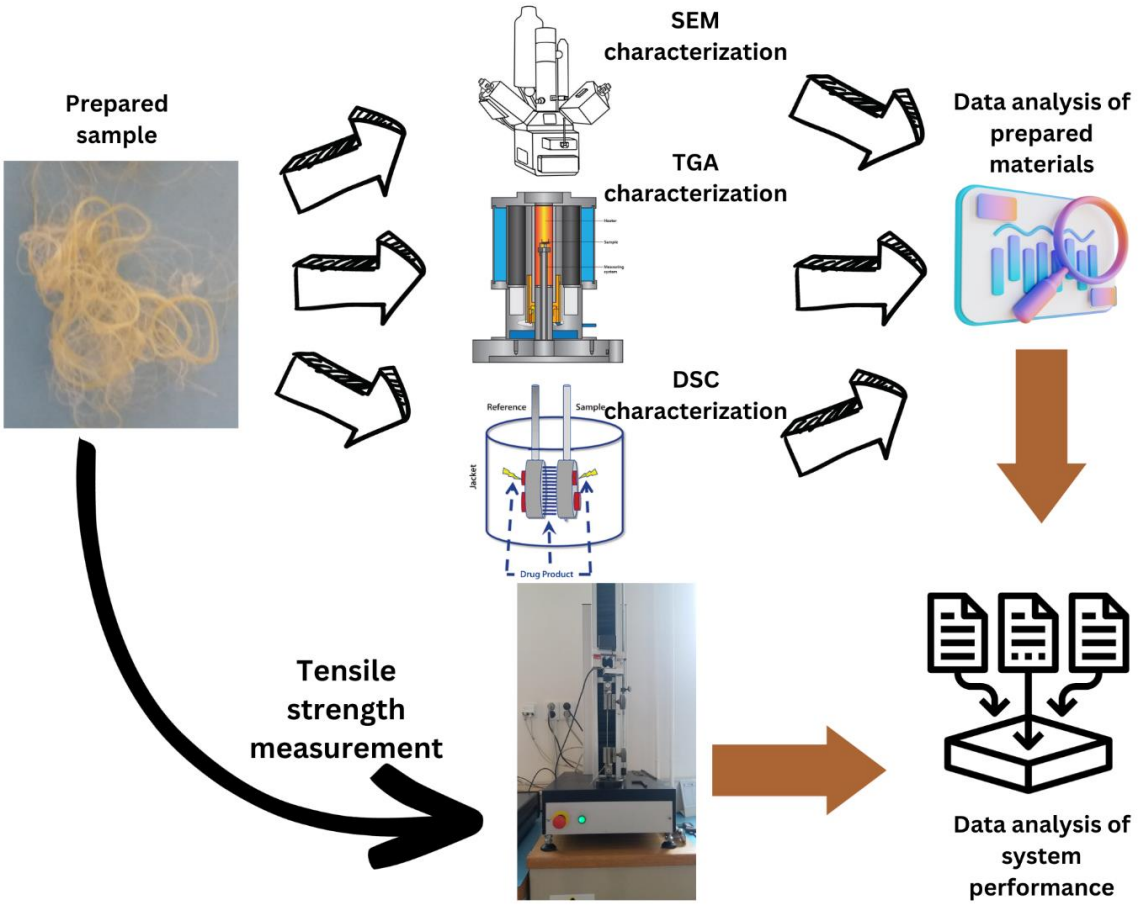


Fig. 3.3.

Figure 3. 3 The steps of various tests and analyses on the sample in this study

3.2 Partial Replacement of Cement by Inorganic Additives in Cement Mixture and Reinforcement with Jute Fiber

3.2.1 Materials and Instruments Used

In the present research all applied materials are summarised in Table 3.3 based on their specifications.

Table 3. 3 The specifications of applied materials in the study.

Material	Specification
Cement	Ordinary Portland Cement ČSN EN 197-1, Denmark
Fly ash	Fly ash for concrete as per DIN EN 450, Betoment OP Germany

Laponite RD	SYnL-1 (Synthetic layered silicate, Hydrous Sodium Lithium Magnesium Silicate), Clay Minerals Society Source Clays Repository P.O.Box 460130, Aurora, Colorado 80046-0130 USA
Bentonite	Bentonite Clay Ekokoza s.r.o, Czech Republic
Jute Technical Fiber	Saifan, S.R.O, Czech Republic

The instruments used in this research are listed in Table 3.4. Some of the applied instruments are related to cement paste performance assessment and some others are connected to characterisation of the prepared mixtures and ingredients.

Table 3. 4 The applied instruments in the study.

Device	**Specification**
Measuring Scale	Table Digital Accurate**,** Czech Republic
Mixer	KENWOOD XL TITANIUM, Great Britain
Vibrating Table	VSB-40 NS, Brio Harnice s.r.o., Czech Republic
Universal Testing Machine	Tira TEST 2300, Germany
Charpy Hammer LAB TEST	CHK 50J LABOR Tech, Czech Republic
SEM and EDS	VEGA3, TESCAN, Czech Republic
PAMAS SSBS particle counting system	PAMAS SLS-25/25, Germany

3.2.2 Research Methodology

The research roadmap of the present research is depicted in Fig. 3.4.

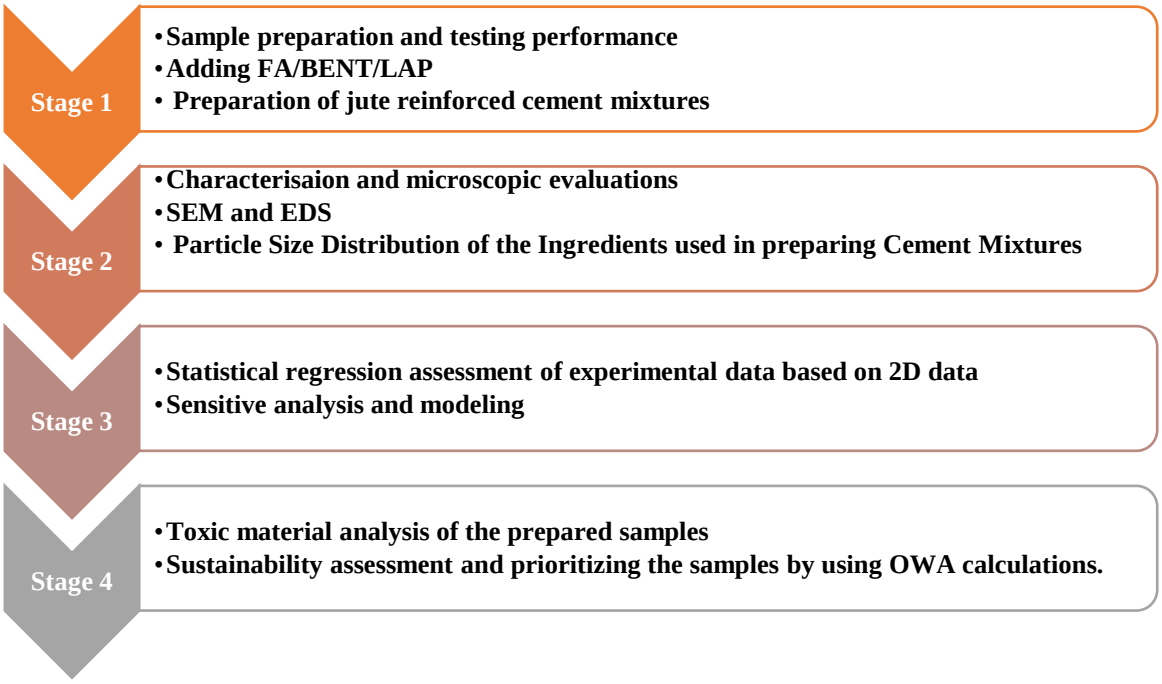


Figure 3. 4 The research roadmap of the investigation

Due to experimental activities in the present investigation, three protocols are applied for sample preparation using mixer (ČSN EN 1008 (732028))[134], determination of flexural and compressive strength of hardened mortars (ČSN EN 1015-11 (722400)) [135], and purpose of impact strength by the Charpy method (ČSN EN ISO 179-2 (640612)) [136]. For particle size distribution calculations, PAMAS SSBS particle counting system followed by ISO 4406 was utilized. The stages of sample preparation and experimental practices are shown in Figs. 3.5 and 3.6, respectively. According to Fig. 3.5, in the first step, different samples were mixed with individual formulation, demonstrated as per Table 3.5. It should be noted that in all the samples in Table 3.5, the Water to Binder Ratio (WBR) was equal to 0.4. The prepared samples were cast in simple rectangular and cube shapes (30mm*30mm for cubes and 140mm*30mm*10mm for rectangular-shaped samples) following the shaking of the samples for uniform distribution and compaction. The samples were then cured for 28 days under standard conditions. Based on Fig. 3.6, the applied materials were characterized by both SEM and EDS tests. Likewise, the cured samples were utilized for three mechanical tests, including 3-point bending, toughness, and compression tests in the lab.

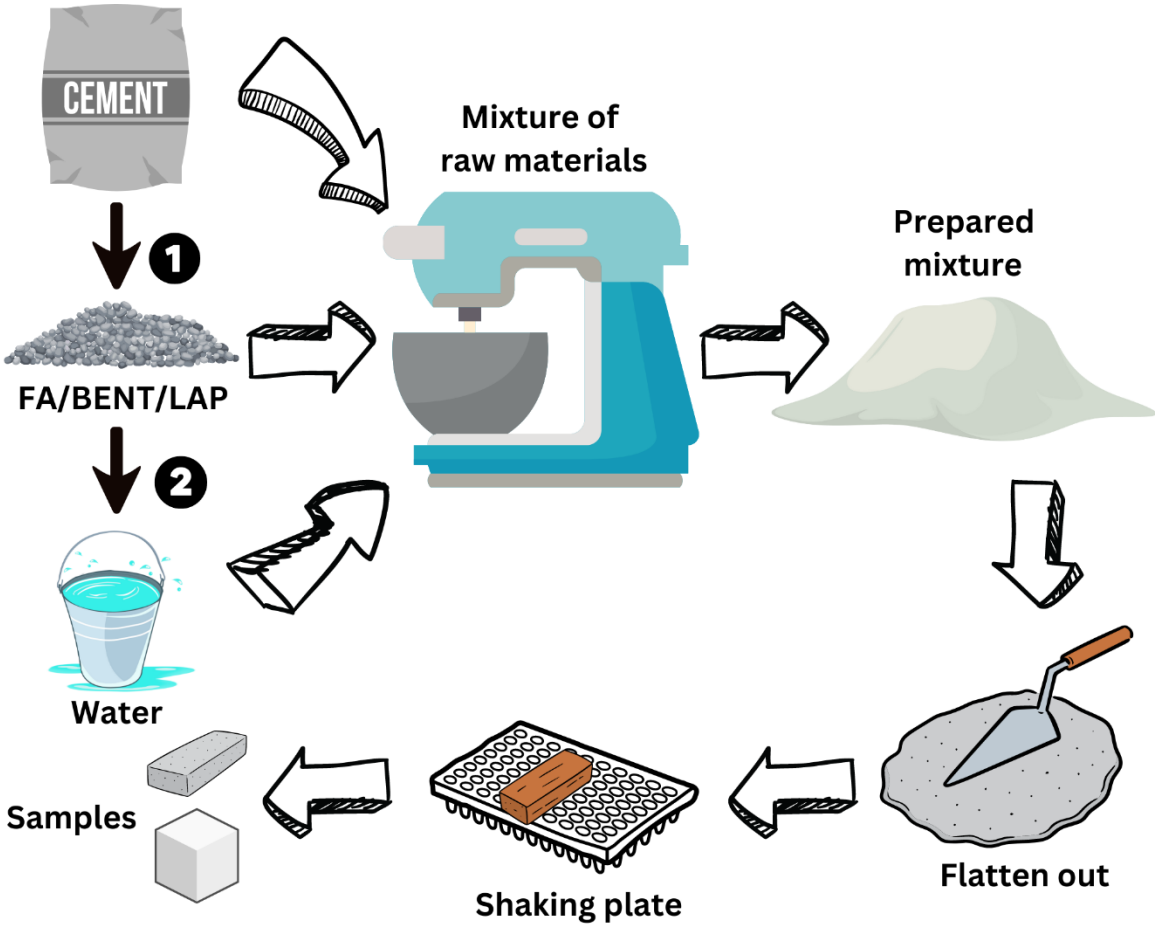


Figure 3. 5 The process of sample preparation in this research.

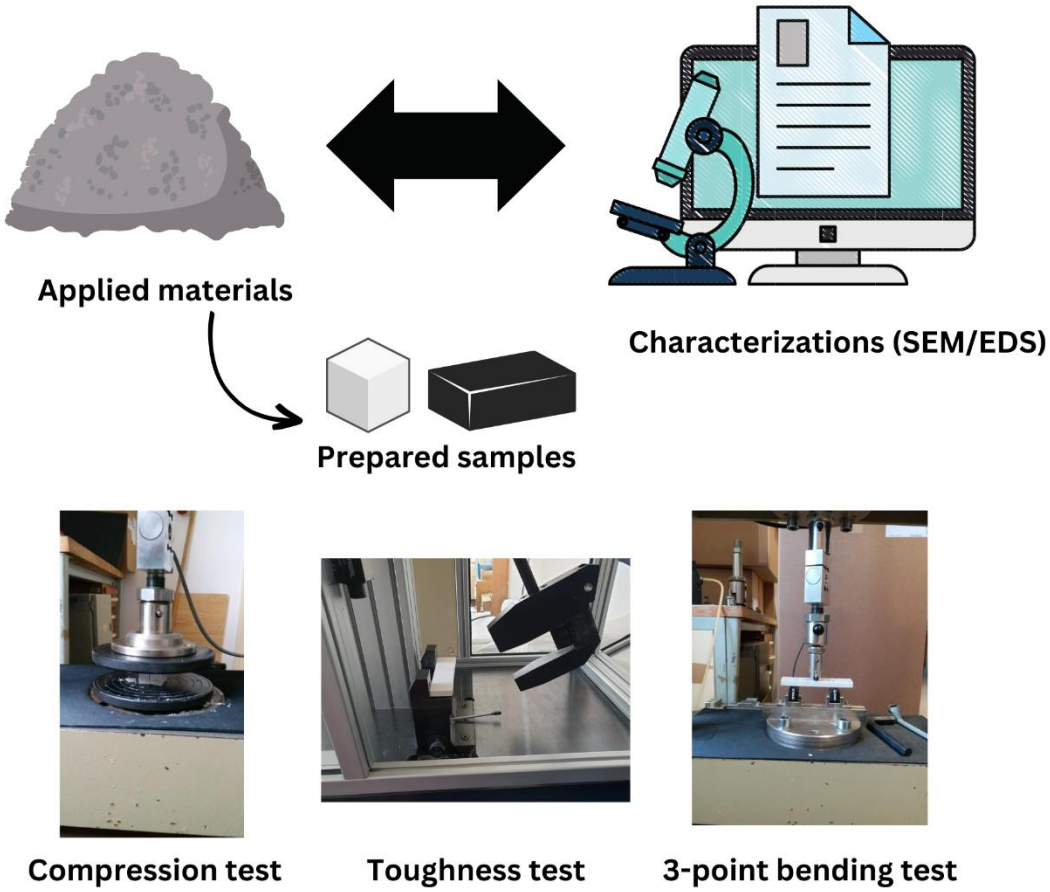


Figure 3. 6 The experimental performance assessment stages of cement paste in the investigation.

Table 3. 5 Samples with different fillers in the present study.

Sample name	Fly Ash (FA)	Laponite (LAP)	Bentonite (BENT)
Sample 1 (S1)	5%	0	0
Sample 2 (S2)	10%	0	0
Sample 3 (S3)	20%	0	0
Sample 4 (S4)	0	1%	0
Sample 5 (S5)	0	3%	0
Sample 6 (S6)	0	5%	0
Sample 7 (S7)	0	0	1%
Sample 8 (S8)	0	0	3%

Sample 9 (S9)	0	0	5%

In the following, the obtained results of experimental practices are modelled with linear regression models (due of available data). Regression analysis was conducted using Excel software. First, the data were categorized, and a curve fitting was done between different percentages of fillers and cement paste functions separately. After quantifying the Environmental Impacts (EIs), the nine prepared samples (Table 3.5) were evaluated concerning sustainability criteria, including economic and EI performance criteria [137].

In the next step, cement mixtures having fly ash and laponite as partial replacements of cement and reinforced with jute fibers (approximately 12 mm in length) were realized. Cement was replaced by 5% fly ash and 1% laponite in each sample. Jute fiber was added to the cement mixture in fractions of 0.2wt.%, 0.5wt.%, 0.7wt.% and 1wt.%. The prepared samples were tested for 3-point bending stress, compressive strength, and toughness properties. For this purpose, cement was partially replaced by fly ash (5%) and laponite (1%) with jute fibers. The prepared samples were tested against 3-point bending stress, compressive strength and toughness. Table 3.6 represents the samples with different percentages of the jute fibers.

Particle size distribution of cement, fly ash, laponite, and bentonite, a fixed amount of each material (in our case, 0.299 g) was mixed in 100 ml of isopropyl alcohol. The mixture was mixed well and was put in PAMAS particle counting system. Stirring in the system was adjusted accordingly and three readings for each sample were taken.

Table 3. 6 Samples with different percentages of jute fiber in the present study.

Sample name	**Fly Ash (FA)**	**Laponite (LAP)**	**Jute Fiber**
Sample 1 (S1)	5%	1%	0.2%
Sample 2 (S2)	5%	1%	0.5%
Sample 3 (S3)	5%	1%	0.7%
Sample 4 (S4)	5%	1%	1%

Chapter 4

4 Results and Discussion

4.1 Aging of Jute Fiber in Alkaline Environment

The weight loss of jute fibers treated with various concentrations of NaOH, KOH, and $Ca(OH)_2$ over different time durations is illustrated in Fig. 4.1. It is evident from Fig. 4.1a that weight loss increases with both concentration and duration. The highest weight loss is observed at a 30g/L concentration over 28 days, reaching up to 19.17%. Even after 7 days, NaOH causes significant weight loss, with 13.13% at a 30g/L concentration. The pattern for KOH, as shown in Fig. 4.1b, is slightly different, with no consistent trend, but weight loss percentages are relatively similar across different concentrations, especially for longer durations. In contrast, $Ca(OH)_2$ shows the lowest weight loss percentages across all conditions compared to NaOH and KOH, as indicated in Fig. 4.1c. Jute fiber consists mainly of cellulose (61-71.5%), hemicellulose (12-20.4%), and lignin (11.8-13%) [138]. Alkali treatment causes leaching of lignin and/or hemicellulose, leading to weight loss [139], as further endorsed by Kataoka and Luz (2022) [140]. The alkali treatment disrupts the hydrogen bonding between the hydroxyl groups in cellulose, hemicellulose, and lignin causing the separation of the fiber bundle into individual fibers [141], [142]. Lignin and hemicellulose are known to impede the matrix-fiber bonding in composite materials; hence, their removal can enhance the mechanical properties of the fiber [143]. During the alkali treatment of the fibres, hydrogen bonding in the network structure is disrupted leading to increased surface roughness and removing lignin, hemicellulose, and other impurities [144]. Moreover, eliminating these components exposes the cellulose content of the fiber, which is primarily responsible for its tensile strength. In natural fibers, cellulose content and the orientation of microfibrils in the cell wall are mainly responsible for the strength and stiffness [145]. Alkaline treatment of natural fibers increases surface roughness for enhanced mechanical interlocking as well as the amount of cellulose exposed on the surface of the fibre, therefore, enhancing the possible reaction following a durable effect on the mechanical properties of the fibre [146], [147]. Thus, alkali treatment is not only responsible for some weight loss of the fibres but also has an indirect indication of the potential enhancement in the fibre's performance when incorporated into composite materials. For instance, improvements in tensile and fatigue properties were noted for 1% and 5% alkali

treatment whereas, for a higher concentration of 10%, no improvements in the mechanical properties of the fibre were observed [148].

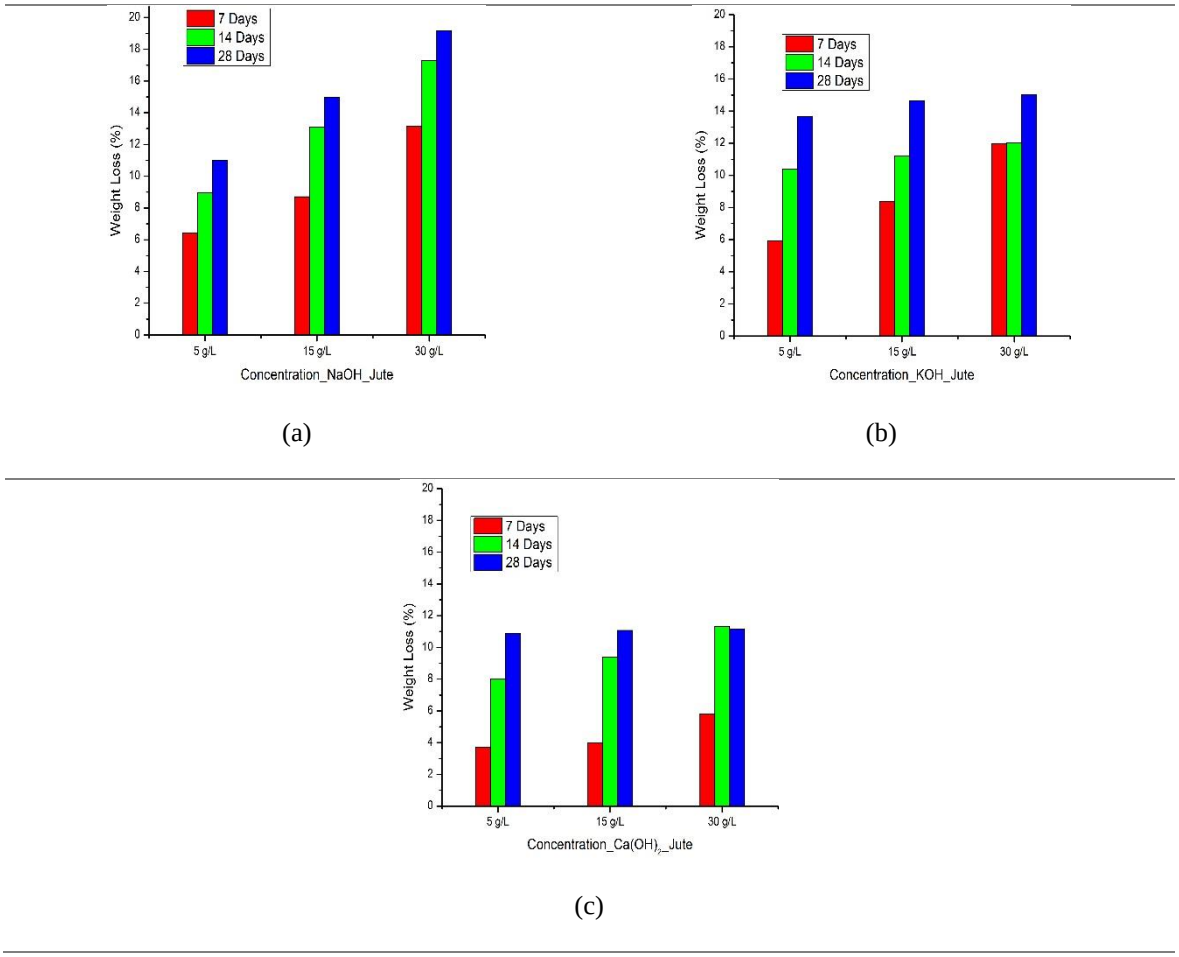
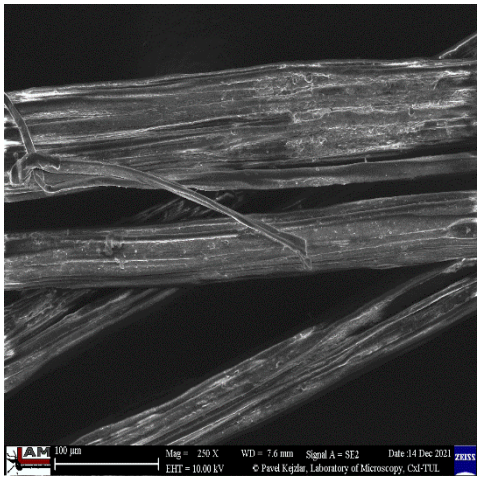
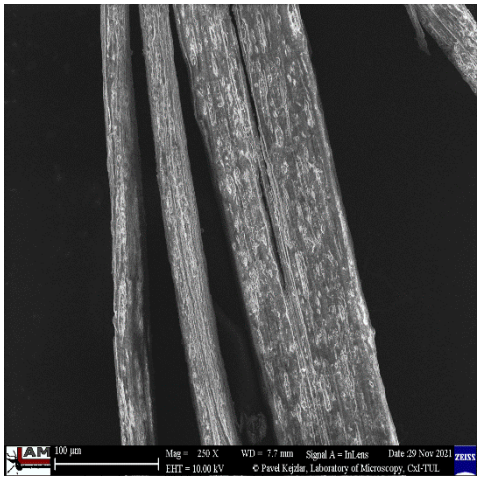


Figure 4. 1 The Weight loss (%) of different alkali treated jute fibres by (a)NaOH, (b) KOH and (c) $Ca(OH)_2$.

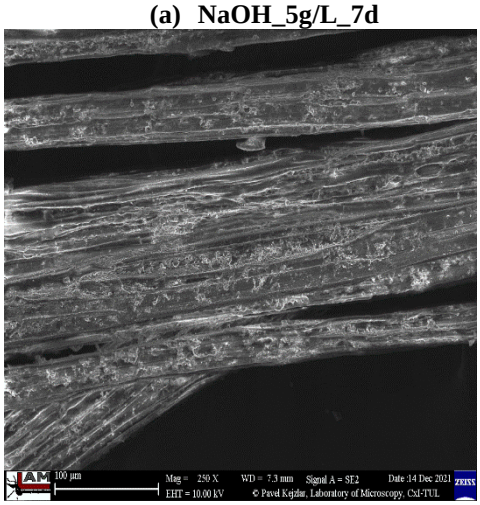
Fig. 4.2 presents the results of SEM characterisations of jute fibres based on different alkali solutions with different concentrations. According to Fig. 4.2, all SEM images are reported in 250 X.



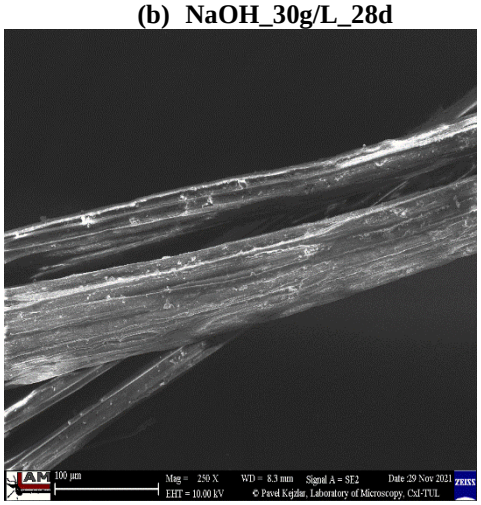
(a) NaOH_5g/L_7d



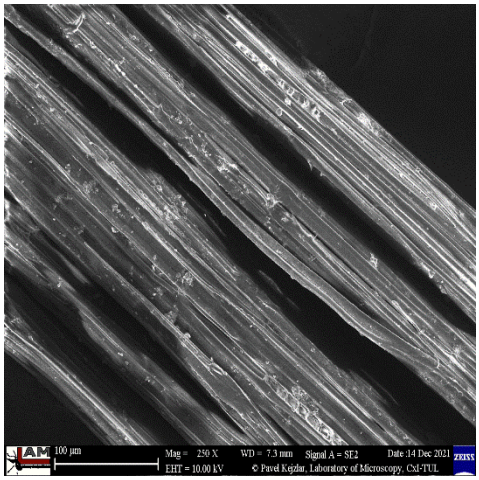
(b) NaOH_30g/L_28d



(c) $Ca(OH)_2$_5g/L_7d



(d) $Ca(OH)_2$_30g/L_7d



(e) KOH_5g/L_7d

Figure 4. 2 The SEM outputs of different alkali-treated jute fibres (a,b) NaOH (c,d) $Ca(OH)_2$ (e) KOH.

The outcomes of OFAT experiments are presented in Fig 4.3. Based on Fig.4.3a, at a shorter duration of 7 days, the tensile strength appears to peak at 15g/L NaOH concentration (79.66

MPa) and then decrease slightly at 30g/L (60.77 MPa). This suggests that there might be an optimal alkali concentration for enhancing the tensile strength within a short treatment period. However, for a duration of 14 days, the tensile strength is highest at 30g/L (181.27 MPa) compared to both 5g/L (84.2 MPa) and 15g/L (58.68 MPa). At 28 days, the 15g/L concentration again exhibits the highest tensile strength (225.05 MPa), with a drop at 30g/L (84.73 MPa) and a lesser value at 5g/L (140.34 MPa) as shown in Figs. 4.2a-b. This might suggest that prolonged exposure to very high alkali concentrations could adversely affect the tensile strength as previously mentioned by [149], while moderate concentrations (15g/L) seem optimal. For the 5g/L NaOH concentration, a noticeable increase in tensile strength with time can be observed, moving from 41.62 MPa (7 days) to 84.2 MPa (14 days) and then to 140.34 MPa (28 days). This suggests that longer exposure to a mild alkali solution significantly benefits the tensile properties of the jute fibres. According to a study conducted by Hoyos et al., fique fibres treated with 5w/v% NaOH solution for 24 hours showed an increase in tensile strength of the fibres [150]. Conversely, for the 30g/L concentration, there's a fluctuation in strength. The strength first increases from 60.77 MPa (7 days) to 181.27 MPa (14 days) but drops to 84.73 MPa (28 days), reinforcing the idea of possible damage with prolonged high-concentration treatments. The 15g/L treatment displays a steady increase with time: 79.66 MPa (7 days) to 58.68 MPa (14 days) and then a significant jump to 225.05 MPa (28 days). The decrease from 7 to 14 days might require further investigation.

Based on Fig. 4.3b, For the 7-day duration, the tensile strength peaks at the 30g/L KOH concentration (82.67 MPa). The 15g/L concentration (49.05 MPa) shows a decrease compared to the 5g/L concentration (69.38 MPa) as shown in Fig. 4.2e. This suggests that, in a short treatment time, the jute fibres might respond better to higher concentrations of KOH. At the 14-day mark, the tensile strength is highest for the 15g/L concentration (237.58 MPa), followed closely by the 5g/L (194.81 MPa) and then a significant decrease at 30g/L (103.7 MPa). This indicates an optimal response at a moderate alkali concentration for this treatment duration. By 28 days, the tensile strengths are fairly close across the three concentrations: 130.7 MPa (5g/L), 131.5 MPa (15g/L), and 163.06 MPa (30g/L). This indicates a more uniform response to KOH treatment over an extended period, with a slight advantage for the highest concentration. For the 5g/L concentration, the tensile strength steadily increases from 69.38 MPa (7 days) to 194.81 MPa (14 days), then slightly decreases to 130.7 MPa (28 days). This could suggest a plateau or limit to the fiber enhancement after

a certain treatment time. The 15g/L concentration starts with 49.05 MPa (7 days), surges to 237.58 MPa (14 days), and then slightly decreases to 131.5 MPa (28 days). This again suggests a potential plateau effect after two weeks. The 30g/L concentration shows a variable trend: 82.67 MPa (7 days), 103.7 MPa (14 days), and 163.06 MPa (28 days). The increase from 14 to 28 days might suggest that longer treatments are beneficial at high concentrations, but not as effectively as at the 5g/L or 15g/L levels.

Based on Fig.4.3c, at 7 days, the tensile strength peaks at the 15g/L concentration of $Ca(OH)_2$ (67.4 MPa) as shown in Fig. 4.2c and 4.2d. The strength is lower at 5g/L (51.48 MPa) and a considerable decrease in tensile strength can be observed at 30g/L (41.41 MPa). This might suggest that, for short durations, a moderate concentration is optimal. At 14 days, the 30g/L concentration gives the highest tensile strength (111.28 MPa), more than the 5g/L (74.38 MPa) and 15g/L concentrations (62.73 MPa). This indicates that the fibres benefit from a higher alkaline concentration with slightly longer treatment [151]. By 28 days, the tensile strength at 15g/L (95.92 MPa) is higher than both the 5g/L (67.75 MPa) and 30g/L concentrations (86.72 MPa), suggesting that prolonged exposure to an extremely high concentration might not be as effective as a moderate one. At the 5g/L concentration, there's a progressive increase in tensile strength from 51.48 MPa (7 days) to 74.38 MPa (14 days), and a minor decrease to 67.75 MPa (28 days). This indicates that the effect of a mild alkali solution may plateau after two weeks. The 15g/L concentration sees an initial increase from 67.4 MPa (7 days) to 62.73 MPa (14 days), and then another increase to 95.92 MPa (28 days). This nonlinear response suggests that the fibres may undergo different mechanisms of interaction at this concentration over time. For the 30g/L concentration, the tensile strength first decreases from 41.41 MPa (7 days) to 111.28 MPa (14 days) and then drops slightly to 86.72 MPa (28 days). This fluctuation indicates that longer exposure times at high concentrations can lead to variable outcomes, with potential damage or saturation effects [152].

Jute fibres demonstrate varied tensile strengths based on alkali type, concentration, and treatment duration. While NaOH-treated fibres emphasise the necessity of balancing concentration and time to maximise tensile strength, the KOH series showcases distinct behavioural patterns. The $Ca(OH)_2$ treatments further underscore these differences, with the peak tensile strength achieved at a 30g/L concentration over 14 days. These variances across alkali types underline the pivotal role of alkali selection in treatment outcomes. Some recent

studies indicating different treatments of various cellulosic fibres with alkalis include [153]–[162].

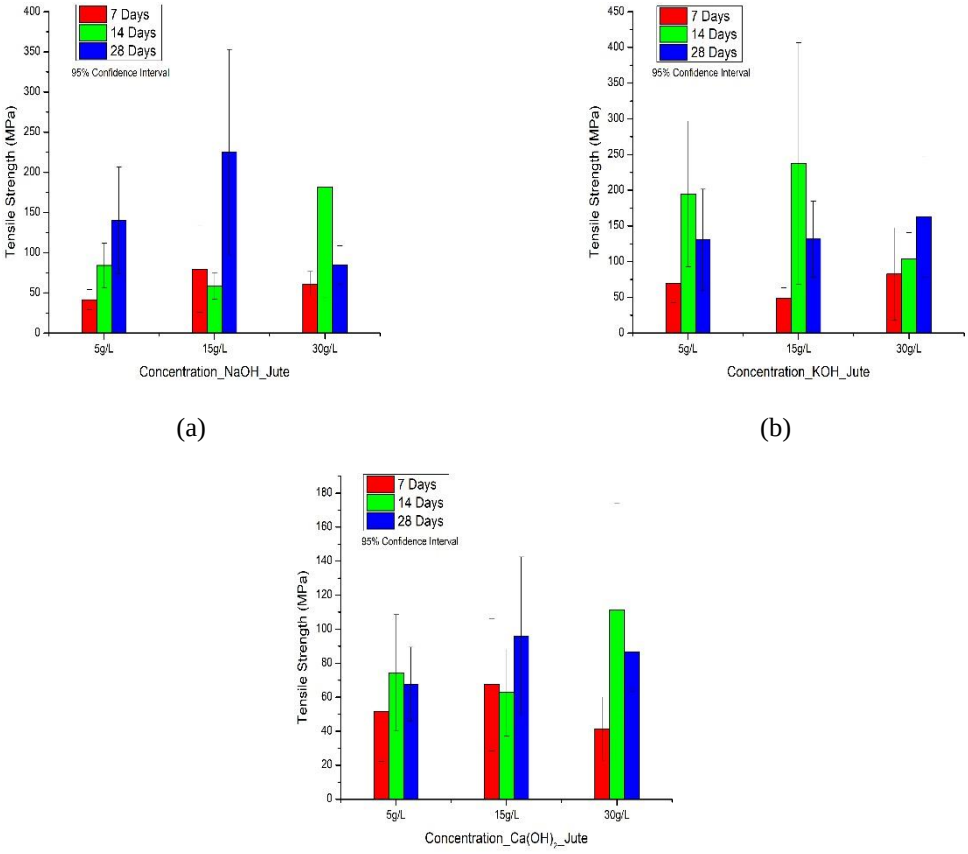


Figure 4. 3 The tensile strength of jute fibres treated with different alkalis, concentrations, and time periods (a) NaOH (b) KOH (c) $Ca(OH)_2$.

Fig. 4.4 presents the DSC curves of all the samples. Before 100 ºC, there is one single peak of all the samples. By combining with the following analysis of TGA, it is caused by moisture evaporation [163]. In the temperature range from 300 ºC to 400 ºC, DSC curves of all the samples experience a fluctuation. By combining with the following analysis of TGA, the fluctuation is caused by thermal decomposition.

The endothermic peaks, associated with energy-absorbing processes such as melting or evaporation [164], appear to have somewhat similar behavior for the NaOH-treated jute fiber and the KOH-treated sample. The exothermic peaks that is usually related to energy-releasing processes such as decomposition or oxidation [165] have also a somewhat similar trend for NaOH-treated and KOH-treated samples with varying specific temperatures and intensities. In contrast, $Ca(OH)_2$-treated fibres seem to undergo different thermal events, as indicated by exclusively exothermic reactions. This might indicate that $Ca(OH)_2$ treatment

significantly alters the jute fibre's composition or structure. The $Ca(OH)_2$-treated sample shows higher heat flow values (more significant reactions) compared to the others, suggesting more pronounced changes or reactions in this sample. The peaks above 300°C in all samples likely relate to cellulose decomposition [163], [166]. The DSC data suggests that the alkali treatment indeed affects the thermal behavior of jute fibres [167], with $Ca(OH)_2$ treatment showing the most distinct differences. It has almost little or no effect on the jute fiber.

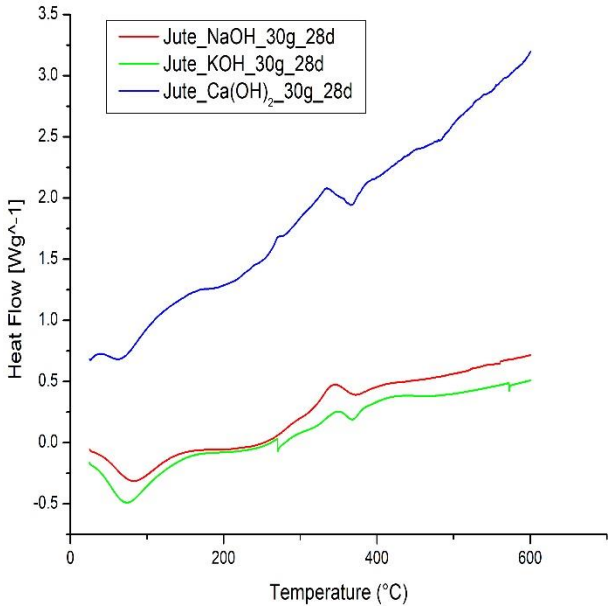


Figure 4. 4 The DSC analysis outputs of different jute samples.

The Thermogravimetric Analysis (TGA) diagram shows the weight loss of jute fibers treated in different alkaline environments as a function of temperature. Fig. 4.5 has three curves representing jute treated with NaOH, KOH, and $Ca(OH)_2$. All three curves exhibit a similar trend, showing a gradual weight loss up to around 300°C followed by a steep decline. This indicates that the jute fiber undergoes thermal degradation in multiple stages. The initial weight loss is likely due to the evaporation of moisture and other volatile compounds from the beginning. The major weight loss between 300°C and 400°C represents the decomposition of cellulose, the main component of jute fiber. The final weight loss after 400°C corresponds to the breakdown of lignin and hemicellulose, which are the other major components of the fiber [163] as lignin decomposes at larger temperatures [168]. The range for T_g is from 220 ^oC till 350 ^oC. The TGA data suggests that the different alkaline treatments significantly impact the thermal stability of jute fibers. For instance, $Ca(OH)_2$ treatment imparts the highest thermal stability, followed by KOH and NaOH. This could be

due to the different chemical interactions between the alkaline agents and the jute fiber components. The treatment with NaOH weakens the fiber structure more than the other two, resulting in a lower thermal degradation temperature and faster decomposition.

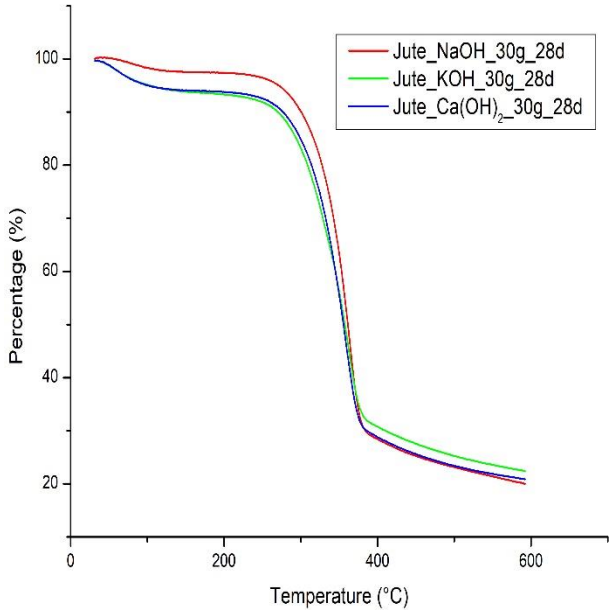


Figure 4. 5 The TGA results of different jute samples.

The RSM analysis data are presented in Table 4.2. As indicated in the table, we evaluated the impact of three parameters: alkali type, alkali concentration, and time, on the tensile strength as the response variable in our model.

Table 4. 1 The data used in the RSM modelling.

Alkali type	**Alkali concentration (g/L)**	**Time (day)**	**Tensile Strength (MPa)**
NaOH	5	7	41.62
NaOH	15	7	79.66
NaOH	30	7	60.77
KOH	5	7	69.38
KOH	15	7	49.05
KOH	30	7	82.67
$Ca(OH)_2$	5	7	51.48
$Ca(OH)_2$	15	7	67.4
$Ca(OH)_2$	30	7	41.41

Alkali type	Alkali concentration (g/L)	Time (day)	Tensile Strength (MPa)
NaOH	5	14	84.2
NaOH	15	14	58.68
NaOH	30	14	181.27
KOH	5	14	194.81
KOH	15	14	237.58
KOH	30	14	103.7
$Ca(OH)_2$	5	14	74.38
$Ca(OH)_2$	15	14	62.73
$Ca(OH)_2$	30	14	111.28
NaOH	5	28	140.34
NaOH	15	28	225.05
NaOH	30	28	84.73
KOH	5	28	130.7
KOH	15	28	131.5
KOH	30	28	163.06
$Ca(OH)_2$	5	28	67.75
$Ca(OH)_2$	15	28	95.92
$Ca(OH)_2$	30	28	86.72

Different combinations of alkali type (Ai), alkali concentration (Ci), and time (ti) are used in each of these tests. Different test results are a result of these changing parameters. We will investigate the connections between the alkali type, concentration, time, and the observed responses using RSM. The mathematical expression of the model is demonstrated in Equation 2.

$$Yi = f(Ai, Ci, ti) \quad \text{Eq. (4.1)}$$

Yi representing the outcome of the ith response. This function f will be a mathematical expression that captures the behaviour of the system under study. In the course of conducting regression analysis on the experimental data, we derived a mathematical model as depicted

in Equation 4.2. As indicated in Table 4.2, it becomes evident that the quadratic model outperforms the others due to its minimal standard deviation and maximal R-squared value.

$$Tensile\ Strength = 221.65 * AlkaliType + 4.18 * AlkaliConcentration + 21.14 * Time - 0.047 * AlkaliType * AlkaliConcentration - 1.42 * AlkaliType * Time - 0.029685 * AlkaliConcentration * Time - 39.41 * AlkaliType^2 - 0.09 * AlkaliConcentration^2 - 0.42 * Time^2 \quad \text{Eq. (4.2)}$$

Table 4. 2 The results of statistical indicators in different regression models.

Source	Std. Dev.	R^2	Adjusted R^2
Linear	50.88	0.24	0.1412
2FI	53.19	0.28	0.1864
Quadratic	46.15	0.54	0.4802
Cubic	55.78	0.6	0.548

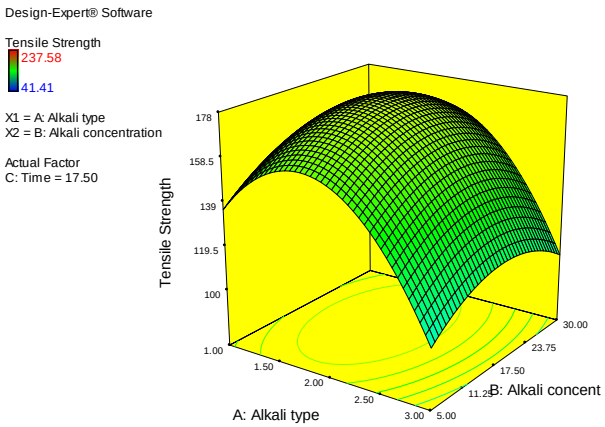
Based on the insights gleaned from Table 4.3, it becomes apparent that the Time of sample curing, with the highest F-value of 8.65, emerges as the most pivotal feature in our analysis. As we delve further into our investigations, we find that Alkali type assumes the mantle of being the most influential factor in our experimental endeavours. This hierarchical order of significance among the variables underscores the importance of these factors in shaping our outcomes.

Table 4. 3 The outputs of ANOVA assessment in this study

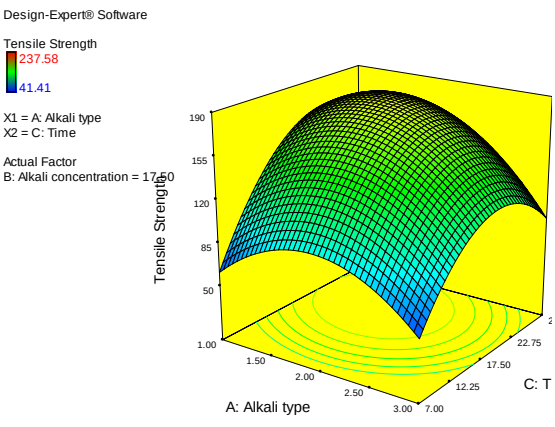
Source	Sum of Squares	Mean Square	F-Value	p-value
Model	42917.42	4768.60	2.24	0.0729
A-Alk. type	5827.50	5827.50	2.74	0.1165
B-Alk Conc.	154.27	154.27	0.072	0.7911
C-Time	18421.18	18421.18	8.65	0.0091
AB	4.21	4.21	1.979E-003	0.9650
AC	2772.40	2772.40	1.30	0.2697
BC	191.42	191.42	0.090	0.7680
A^2	9322.30	9322.30	4.38	0.0518
B^2	1207.60	1207.60	0.57	0.4618
C^2	9835.74	9835.74	4.62	0.0463

Residual	36210.37	2130.02
Cor Total	79127.79	

Analysing Fig. 4.6a, it becomes evident that the variations in slope for alkali type are more pronounced when compared to those of alkali concentration. This observation highlights the greater significance of alkali type in contrast to alkali concentration in our study. Moreover, examining Figs. 4.6b-c, we discern that the time of sample curing exhibits more pronounced slope changes than both alkali type and concentration. This finding underscores the heightened importance of time of sample curing, as reflected in the magnitude of its slope variations, in shaping our research outcomes. Taking Fig. 4.6 into account, it becomes evident that the extremum points, indicative of absolute maximums, can be qualitatively identified. For precise values, however, the equation presented must be solved using classical methods. Similarly, in Fig. 12-c, the residual values derived from the variance between actual and predicted values are observable. This suggests that the model's accuracy regarding alkali type versus time and alkali type versus its concentration is notably higher due to the insignificant residual values.



(a)



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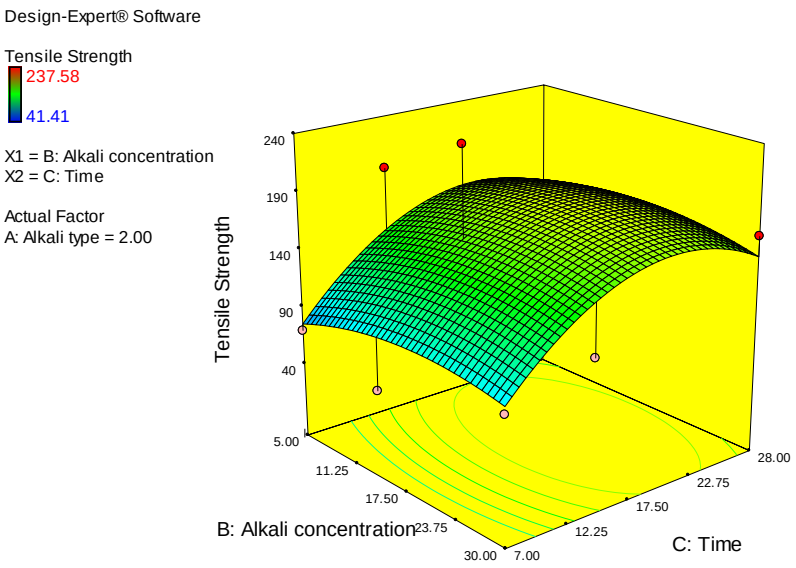


(c)

Figure 4. 6 The sensitive analysis of the effective features as per tensile strength (a-c).

Based on the observations from Fig. 4.7, it is evident that the distribution of the results data in our experimental practices conforms to a normal distribution and closely adheres to the Gaussian model. This adherence to a Gaussian distribution is an important characteristic, signifying the robustness and reliability of our experimental data, which can facilitate more robust statistical analyses and inferences. The normal plot of residuals reveals a linear pattern, indicative of a well-fitted model. Moreover, the distribution of data points tends to cluster predominantly around the center and lower sections, suggesting that the majority of observations fall within these regions. This concentration is further reflected in statistical descriptors such as the mean and median, which likely exhibit values close to each other due to the symmetrical distribution of the data. The absence of significant outliers in the upper tail of the distribution reinforces the adequacy of the model without the need for transformation functions. Thus, based on these statistical insights, the data and its associated model exhibit robustness and reliability for further analysis or predictive purposes.

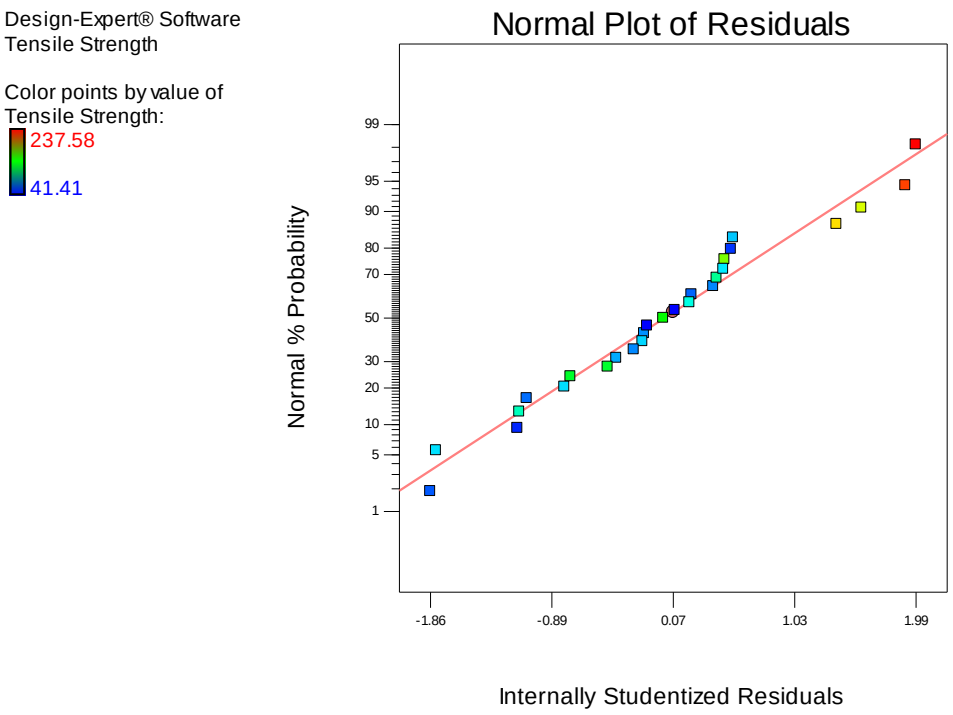


Figure 4. 7 The data distribution of experimental practice in the present research.

As illustrated in Table 4.4, our model has identified optimal conditions for the fiber curing process. This analysis reveals distinct characteristics for three different types of alkalis, namely NaOH (type 1), $Ca(OH)_2$ (type 3), and KOH (type 2). These findings provide critical information for selecting the most suitable alkali and its associated concentration, thereby influencing the curing time of the fibres. When using NaOH (type 1) as the preferred alkali, it is recommended to employ a concentration of approximately 23 g/L. Under these conditions, the fibres reach their desired state within a remarkably short curing time of just 7 days. This suggests that NaOH (type 1) is an ideal choice for those seeking a rapid preparation technique. Conversely, for KOH (type 2), the optimal concentration is lower, around 8 g/L, but it results in a longer curing time of 28 days. This implies that KOH (type 2) might be preferred in situations where an extended curing process is acceptable or beneficial. For those interested in using $Ca(OH)_2$ (type 3), our model suggests applying an alkali concentration of approximately 21 g/L, which is lower than that of NaOH. This offers the advantage of lower alkali concentration while still achieving effective curing. Furthermore, to provide a visual representation of the first optimal condition (type: NaOH, Concentration: 8 g/L, and Time: 7 days), we have included a surface visualisation in Fig. 4.6.

Table 4. 4 The results of optimisation in this research.

Alk. type	Alk Conc. (g/L)	Time (d)
NaOH	22.7	7.1
KOH	8.3	27.3
$Ca(OH)_2$	21.3	9.4

Analysing the data presented in Fig. 4,8, it becomes evident that when it comes to enhancing the tensile strength of jute-based fibres, the choice of alkali treatment plays a crucial role. In this discussion, we will delve into the findings from the figure and explore the implications of these results in the context of jute fiber reinforcement. Fig. 4,8 clearly illustrates that there are three different alkali types under consideration: Type 1 (NaOH), Type 2 (KOH), and Type 3 ($Ca(OH)_2$). Each of these alkalis is used for fiber treatment, to evaluate the tensile strength of jute-based fibres. The tensile strength is a critical parameter in determining the durability and applicability of these fibres in various industries, including textiles, construction, and automotive.

It first need focusing on the data regarding alkali Type 1, which is sodium hydroxide (NaOH). According to Fig. 4.8, the use of NaOH results in the highest tensile strength among the three alkali types considered. This finding suggests that NaOH treatment effectively modifies the jute fibres, enhancing their ability to withstand tensile forces. The mechanism behind this improvement may involve the removal of impurities, lignin, and hemicellulose from the jute fibres, which leads to better alignment of cellulose chains and increased intermolecular forces, ultimately boosting tensile strength.

Moving on to alkali Type 2, potassium hydroxide (KOH), we observe a similar trend in Fig. 4.8. The tensile strength of jute-based fibres treated with KOH is also notably higher than that of Type 3 ($Ca(OH)_2$) treatment. This suggests that KOH treatment is an effective method for strengthening jute fibres. The chemical properties of KOH likely contribute to breaking down non-cellulosic components, thus enhancing the fibre's structural integrity and tensile strength.

In contrast, the data for alkali Type 3, calcium hydroxide ($Ca(OH)_2$), show the lowest tensile strength improvement among the three alkali types. This result implies that $Ca(OH)_2$ treatment may not be as effective as NaOH or KOH in enhancing the tensile properties of jute-based fibres. The reasons for this could be related to differences in the chemical reactions between $Ca(OH)_2$ and jute fibres, or it may indicate that $Ca(OH)_2$ treatment is less

efficient in removing impurities and altering the fibre's structure compared to NaOH and KOH. These findings from Fig. 4.8 have significant implications for industries that rely on jute-based materials. Manufacturers and researchers can use this information to select the most appropriate alkali treatment method for their specific applications. For applications where maximum tensile strength is a priority, such as in the production of high-strength textiles or composite materials, NaOH or KOH treatment should be considered as the preferred options. Conversely, $Ca(OH)_2$ treatment may find more relevance in applications where tensile strength is less critical, but other properties like flame resistance or biodegradability are more important.

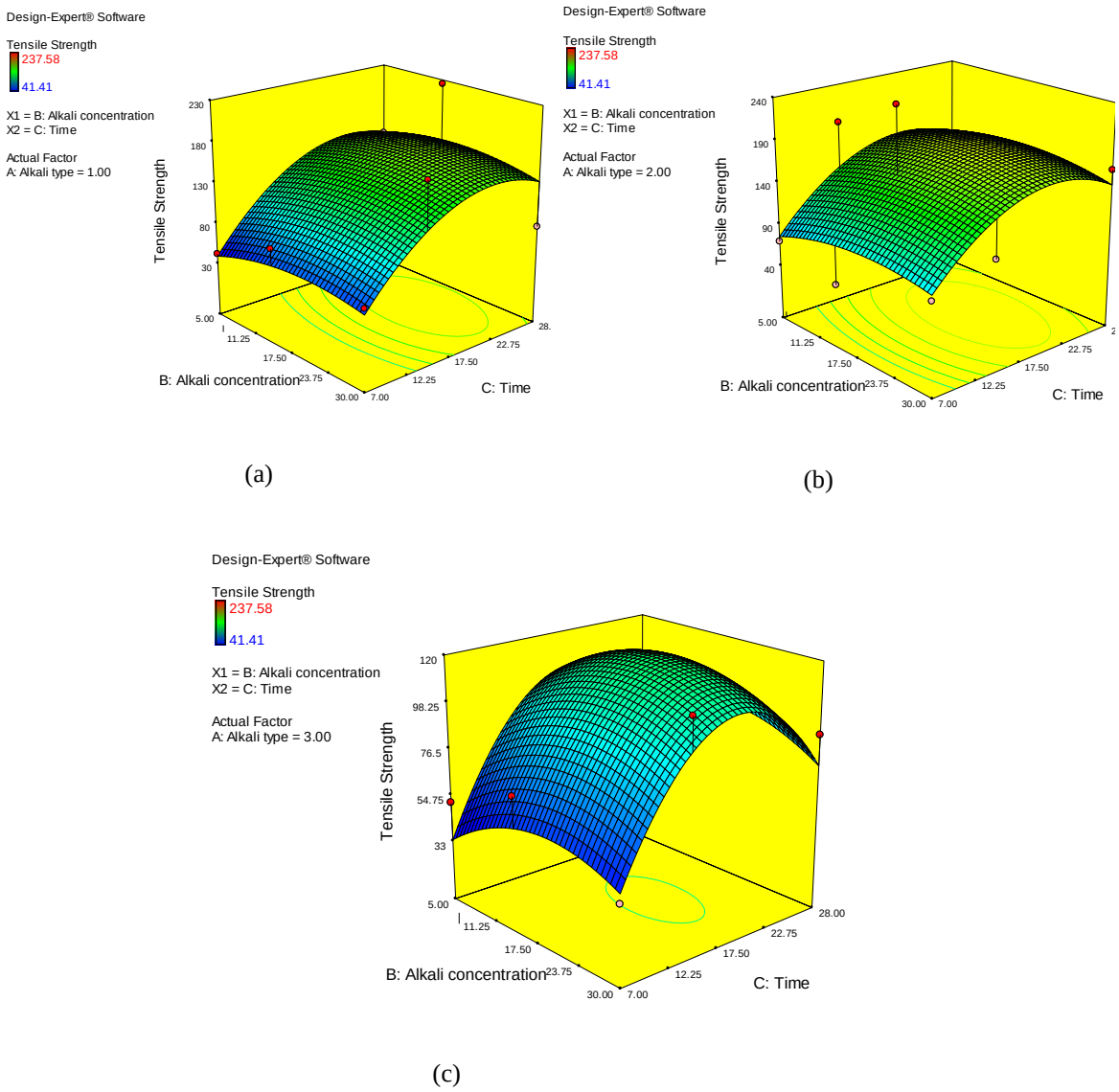


Figure 4. 8 The graphical result of the optimum condition in (a) alkali type: NaOH, (b) alkali type: KOH, and (c) alkali type: $Ca(OH)_2$.

The research aims outlined in this project are closely aligned with sustainability considerations, particularly in the context of jute-based fibres. The initial aim focuses on the preparation of lab-scaled jute-based fiber samples within alkali environments, with a specific emphasis on assessing tensile strength tolerance using the OFAT method. This pursuit is integral to enhancing the durability and performance of jute-based materials, thus contributing to sustainability by potentially extending their lifespan and reducing the need for frequent replacements [169]. Another crucial aspect of the research involves the characterisation of the prepared samples through advanced techniques such as DSC, TGA, and SEM instruments. This characterisation process offers insights into how jute-based fibres behave under varying conditions. Such knowledge is instrumental in optimising their utilisation across diverse applications, potentially resulting in more sustainable end-products. For instance, understanding thermal properties can facilitate the creation of energy-efficient manufacturing processes [170]. The research project also emphasises the optimisation and mathematical modeling of key factors affecting tensile function using the RSM technique. This endeavour has the potential to yield highly efficient processes for jute-based fiber production and application, leading to reduced resource consumption and waste generation. Analysing historical data provides the opportunity to identify patterns and trends that can inform sustainable practices, further enhancing the project's contribution to sustainability [171], [172].

Various studies have explored different aspects of cellulose fibers, as depicted in Fig. 4.9. Kumar and Sarwade (2005) investigated the evolution of tensile modulus during the aging of composites containing commercial microcrystalline cellulose powder over a span of 300 hours. This study shed light on how mechanical properties change over time [173]. In 2011, Kawashima and Shah examined cellulose fibers' influence on early-age shrinkage behavior, focusing on a timeframe of approximately 10 days. Parameters such as fiber percentage were analyzed for their effect on tensile strength variations during this period [174]. Furthermore, Cai et al. (2022) conducted a study on flax fiber reinforced phenolic composites, investigating changes in hydrothermal aging across different temperatures over a duration of 160 weeks. This long-term study provided insights into the durability of such composites under varying environmental conditions [175].

In another facet of research, the present study focused on the effects of three alkali environments on the treatment of jute fibers. Sensitivity analysis revealed that curing time and alkali type are crucial factors affecting the tensile strength of the samples. Notably, the results indicated that the highest tensile strength was observed in the KOH environment after

approximately 14 days, reaching 237.5 MPa. For NaOH treatment, the peak tensile strength occurred on the 28th day, with a value of 225 MPa. Finally, with $Ca(OH)_2$ treatment, the highest tensile strength was observed on the 14th day, albeit with a lower value of 111 MPa. These findings underscore the importance of both the type of alkali treatment and the duration of exposure in enhancing the mechanical properties of jute fibers.

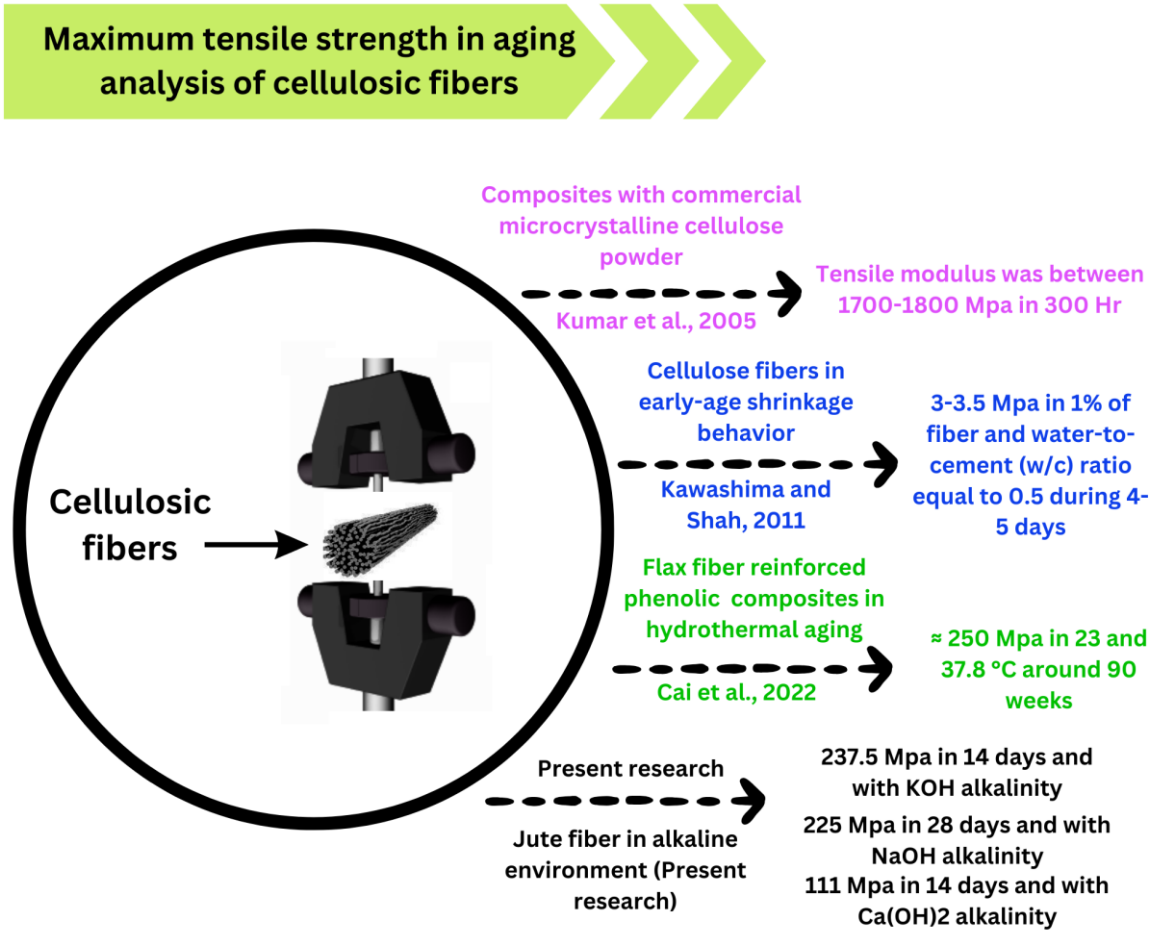


Figure 4. 9 The comparison of main outputs about cellulose fiber tensile strength evaluations in different studies.

4.2 Partial Replacement of Cement by Inorganic Additives in Cement Mixture and Reinforcement with Jute Fiber

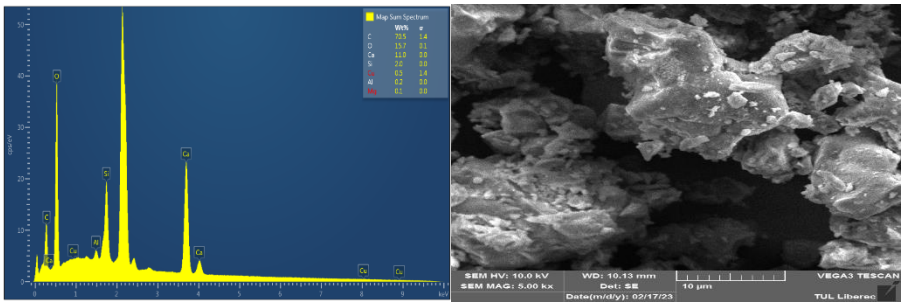
For achieving this task, different percentages of FA (5%, 10%, 20%), LAP (1%, 3%, 5%) and BENT (1%, 3%, 5%) were used to prepare the cement based mixtures. After 28 days of curing, samples were tested against 3-point bending stress, compressive strength and toughness. In the next step, the obtained data was examined with the application of regression modeling due to sensitive analysis and mathematical modeling. Then, prepared

samples are evaluated based on their performance, investment costs, and toxic elements utilizing OWA.

Later, new cement mixtures with partial replacement of cement by fly ash (5%) and Laponite (1%) reinforced with jute fibers (0.2%, 0.5%, 0.7%, 1%) were realized. The length of the jute fibers used was approximately 12 mm. The specifications of each sample were evaluated by Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray Spectroscopy (EDS) along with particle size distribution of the ingredients used in cement mixtures.

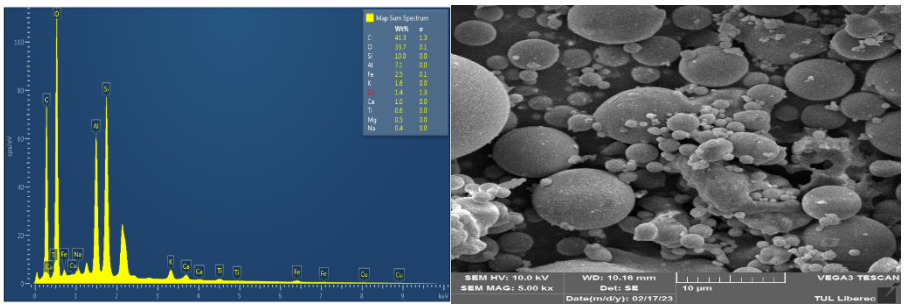
Fig. 4.10 shows the results of EDS and SEM characterisations based on different raw materials and prepared samples. As can be seen, all SEM images are reported in 5kx.

Cement powder



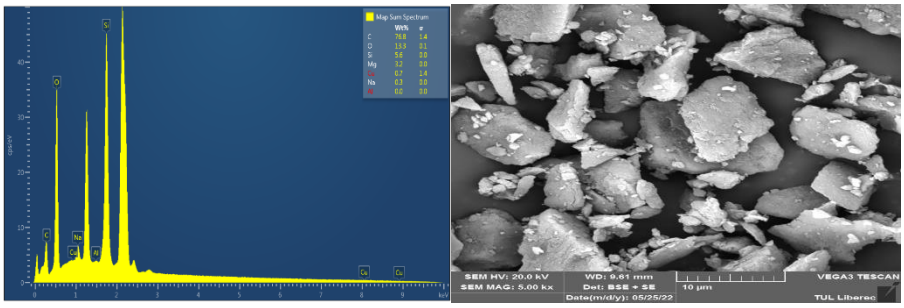
(a)

Fly ash



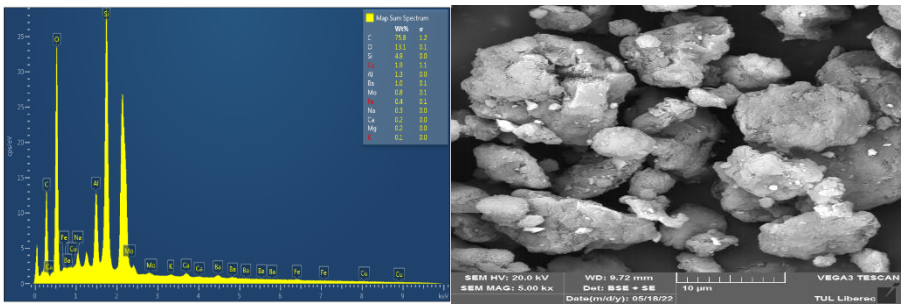
(b)

Laponite



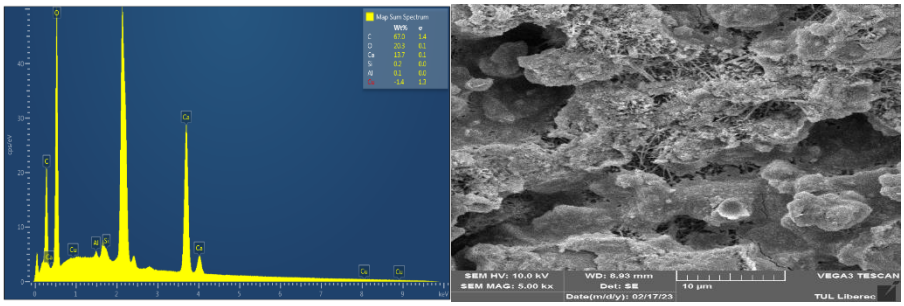
(c)

Bentonite



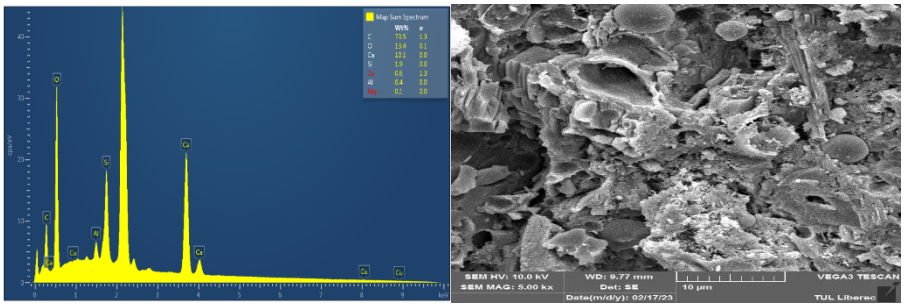
(d)

FA 5%



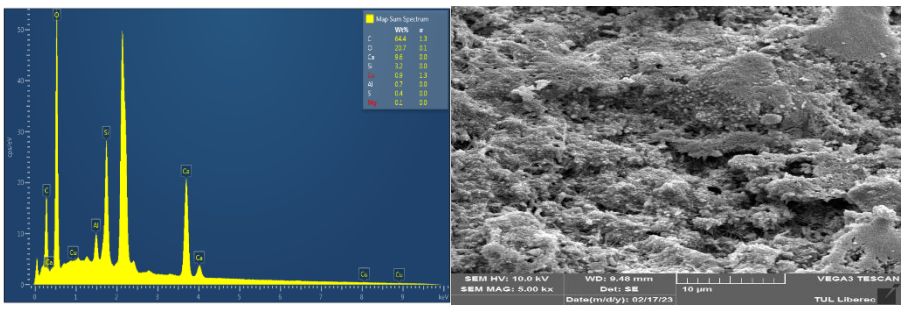
(e)

FA 10%



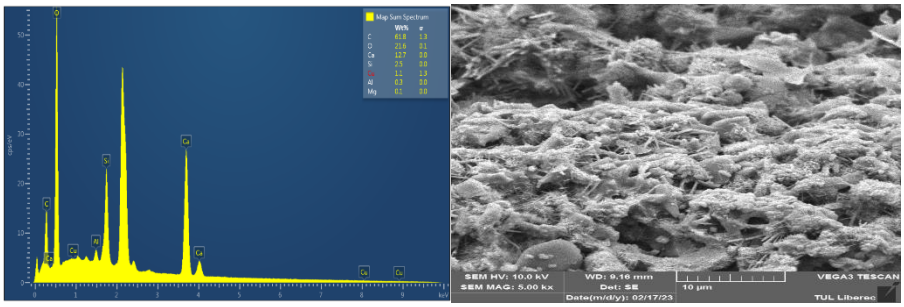
(f)

FA 20%



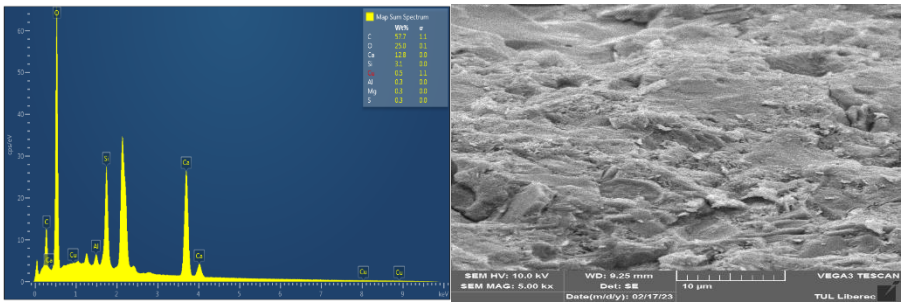
(g)

LAP 1%



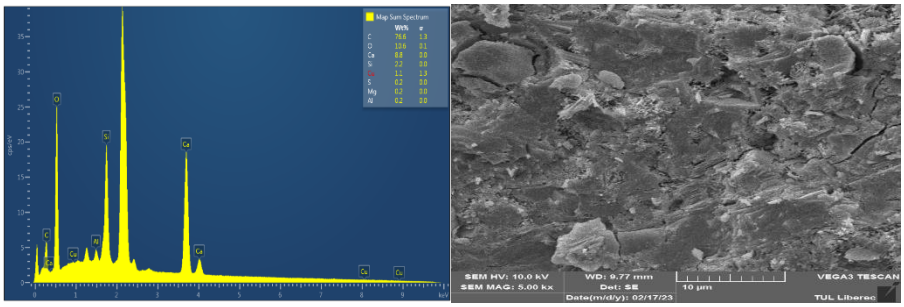
(h)

LAP 3%



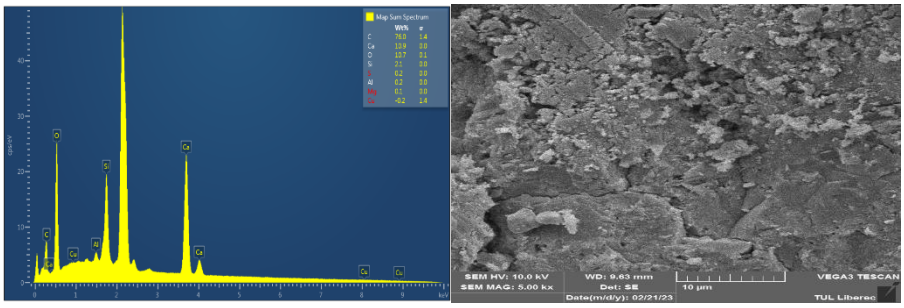
(i)

LAP 5%



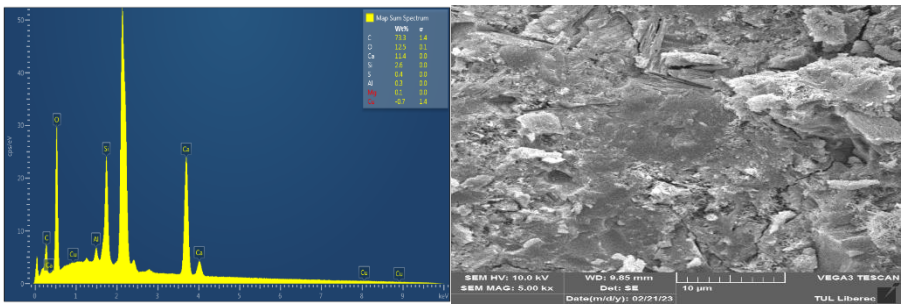
(j)

BENT 1%



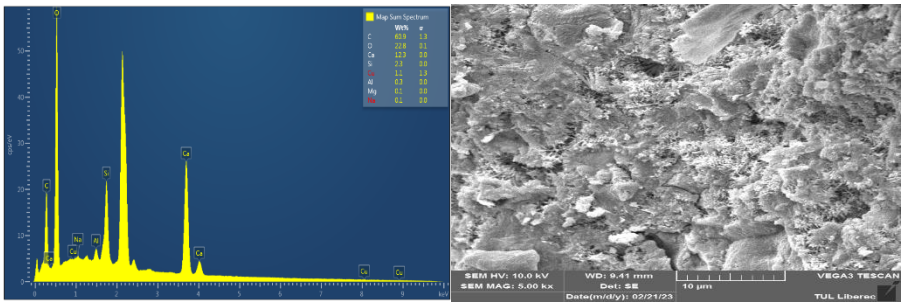
(k)

BENT 3%



(l)

BENT 5%



(m)

Figure 4. 10 The results of characterisation study for the three cement paste additives with different rates (a-m).

Fig. 4.11 summarises the results of the OFAT experiments. By comparing Figs. 4.10 and 4.11, it can be seen that adding higher percentage of fly ash in the mixture of cement paste would increase the percentage of C, O, Al, and Si elements and therefore increase, the 3-point bending value. However, increasing the mentioned elements would considerably reduce, the amounts of toughness and compressive strengths.

Comparing Figs. 4.10 and 4.11 can justify the reason for increasing in the percentages of C, O, Al, and Si elements when adding more fly ash in the mixture of cement paste. These reasons can be attributed to several factors that are discussed here. Firstly, the presence of fly ash in cement paste introduces additional reactive components into the mixture. Fly ash is a byproduct of coal combustion and contains a significant amount of silica (SiO_2) and alumina (Al_2O_3) [176]. These components react with the alkaline compounds in cement, such as calcium hydroxide, during the hydration process, forming additional calcium silicate hydrate (C-S-H) gel. The formation of C-S-H gel contributes to the overall strength and

durability of the cementitious material [177]. Moreover, the increase in these elements can be linked to the pozzolanic reaction, which is a key mechanism associated with the incorporation of fly ash in cement paste. The pozzolanic reaction occurs between the fly ash particles and the calcium hydroxide present in the cementitious system. This reaction produces additional hydration products, including calcium silicate hydrate and calcium aluminate hydrate (C-A-H) gels. These gels fill in the pore spaces within the cement paste, resulting in a denser microstructure and improved mechanical properties [178]. Additionally, the increase in the carbon and oxygen percentages can be attributed to the carbon content present in fly ash. Fly ash contains unburned carbon particles, which contribute to the overall carbon content of the cement paste when added to the mixture. The presence of carbon can influence the microstructure of the cement paste, affecting its mechanical properties [179]. The increased carbon content can enhance the binding of the cementitious materials, leading to improved 3-point bending values. However, while the addition of fly ash and the subsequent increase in the mentioned elements can enhance certain properties, it is worth noting that there are trade-offs in terms of toughness and compressive strengths. The incorporation of fly ash generally results in a decrease in toughness and compressive strengths. This can be attributed to the dilution effect caused by the addition of fly ash, which leads to a reduction in the overall cement content and a decrease in the inter-particle bonding within the cementitious matrix. Consequently, the material becomes more brittle and less resistant to applied forces.

By increasing LAP in the structure of cement paste mixture, all functions (3-point bending, compressive, and toughness strengths) would reduce. Therefore, it can be concluded that the C, Al, O, Si, Mg, and Na element increasing, the capability of cement paste are damaged. Therefore, with elemental analysis of FA and LAP adding, it can be found that the Si, O, and C elements caused decreasing the cement paste specifications (3-point bending, compressive, and toughness strengths). Although, with increasing Al element has positive effect on 3-point bending function. However, with evaluation of BENT (main elements: C, O, Al, Si, Cu) the 3-point bending and compressive strengths are increased and reversely, the capacity of toughness is decreased. Thus, the Cu and Al have positive influences on 3-point bending. While just Cu has direct relationship on compressive strength.

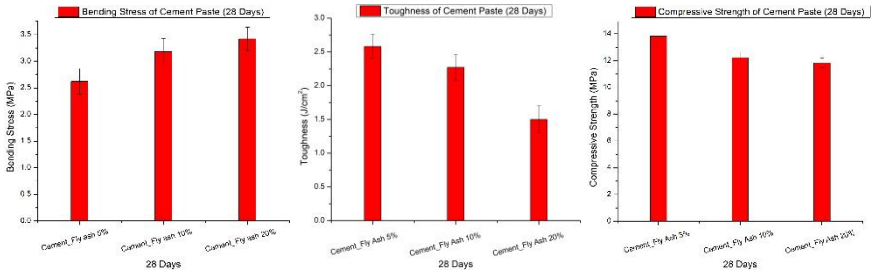
The presence of LAP can impact the hydration process of cement, which is essential for the development of strength in the paste [180]. The water associated with LAP, along with the water required for cement hydration, influences the availability of water molecules for the chemical reactions. Excess water from LAP can dilute the cementitious system, affecting

the formation of stable calcium silicate hydrate (C-S-H) gel, which is responsible for the strength and durability of the cement paste. This dilution effect can lead to reduced 3-point bending strength, compressive strength, and toughness. Furthermore, LAP contains carbon, which can directly affect the cementitious system. Carbon from LAP can react with calcium hydroxide ($Ca(OH)_2$) generated during cement hydration, leading to the formation of carbonates. This reaction can result in the consumption of calcium ions, which are essential for the formation of C-S-H gel. Consequently, the availability of calcium ions for C-S-H gel formation decreases, leading to a decrease in the overall strength of the cement paste. In the case of BENT, its chemical composition primarily comprises elements such as Si, Al, O, C, and Cu. These elements can interact with the cementitious system and influence its properties differently. The presence of Cu in BENT can have a positive effect on the mechanical properties of the cement paste. Copper ions can act as a catalyst in the hydration reactions, promoting the formation of a denser and stronger cementitious structure [181]. This can lead to an increase in 3-point bending strength and compressive strength. On the other hand, Al in BENT can also influence the cement paste, particularly the 3-point bending strength. Aluminum ions can react with the silicate compounds in the cement, leading to the formation of additional hydration products. These products can contribute to improved bonding and enhance the material's resistance to bending stresses. Also, by comparing the SEM images, it can be concluded that with increasing FA, LAP, and BENT, the porosity of cement paste is reduced. While there are different behavior in all functions. Therefore, it can be concluded that the strength outputs are independent in comparison of sample porosities.

According to Fig. 4.10, fly ash is a fine powder that is primarily composed of spherical particles. It is a byproduct of coal combustion in thermal power plants. The chemical composition of fly ash can vary depending on the composition of the coal burned, but it generally consists of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), iron oxide (Fe_2O_3), calcium oxide (CaO), and small amounts of other elements. The morphology of fly ash particles is typically irregular, with varying sizes ranging from a few micrometres to several tens of micrometres. The particles are often hollow and porous, giving them a light and powdery texture. The surface of fly ash particles can be rough and angular. Laponite is a synthetic clay-like material that belongs to the class of layered silicates. Its structure consists of a two-dimensional sheet of silica and magnesium ions, with water molecules located between the sheets. Laponite particles are disc-shaped, with a diameter typically ranging from a few nanometres to a few micrometres. These particles can stack together to form aggregates or gel-like structures in water or other polar solvents. Laponite has a high aspect

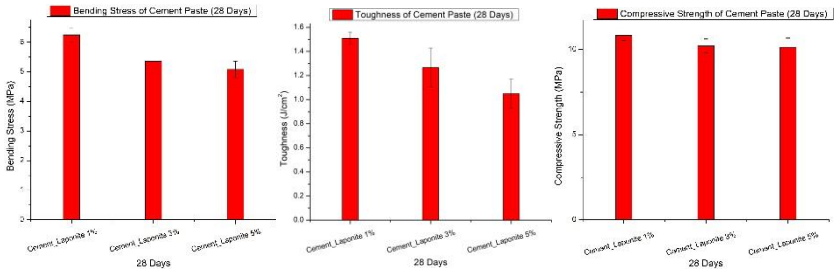
ratio, meaning its width is much smaller than its length, resulting in a plate-like morphology. Bentonite is a type of clay formed from the weathering of volcanic ash. The structure of bentonite consists of individual clay platelets stacked on top of each other. These platelets have a layered structure, with each layer being composed of two silica tetrahedral sheets sandwiching an alumina octahedral sheet. The layers are held together by weak van der Waals forces, allowing them to slide and swell in the presence of water. Bentonite particles can vary in size, ranging from a few nanometres to several micrometres. They have a flake-like or needle-like morphology, with a high surface area due to the presence of numerous platelets. The interlayer spaces between the clay platelets can accommodate water molecules and other ions, giving bentonite its unique swelling and adsorption properties.

FA%



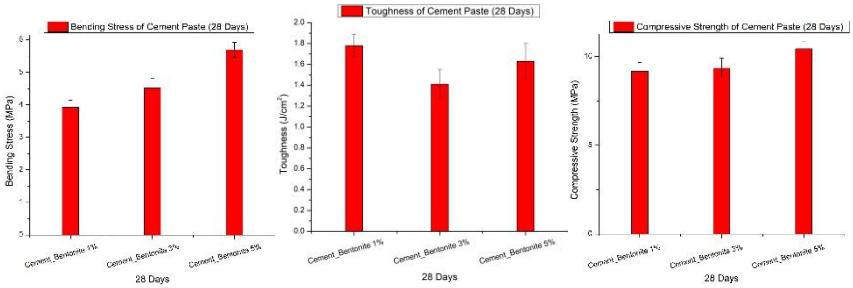
(a)

LAP%



(b)

BENT%



(c)

Figure 4. 11 The results of the three evaluation functions (bending stress, toughness, compressive strength) for the three cement paste additives; (a) FA%, (b) LAP%, and (c) BENT% function performances.

The results of this study show that with increasing fly ash content, the compressive strength of the cement paste decreases. It is well known that fly ash is a pozzolanic material that reacts with calcium hydroxide during hydration of cement to form additional cementitious compounds [182]. However, excessive amount of fly ash in the cementitious composites cannot fully participate in the pozzolanic reaction thus resulting in a reduction of hydration products in cement-based composites. This can result in the reduction of the compressive strength [183]. It is important to note that higher compressive strengths are possible with fly ash content in cementitious composites when fly ash will be mechanically activated the outcomes of different studies such as [184]–[186]. Also, the declared research items conform to the present investigation outputs and explanation. Results with LAP as a partial replacement in this study depict that the compressive strength of cement pastes decreased with increasing content of the LAP. The possible reasons for this is that LAP clay being very fine disk like particles belonging to the Smectite group of phyllosilicates [66], [67] possess pozzolanic reactivity and can increase the C-S-H during cement hydration process. Moreover, it can fill the voids thus improving packing of the cementitious system thus increasing the compressive strength of the cement paste [187]. However, with increasing LAP content causes agglomeration and also affects the water demand and workability of the cement which can negatively affect the hydration procedure. Previous studies [188], [189] reported similar results for compressive strength with different clays. Compressive strength of the cement paste having bentonite as a partial replacement of cement in this research work showed that the higher value for compressive strength was achieved with 5% replacement of cement by BENT. This behavior of BENT in cement pastes may be due to the improved particle packing within the cement paste matrix. Furthermore, it can be due to the better binding and cohesion properties with increased hydration and cementitious products.

The outcomes of this study reveal that with increasing FA and BENT content, the 3-point bending property of the cement paste also improved. This can be attributed to the better interfacial bonding between the FA/BENT particles and cement paste thus resulting in improved flexural strength [190]. Whereas in case of LAP, 3-point bending decreased with increasing content. The reduction in strength with increasing content of LAP can be because of dilution effect of the LAP particles which lead to poor participation in interfacial bonding.

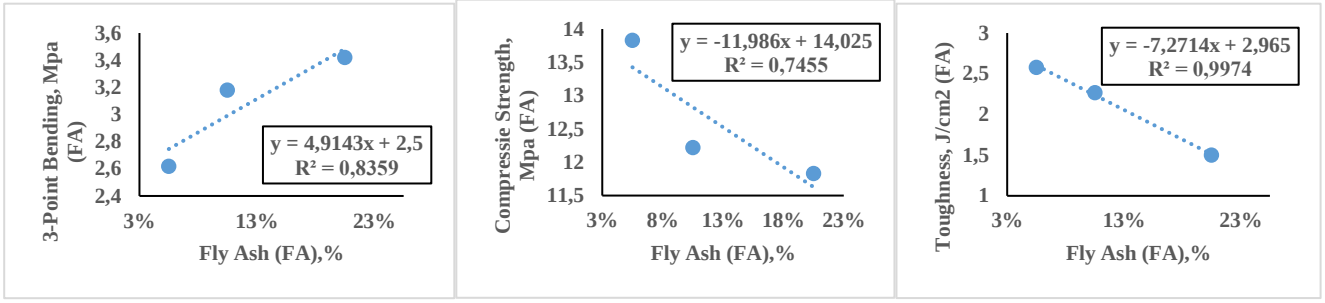
Cement paste with FA/LAP/BENT in this study showed a decreasing trend with increasing content of fillers. In case of FA, this behavior may be because of the increasing brittleness and reduced ductility of the cement paste, while the decreasing trend of the cement pastes having LAP may be attributed to the ineffective role of LAP with higher percentages in cement paste leading to poor toughness properties. Cementitious composites with partial replacement of cement by BENT firstly showed a decrease with 3% but at 5% it showed some improvement. Cement paste with 3% showed a reduction in toughness by 20.8% compared to cement paste with 1% BENT, while cement paste with 5% BENT showed an improvement of 13.5% compared to cement paste with 3% BENT. This behavior may be due to the formation of cracks and their propagation due to the internal stresses within the cement pastes.

The results of regression statistical analysis for curve fitting of LAP, FA, and BENT against 3-point bending strength, compressive strength, and toughness are summarised in Fig 4.12. The results show that in adding different percentages of FA in the mixture of cement paste, toughness and 3-point bending strengths have acceptable (R^2> 82%) Coefficient of determination. Likewise, the FA % addition had direct effects onto 3-point bending and had reverse impact on both others. Fig 4.12 depicts that the Coefficient of determination of all functions based on LAP is acceptable (more than 84%). However, the slope of all functions (3-point bending, compressive, and toughness strengths) are minus in the provided equations and it shows reverse relationship between adding LAP in mixture of cement paste. The response of both 3-point bending and compressive strengths for the case of BENT is acceptable (R^2> 84%) as they had direct relationship with the additive. The reaction of BENT % and cement paste mixture vs toughness was strange, and the linear equation could not describe it.

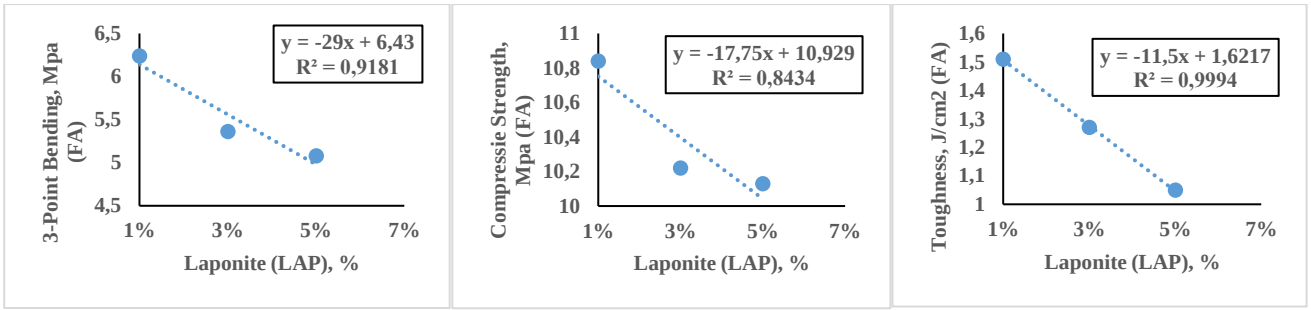
The Fig 4.12.a demonstrates that the FA% filler has the maximum effect onto compressive strength more than two others because of its higher slope value in the obtained equations. In the next step, the higher relativity of FA% is linked to toughness (FA% vs compressive strength: -11.98> FA% vs toughness strength: -7.2> FA% vs 3-point bending strength: 4.9). About LAP% effects, it should be mentioned that in curve fitting computations, the slope values are: LAP% vs 3-point bending strength: -29> LAP% vs compressive strength: -17.7> LAP% vs toughness strength: -11.5. Therefore, the maximum and minimum effects of LAP% addition to cement paste is connected to 3-point bending strength and toughness, respectively. While in comparison of FA%, order of LAP% equation slopes was higher and

thus, LAP% additives were more important than FA% in the changing of cement paste specifications.

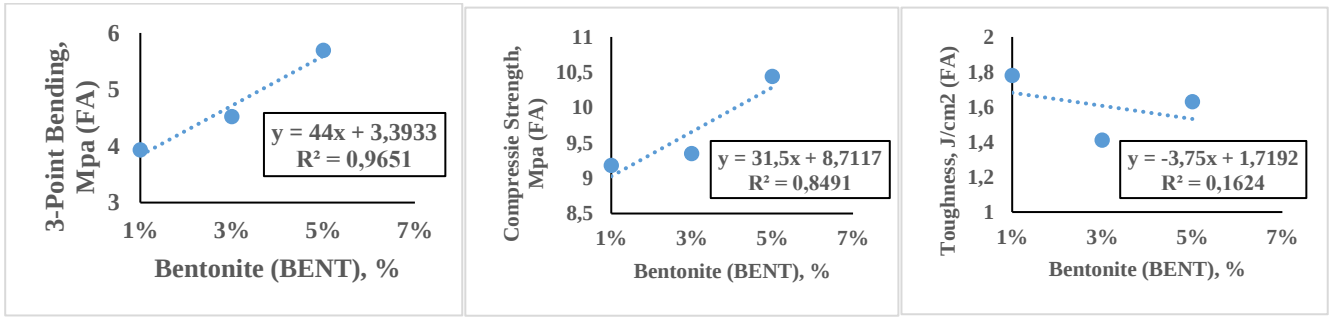
Finally, it is clear that the slope order of BENT% equations in 3-point bending and compressive strengths are more than both FA% and LAP%. Also, BENT% effects onto both mentioned functions were direct, however, both FA% and LAP% influences were reverse. Overall, similar to LAP% effects, in BENT%, the maximum slope (effect) and minimum one was related to 3-point bending and toughness strengths, correspondingly.



(a)



(b)



(c)

Figure 4. 12 The results of regression statistical analysis for curve fitting of the present research (a-c).

The outcomes of the EIA for nine samples are presented (Fig. 4.13). The diagram illustrates that the presence of Al element in the FA and higher percentages of the additive used in the study result in the highest level of toxicity. Similarly, in the subsequent phase, varying percentages of BENT, due to the presence of Mg and Al elements, exhibit the most toxicity

and EIs. Finally, based on its chemical structure, the least hazardous additive is associated with the LAP.

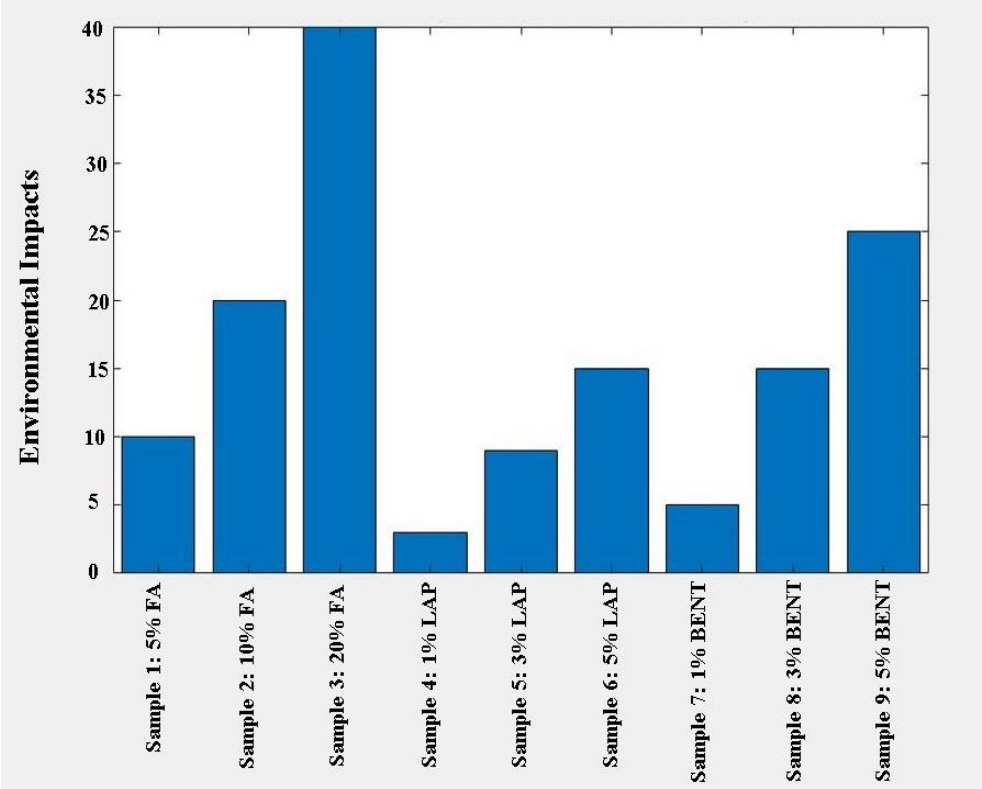
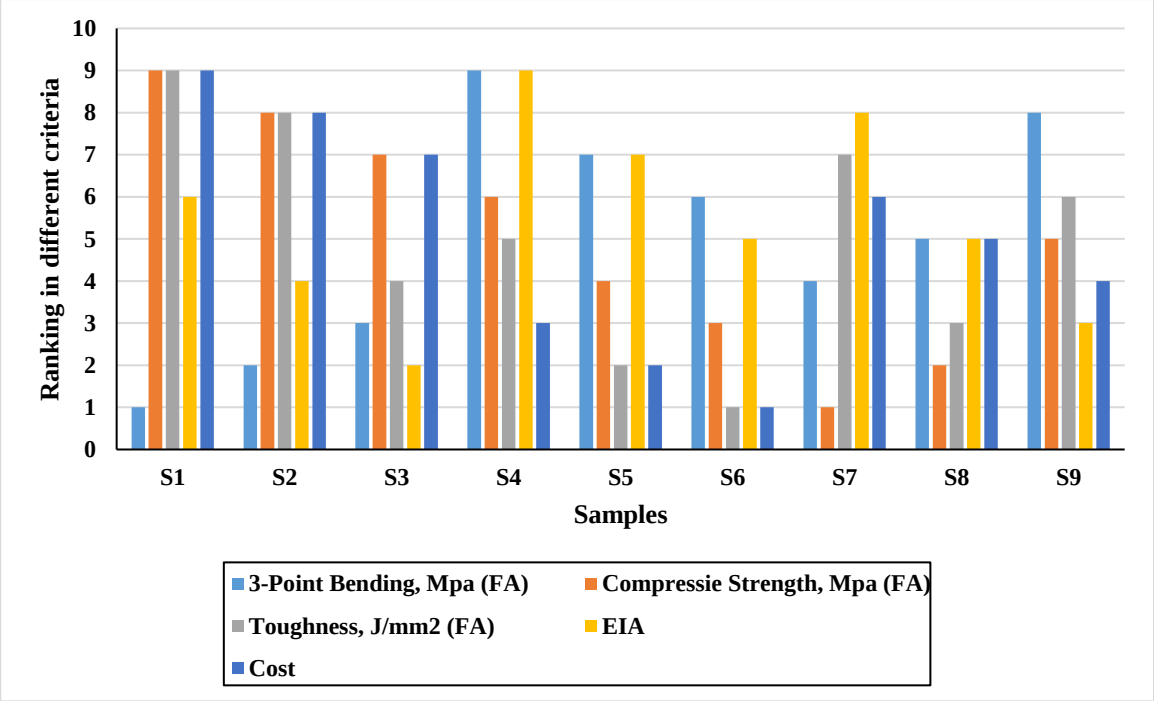
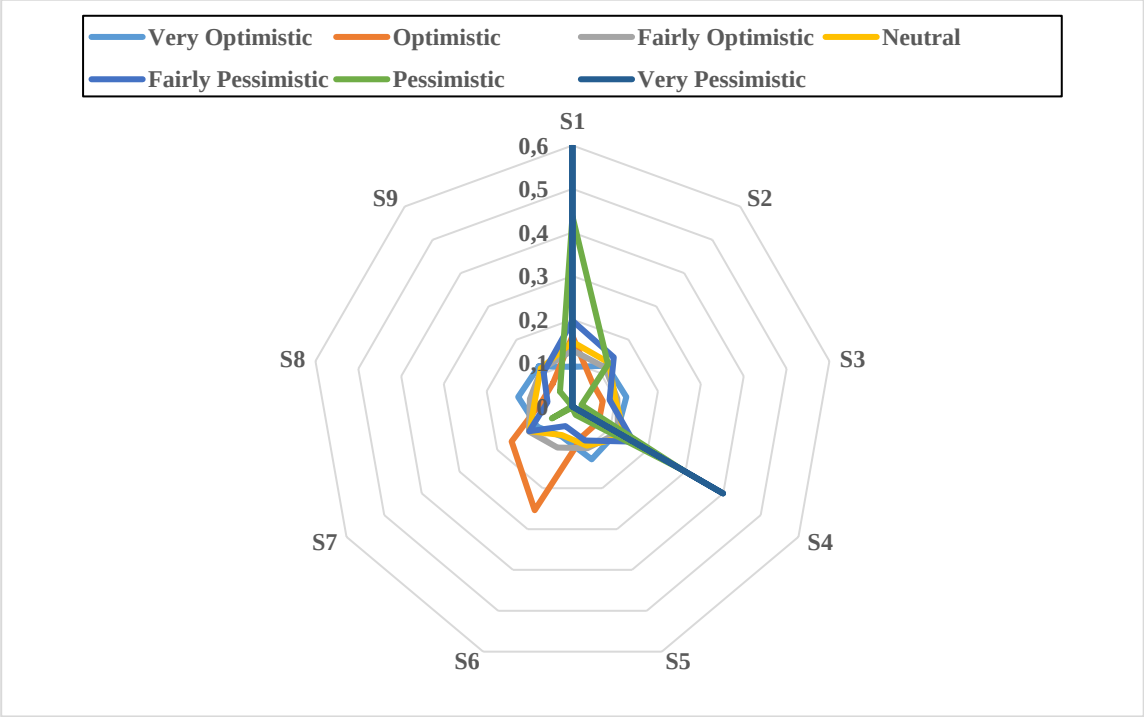


Figure 4. 13 The outputs of EIA assessment of prepared samples in this research.

The results of the OWA ranking model are demonstrated in Fig. 4.14. According to the scheme (Fig. 4.14 a and b), it can be concluded that based on SA indicators, from very pessimistic and neutral points of view (idea of managers), the samples S1 and S4 should be selected for the construction preparation process. In both the options, the least levels of FA (5%) and LAP (1%) are used as an additive in the structure of cement paste. Besides, in a very optimistic selection perspective, S3 (with 20% FA, weight=0.125), S5 (with 3% LAP, weight=0.129), and S8 (with 3% BENT, weight=0.126) are selected. Therefore, in an optimistic condition, all the materials can be applied based on the viewpoint of managers and decision-makers. However, in the mention situation, maybe consideration to EIA can be useful for selection and therefore, 3% LAP is recommended.



(a)



(b)

Figure 4. 14 The outcomes of OWA computations according to (a) sample rankings as per different performance/ cost/EIA and (b) final OWA weights.

The analysis of cement particle distribution reveals a grain size of 15.18 µm and a mean volume of 38.00 µm. The histogram describing cement particle distribution suggests that a significant portion of particles falls within the 1-10 µm range, as indicated by the tall initial bars. As we move towards the 20-30 µm range, the bar height decreases, suggesting a lower

frequency of particles in that size range. The overall shape of the cement particles histogram appears to be right-skewed, with a majority of particles concentrated in the smaller size ranges and a tail extending towards larger sizes. This is a common characteristic of cement and other powder materials. The cumulative curve on the graph represents the percentage of particles that are smaller than a given size. For instance, tracing the curve at the 50 μm mark on the x-axis would reveal the percentage of particles with sizes below 50 μm.

The analysis of fly ash particle distribution reveals a grain size of 22.38 μm and a mean volume of 65.38 μm. The histogram describing fly ash particle distribution submits that a majority of the particles are smaller in size with the number of particles decreasing as the size increases. The tallest bars representing the lower size ranges are marked between 1-30 μm suggesting that a significant portion of the fly ash particles are within this range. The particles range from approximately 1 to 70 μm with a few larger particles beyond that range. The cumulative curve shows a steep increase in the lower size range indicating a large percentage of particles are relatively small.

The analysis of laponite particle distribution reveals a grain size of 25.34 μm and a mean volume of 68.92 μm. The histogram describing laponite particle sizes shows a positively skewed distribution, meaning a majority of the particles fall within the smaller size ranges (below 40 μm). The frequency rapidly decreases as particle size increases, with very few particles exceeding 60 μm. the highest bars in the histogram corresponding to 1 to 20 μm suggest the dominant size range of laponite particles. The cumulative curve indicates that approximately 100% of particles are below 80 μm.

The analysis of bentonite particle distribution reveals a grain size of 23.25 μm and a mean volume of 49.62 μm. The histogram of the bentonite appears to be positively skewed meaning a significant portion of particles are smaller in size, with a tail extending towards larger sizes. Most of the particles fall within the range of 0-20 μm and the number of particles decreases as the size increases. The cumulative curve shows the percentage of particles below a specific size. In the case of bentonite, 90% of particles are below 50 μm.

The average grain sizes of the materials are given in Table 4.5.

Table 4. 5 Average grain sizes of the powder materials

Particle Size Distribution		
#	**Material**	**Average Grain Size, µm**
1	Cement	15.18
2	Fly ash	22.38
3	Laponite	25.34
4	Bentonite	23.25

Particle size distribution data Table 4.5 gives us quantitative data regarding these materials. Particle size distribution data is useful in understanding the materials' behavior in cementitious composites using aggregation tendencies, and overall behavior. Particle size reduction increases surface area, which improves mechanical properties. whereas a decrease in surface area caused by a large particle size could lower the mechanical properties. Therefore, it is recommended to consider the particle sizes of the ingredients of the cementitious composites in future work.

The results of 3-point bending stress, compressive strength and toughness are presented in Fig. 4.15. According to Fig. 4.15a, the results of 3-point bending stress of cement mixtures reinforced with various wt.% of jute fiber show a clear trend. With 0.2% jute fiber content, the 3-point bending stress was recorded as 3.07 MPa. For the cement mixture reinforced with 0.5% jute fiber, the bending stress was 3.32 MPa showing an increase of approximately 8.2% compared to the 0.2 % fiber content. As the fiber content further increases to 0.7%, the bending stress also increases and a value of 3.77 MPa was achieved showing an increase of 13.6% to that of 0.5% content and a 22.9% increase compared to 0.2% jute fiber content. The increase in bending stress was previously reported by Shoukry et al. (2013) in a research work where different natural fibers reinforced in cement pastes showed improvement in bending stress up to a 2% fibers content [191]. Similar results were also observed for coated sisal fiber reinforced concrete samples [192]. However, with a further increase in jute fiber content to 1%, we observe a decreasing trend in bending stress with a value of 2.2 MPa showing a 41.6% decrease in bending stress compared to the 0.7% jute fiber content. It can be seen that the optimal value of the jute fiber content against 3-point bending stress was observed at 0.7% fiber content. The decrease in bending stress beyond 0.7% is likely due to several issues such as fiber agglomeration or poor bonding with the cement matrix resulting

in a poor composite matrix. Similar explanations have been reported previously such as [193][194].

According to Fig. 4.15b, Results of the compressive strength of the cement mixture reinforced with jute fiber reveals that the cement mixture reinforced with 0.2% jute fiber has a compressive strength of 26.55 MPa. With a further increase in jute content at 0.5%, the compressive strength approaches a value of 28.17 MPa showing a 6.1% increase compared to the 0.2% jute fiber content in compressive strength of the cement mixture reinforced with jute fiber. However, increasing the fiber content from 0.5% to 0.7% reveals a reduction in compressive strength. At this value, compressive strength reduced to 23.29 MPa showing a decrease of 17.3% from the 0.5% fiber content and 12.3% from the 0.2% fiber content. Further increase in fiber content at 1%, the compressive strength almost remains the same with a value of 23.31 MPa showing a slight 0.1% increase from 0.7% but still a 17.2% reduction from the 0.5% fiber content. The results reveal an optimal value for compressive strength at 0.5% jute fiber content. Similar trends have been observed in previous studies. Chakraborty et al. (2013) reported an improvement in compressive strength in 1% jute fiber-reinforced cement mortar [195]. In another study, compressive strength of kenaf-reinforced cementitious composites showed improved compressive strength values for 0.5, 1, 1.5, and 2% fiber content and the maximum strength improvement was 96% for 1.5% fiber content [196].

According to Fig. 4.15c, cement mixtures with 5% fly ash and 1% laponite, reinforced with various percentages of jute fiber, exhibit a clear trend of increasing toughness with higher fiber content. Specifically, at 0.2% jute fiber, the toughness is 2.3935 J/cm². Increasing the fiber content to 0.5% results in a toughness of 2.8325 J/cm², which is an 18.4% increase compared to the 0.2% fiber content. Further increasing the fiber content to 0.7% boosts the toughness to 3.0360 J/cm², representing a 7.2% increase from 0.5% and a 26.8% increase from 0.2%. At the highest fiber content of 1%, the toughness reaches 3.5114 J/cm², indicating a 15.7% increase from 0.7% and a 46.7% increase from 0.2%. These results suggest that adding more jute fiber to the cement mixture generally improves its toughness, likely due to the enhanced energy absorption capabilities of the fiber-reinforced composite. The increasing trend indicates that jute fibers effectively bridge cracks and improve the post-cracking behavior of the cementitious matrix [193]. Inclusion of fibers can effectively improve the toughness property [197]. The incorporation of short jute fibers into the cement mortar has shown significant improvements in the toughness property of the composites [198]. Overall, the data indicates that jute fiber reinforcement significantly enhances the

toughness of the cement mixtures, with the most substantial improvements observed at higher fiber contents.

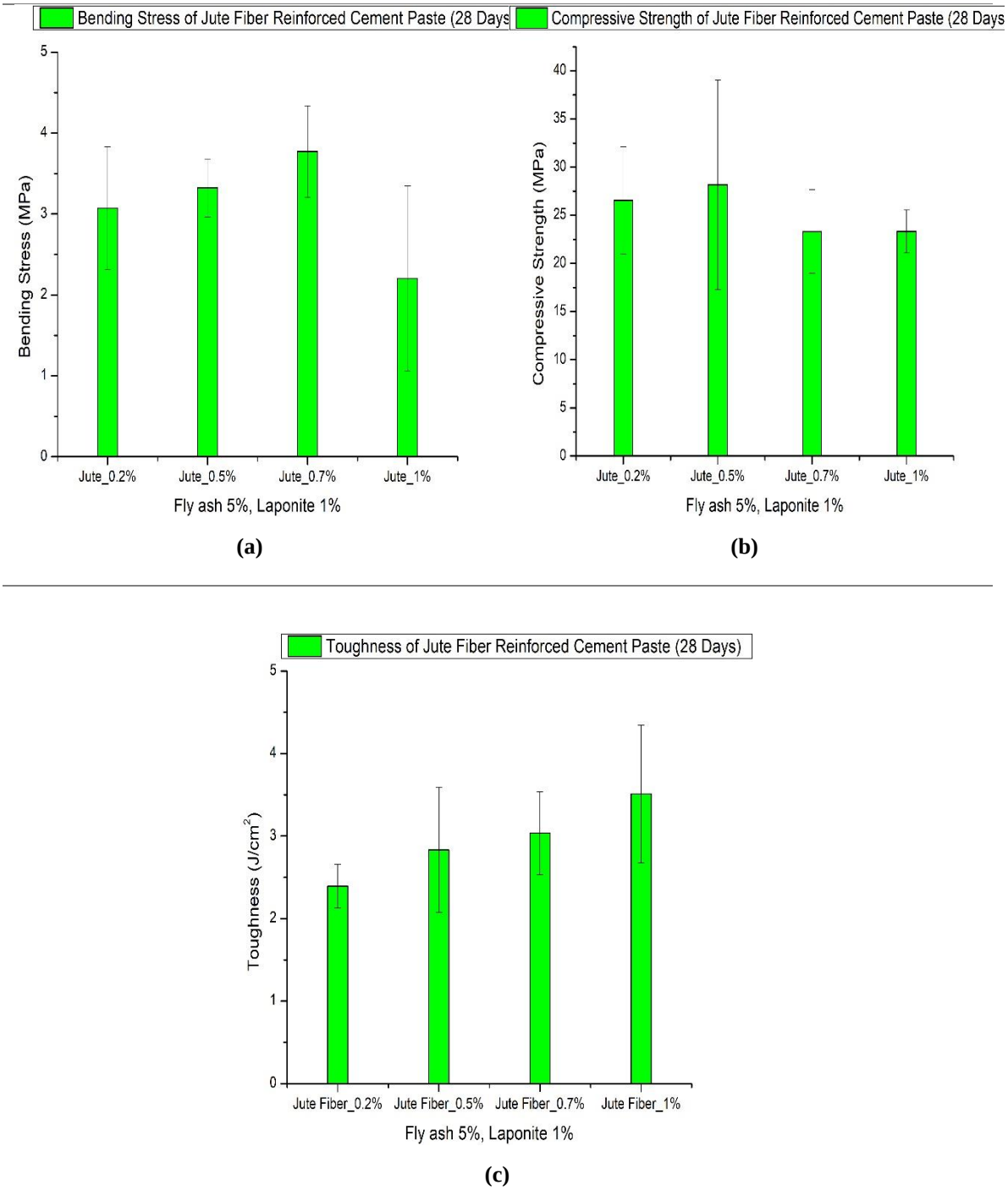


Figure 4. 15 The results of the jute-reinforced cement mixtures having different fiber contents; (a) 3-point bending stress, (b) Compressive strength, and (c) Toughness.

Chapter 5

5. Conclusions and Future Work

5.1 Conclusions

This thesis consists of two main sections: the first investigates the aging behavior of jute fibers in an alkaline environment, while the second explores the partial replacement of cement by inorganic additives and their reinforcement with jute fibers.

Jute fiber is a promising and cost-effective resource for various building and construction applications. This study focused on optimizing jute-based materials through various alkali treatments, examining the impact of different alkali types, concentrations, and curing times on tensile strength. The findings revealed that fibers treated with 15 g/L concentration of NaOH had the highest tensile strength at 28 days (225.05 MPa). For jute fibers treated with KOH, the highest tensile strength was observed with 15 g/L concentration at 14 days (237.58 MPa). With $Ca(OH)_2$ treatments, the highest tensile strength occurred with 30 g/L concentration at 14 days (111.28 MPa). It was also noted that prolonged exposure to very high alkali concentrations could negatively affect tensile strength, as seen with the 30 g/L concentration of NaOH at 28 days (84.73 MPa). The RSM analysis indicated that curing time had the greatest impact on tensile strength, while alkali concentration had the least. For instance, using NaOH, tensile strength varied by around 70% when shifting from a 7-day to a 28-day curing time, and by about 30% when changing NaOH concentration from 5 g/L to 30 g/L. Sodium hydroxide (NaOH) was identified as the most influential alkali compound on the tensile strength of technical jute fiber samples, with curing time being the most significant factor, as shown by ANOVA assessment.

The study also examined the partial replacement of cement with inorganic additives, such as industrial wastes and clays (FA, LAP, BENT). Experimental evaluations were conducted to assess the effects of three percentage rates of FA (5%, 10%, 20%), BENT (1%, 3%, 5%), and LAP (1%, 3%, 5%) on the toughness, 3-point bending, and compressive strength of cement paste. SEM and EDS tests were used for sample characterization. The results showed that FA% positively affected 3-point bending stress but inversely impacted compressive strength and toughness. LAP% had an inverse effect on all three functions. BENT% positively affected 3-point bending stress and compressive strength. Statistical regression analysis highlighted the importance of each additive in different cement paste properties.

FA% had the maximum effect on compressive strength, while LAP% and BENT% had the maximum effect on 3-point bending stress. The OWA ranking model concluded that, from very pessimistic and neutral viewpoints, samples S1 and S4 should be chosen for construction preparation, using the lowest levels of FA (5%) and LAP (1%) as additives. EIA demonstrated that LAP is the safest additive for cement paste and can be selected based on SA analysis by OWA calculations from very optimistic viewpoints. Cement mixtures containing 5% FA and 1% LAP, reinforced with short jute fibers (0.2%, 0.5%, 0.7%, 1%), showed optimal jute fiber content at 0.7% for 3-point bending, 0.5% for compressive strength, and 1% for toughness.

5.2 Future Work

Future studies should delve deeper into the composition of jute fibers and explore alternative cellulose fibers as fillers for composite materials, expanding the range of sustainable options. The application of electrolysis and heat treatment techniques could further enhance the properties of jute-based fibers and deserves attention from the scientific community. Moving beyond the RSM model, the use of metaheuristic algorithms presents an exciting opportunity for optimizing fiber characteristics, offering new insights and paths for enhancing the sustainable potential of jute-based materials. These efforts will help elevate the role of green materials in promoting sustainability globally.

On the other hand, partial replacement of cement by inorganic additives and reinforcement with fibers opens new perspectives in this area of research. The use of new additives, changing additive percentages, increasing their surface area by milling are the interesting factors that can be considered. For reinforcement of the cementitious composites, the change in the length of fibers along with their orientation of the composites is another interesting topic for future studies. Furthermore, FTIR technique shall be applied in future studies to better understand the behaviour of the ingredients in the cementitious composites.

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Curriculum Vitae

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OBJECTIVE AND SUMMARY OF QUALIFICATIONS:

Motivational attitude with a goal of conducting result oriented quality research utilizing my extensive twenty years relevant experience in working with construction companies and educational institution, assignments undertaken include site management and staff supervision, estimation and costing, working with subcontractors & material suppliers. Currently teaching Civil Engineering & Environmental Management & Policy courses at university level.

ACADEMIC QUALIFICATIONS:

Vinnitsia State Technical University, Ukraine.	1999
Masters of Science in Civil Engineering.	
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RELATED PROFESSIONAL EXPERIENCE:

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July 2004 - Nov 2004.	Husnain Cotex Limited (H.C.L) Kandahar (Afghanistan). Worked as Civil Engineer on Kandahar – Tirin Kot Road project
Sep 2003 - June 2004.	Participatory Integrated Development Society (PIDS) Worked as Civil Engineer on "European Commission Humanitarian Aid Office (ECHO) Drought Relief Project" for Balochistan.
Oct 2000 - Jan 2003	Saadullah Khan & Brothers (S.K.B) Ashqabad (Turkmenistan). Worked as Civil Engineer on construction projects of Turkmen government.
Apr 1999 - Sep 2000	Zareef Khan Kibzai & Brothers Quetta (Pakistan). Site Engineer

EXPERTISE:

- Preparation of project documents, conceptual and detailed estimation of costs.

- Preparation of onsite working drawings for supervisors.
- Well conversant with the processes of project management, disaster management and urban environmental management.
- Well conversant with process monitoring of ongoing projects, onsite support and technical backstopping.
- Development of proposals on construction projects and disaster management.

LANGUAGES

- English
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