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The aim of the conference is to bring together researchers and administrators from different countries, and to discuss theoretical and practical issues in all fields of Engineering, Technology and Basic Sciences.

Articles: 1-5

CONTENTS

The Eurasia Proceedings of
Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Review of Algerian Building Seismic Code(RPA) in Seven Points Compared to American and European Codes / Pages: 45-50

Boulaouad ABDERRACHID, Belagraa LARBI, Bouglada Mohamed SALAH

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
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The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2021

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Synopsis of the Speed Control Methods of Electric Drives with BLDC Motor

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Abstract: The use of BLDC motor has had rapid growth in various applications, in all areas of use of electromechanical systems. This has come as a result of not only the advantages, that have the BLDC motor compared to other types of electric machines of alternating and direct current, but also the possibility of using all control methods to ensure safe and high-precision work, which have given it a very large advantage in adapting it to perform a variety of tasks. Electronic control of BLDC motor gives it the advantage of being suitable for control schemes, starting with the ones with sensors, to determine the position of the rotor, to sensorless methods, from traditional control methods PI, PID and up to advanced and intelligent control methods, or in the production of controllers as integrated circuits, for specific commercial purposes. This advantage makes possible for the motor to be selected for different functions, be flexible and adaptable. BLDC motor control can be accomplished with or without sensor methods. The advantage of sensorless control methods is the realization of the required quality indicators at the lowest cost. But the disadvantage of BLDC control methods without sensors is that it needs a control algorithm and more complex electronic circuits. The purpose of this paper is to examine the different methods of BLDC motor control with sensor and without sensor, to point out the advantages and disadvantages of each, as well as to recommend the field of application of each of these methods. Based on the literature review all of these control methods for electrical transmissions with BLDC motor, will be briefly reviewed in this paper.

Keywords: BLDC motor, Control methods, Sensorless methods, İntelligent control, Advanced control

Introduction

One of the most important issues today is the saving of electricity and reduction of green gases emission. Initially this will be required by the end-users that consume it more. According to the world electricity consumption statistics, electric motors consume 46% of the total electricity consumption (Waide et. al., 2011).

Saving electricity is associated with increasing the efficiency of electric drives. This is made possible by using higher energy efficiency motors on newer electrical drives or replacing them with higher energy efficiency motors on older drives. Using the static converters for control of the electrical drivers, creates the good conditions to control the speed, position or torque of the motors. On the other hand, high efficiency electrical motors have less electrical losses, are more robust and increase the performance of the motors. (Splahiu et. al., 2008; Miller, 1989). On the table 1 there are given advantages of BLDC motors, taken in study on the paper.This paper presents some of the BLDC motor control methods as well as their advantages and disadvantages.

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Table 1. Advantages of BLDC motors (Splahiu et. al., 2008; Miller, 1989).

Advantages of BLDC motors	The reason about these Advantages
Small size Motors	The using of modern permanent magnet makes that BLDC motors to have the smaller size compare to the induction motors.
High efficiency motors	The permanent magnet in the rotor reduces the core losses in comparison with induction motor (AC) and there are no losses in brushes compare of direct current motor with brushes (DC).
Higher speeds	There are no brushes to limit the speed, smaller size, lower inertia. BLDC motors are designed to work with high speed up to 100000 rpm. This motor has losses for low speed.
Low maintenances	Brushes privation, this means that motors don`t need replacement, inspections, or maintenances.
Fast dynamic response	Lower rotor inertia in comparison with the DC and Induction motors.
Lower interference, radio frequency interference, RFI	Eliminations of brushes
Linear mechanical characteristic, speed versus torque.	The internal feedback of the rotor position is the reason of the linear mechanical characteristic of BLDC motors.
High starting torque	The internal feedback of the rotor position creates the possibility of a higher starting torque compared to induction motors with open loop
Speed control	Electronic commutation can be used to control the speed, without increasing the cost of the electrical drive.
Good thermal condition	The element which generates the thermal energy is the stator, that is in the outer part of the motor. compared to DC motor, which has the stator in the inner part of the motor.
More control possibility as induction motors.	Due to linear mechanical characteristic, pole design, and feedback of the rotor position, there are good conditions for better speed and position control.

Applications

The use of BLDC motor has had rapid growth in various applications, in all areas of use of electromechanical systems. The applications of BLDC motor are presented in the table 2

Table 2. The application of BLDC motors. (Xia, 2012)

The field of applications	Equipment
Hybrid and electric autos	Air conditioning, wiper glasses, air bags, electrical doors, control of the seats, fuel pump control, electronic steering control, engine control
Industry	In the industry of robots and manipulators, in the textile machineries, printed machinery, woodworking machinery, paper industry machinery, food industry machines, packaging machines, machinery manufacturing of plastics etc.
Office Equipment	To drive the main shaft of the hard disc, to drive the optic disc and floppy disc. The blower of the computer, Digital Camera, Lesser Printer, Photocopy
Household appliances	Vacuum cleaner, air conditioning, refrigerator, DVD, cd players, camera
Medicine	Respiratory equipment, medical analyzer
Aerospace	High-speed centrifugal pumps, robotic arm control, gyroscope control, high-speed cameras

Method

Based on the requirements of various electromechanical systems, regarding the accuracy, quality of different dynamics during work, in order to meet all the requirements of load, the control method for the BLDC motor is also selected, sometimes combinations of different control methods can also be used to take advantage of the positive sides of each.

In general, if the electromechanical system operates under conditions of immutability of the internal parameters of the motor, with constant load, and when there are no speed control requirements, traditional speed control methods give satisfactory results. In this case the system is seen and treated as a linear system and studied and designed according to well-studied methods. The most commonly used regulators in industrial applications are PI, PD, PID. In case the system is in the conditions of changing the motor parameters, of a change in wide load limits and has high demands on the accuracy of the technological process, then it is presented as a nonlinear

system and its mathematical model is expressed through state equations. The most used methods in this case will be Estimation based methods, Sliding mode Observer, MRAS, Extended Kalman Filter, etc.. (Xia, 2012). Of course each method has its limitations and performance enhancement and optimization of system operation is achieved using intelligent methods where, Fuzzy based control, sliding mode control, neuro-network control, genetic algorithm etc. are included. Intelligent methods do not need a mathematical model of the system, because they are distinguished by their property of analyzing, learning off and on line and finding the optimal solution in each case, when working conditions change (Xia, 2012).

The field of use of the wide range of control methods, provides indicators of high performance of BLDC motor control systems. The control problem is to monitor the state of the system and bring it to the desired state. The initial state of the system must match the desired initial state. While other states must follow the desired state every moment with zero error without endless action but certainly after a transitional process. The tasks included in the BLDC motor control system are: switching the motor through the inverter, providing the pulse to turn the transistor on or off through the PWM strategy. Detection of rotor position using sensors, or sensorless methods. Various control methods are used to improve the performance of electrical drives.

One of the indicators of electrical drives performance is the dynamic output response of the system expressed by the output signal as a function of time. In control systems, the output signal as a function of time is given through two components, the transient response and the continuous response. Sometimes specifications can be added, such as sensitivity from variation of parameters, stability, disturbances, cost, etc. (Kuo, 1975).

Figure 1 shows the typical transient response of the electrical drives and its main indicators.

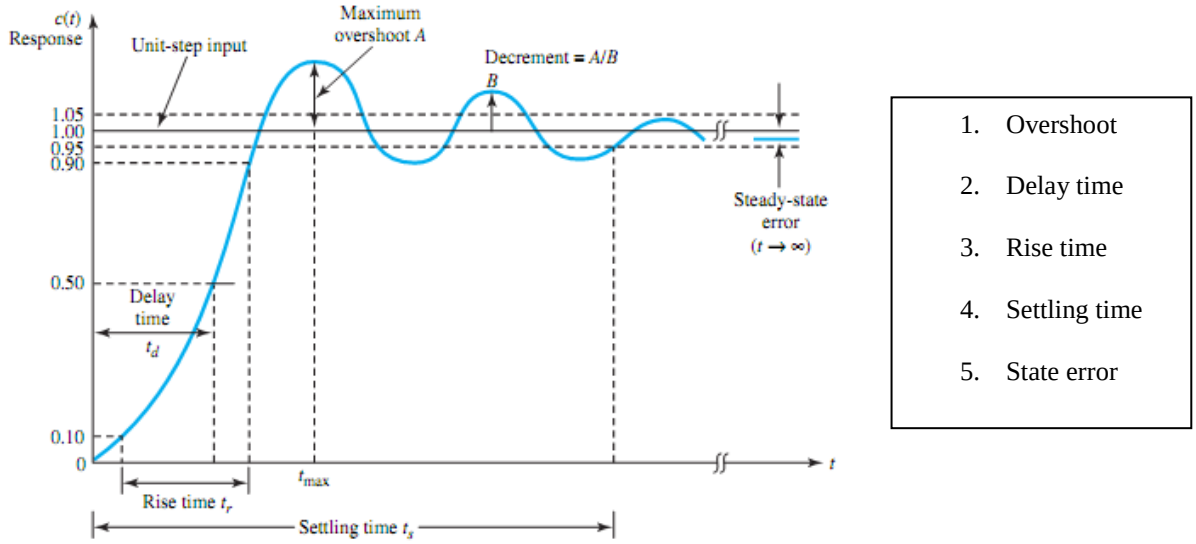

Figure 1. Transient response of the system (Kuo, 1975)

Sensor and Sensorless Control Method

The BLDC motor unlike other motors does not feed the winding phases continuously, but feeds them sequentially according to the rotor position. Depending on the position of the rotor poles it is determined which phase of the coil should be fed and how long. Therefore, different methods have been developed to determine the position of the rotor, two of the most important are as follows:

The method of direct detection of the rotor position, which is realized with sensors and is called the traditional method. Sensors can be the Hall effect sensor, optical encoder, resolver, etc. Methods of indirect detection of rotor position, which are realized by methods without sensors. This is based on an algorithm, which measures the value of voltage or current in the motor (Miller, 1989). Of all the rotor position detection methods, the motor back EMF method is the most elaborate method, which has been used since the beginning of the sensorless method and continues to be used successfully today.

On the table 3 are presented advantages and disadvantages of sensor and sensorless methods, and in the table 4 advantages and disadvantages of detection methods of rotor position. (Xia, 2012; Loreta et. al., 2018)

Table 3. Advantages and disadvantages of sensor and sensorless methods (Xia, 2012; Gamazo-Real et. al., 2010; Loreta et. al., 2018)

Methods	Advantages	Disadvantages
With sensor	Simple schemes	It increases the motor volume, they have higher costs, it causes magnetic interference. They are affected by temperature and humidity and so the accuracy drops. It is difficult to assemble. A small displacement reduces process performance.
Without sensor (sensorless)	Low cost, The motor size decreases, the performance increases.	Requirements for control algorithms. The complexity of electronic circuits increases.

Table 4. Advantages and disadvantages of detection methods of rotor position (Xia, 2012; Gamazo-Real et. al., 2010)

Detection methods of rotor position	Advantages	Disadvantages
Terminal voltage sensing method	It is widely used for low-cost industrial applications such as fans, pumps, compressors that do not require frequent speed variation. They are also used in work tools with very high speed, due to their light weight and small size for the same power.	It needs a position sensor, which can be eliminated by taking the value of back EMF through this method.
Back -EMF integration method	Switching the motor in delay or phase progress is done by adjusting the voltage Vth, and is not sensitive to the switching signal. It reduces sensitivity to switching noises and automatic adjustment of the inverter connection.	There are accumulated integration errors and the threshold setting problem. Problems in the accuracy of back EMF at low speeds.
Third-harmonic back-EMF method	Simplicity in implementation, low sensitivity to noise, wide speed range, small phase delays, compared to the first method. Signal detection at low speeds is possible because the frequency is three times higher. It is used in a range (100–6,000 rpm)	Continuous accumulation of noise signal error at low speeds, errors are made during the integration process, which will cause inaccurate switching.
Freewheeling diode method	High sensitivity, wide adjustment range. It outperforms the previous methods for low speed.	There is error around the zero point of back EMF as well as other methods. Six independent sources are needed in the additional detection circuit which complicates the application. So the detection circuit is a bit complicated and costly expensive.

Traditional Control Methods

In general, if the system operates under conditions of invariability of the internal parameters of the motor, or with constant load, the traditional methods give satisfactory results. In this case the system is seen and treated as a linear system and the selection of the controller and its parameters in such a way that the transient response meets the specified design requirements. On the table 5 are presented advantages and disadvantages of traditional controllers (Kuo, 1975).

Table 5. Advantages and disadvantages of traditional controllers (Kuo, 1975).

Traditional controllers	Advantages	Disadvantages
PD	It is a predictive control. It gives with precision the effect of the required compensation of the error in the stabilized state. It reduces overshoot and increase time of the transient process.	It has an effect on the steady state error only if the error changes with respect to time. If it is constant, then this adjustment does not affect it.
PI	It improves steady state error and damping.	There is a greater growth time and greater set time of the transient process. So, the system is slower.
PID	Overshoot approximately is equal to the PI regulator, Shorter duration. Error in the stabilized state is zero.	

PWM Strategy

In controlling systems with the sensorless method, signal processing and impulse input for switching inverter transistors based on the PWM control strategy, is most useful. Some of the techniques based on this strategy are listed in the table 6, (Xia, 2012; Spahiu, 2009; Gamazo-Real et. al., 2010).

Table 6. Advantages and disadvantages of PWM strategy in sensorless control (Xia, 2012; Spahiu, 2009; Gamazo-Real et. al., 2010).

PWM strategy in sensorless control	Advantages	Disadvantages
PWM technique for low speed and voltage	With signal amplification and offset voltage adjustment, the speed range of the motor, that can use this technique, is greatly expanded. (50-2500) rpm	Difficulty in detecting back EMF, due to its very small values. An amplifier is used as the preliminary circuit to adjust the offset voltage and amplify the signal near the zero-crossing point.
PWM technique for high speed and voltage	With the reduction of the motor time constant due to the voltage and high-speed technique, it is successfully used for speeds up to -30000 rpm.	Difficulty of connection in time, frequency of connection disconnections very large. Additional elements, such as resistors and diodes, are used to reduce the time constant and avoid errors leading to erroneous detection due to delays, as well as diodes to block the passage of current to additional resistors.
PWM technique for low power applications	Significantly reduces the voltage drop caused by the connection of the resistor to the power circuit, the load current, compared to the positive voltage drop of the diode. Power consumption and heat loss are significantly reduced.	The problem in these schemes is to reduce power consumption and losses, which are reduced by the way of command and control and the addition of a resistor in the power circuit.
Direct current control (Hysterezis current control)	In order for the phase currents to be as close as possible to the reference currents the regulator bands need to be as narrow as possible. Reducing the hysteresis, the regulator band increases the switching frequency. Better performance than PWM technique.	The cost of static converter component increases and also the losses in it from increasing the frequency due to the reduction of the regulator band. The hysteresis regulator band takes 5% of the reference currents. Variable frequency compared to the PWM technique, which has a constant frequency.

Advanced Control Method

In traditional control of BLDC motor drives, the mathematical model of the system must be known. The closer this model is to the real one, the better its performance indicators are. But again, in the mathematical equations of the model there are inaccuracies which are divided into two major groups:

1. The inaccuracies that include the difficulty of recognizing the parameters of the model, or even changing them during load operation.
2. The inaccuracy of mathematical model presentation, and non-modellable dynamics.

The sliding mode is a control method that ensures that quality requirements are met even in the presence of inaccuracies, because it finds a control law capable of adapting. In table 7 are presented advantages and limitations of advance control methods (Xia, 2012; Gamazo-Real et. al., 2010).

Intelligent Control Methods

The intelligent control system combines the techniques of the field of artificial intelligence, with those of control engineering to design autonomous systems which can understand, reason, plan, learn and act in an intelligent way. Such a system must be able to achieve the desired consistent behavior in conditions of uncertainty, with regard to the plant model, with unpredictable changes in the environment, uncertainties, incomplete, incorrect, unreliable information of the sensor and improper functioning of the actors.

The intelligent control system has several subsystems. The perceptual subsystem that collects information from the plant and the environment, and processes it in a form suitable for recognition by the subsystem. Under the recognition system associated with the decision-making process under conditions of uncertainty. Key activities include reasoning, strategic planning, learning. The operating subsystem uses signals from the recognition

subsystem in order to operate the plant in certain desired states. If the action of the actor or sensor fails, then the intelligent control system is available and is able to reconfigure its control strategy. In table 8 are presented Advantages and problems of intelligent control methods (Xia, 2012).

Table 7. Advantages and limitations of advanced control methods (Xia, 2012; Gamazo-Real et. al., 2010; Zhixun et. al., 2018; Lenine et. al., 2007; Nicosia et. al., 1984; Sugimoto et. al.; 1987).

Advanced control methods	Advantages	Limitations
Estimation and model- based method	Simplicity of design is the biggest advantage of using the observer. It can evaluate all measurable states or not in the system model	
Applications	PMSM, BLDC, etc.	
Sliding- mode observer (SMO) DTC techniques	It is very efficient in assessing the conditions of the system, it is robust against the variation of parameters and concerns including measurement noises. Also with the introduction of DTC Technical, an optimal performance is achieved even in the area of low speeds, because the change in the value of the stator resistance can be taken into account. These bugs are solved through the DTC space vector modulation scheme, which uses a constant frequency switching.	This method applied in practice has the problem of high voltage values given by the power supply and stress caused on static power converters. To improve the control performance, we can use digital observer. However, hysteresis-based DTC methods have some serious drawbacks: High torque pulse, flow pulse, inverter switching variable frequency. Great time for calculations.
Applications	Position control in induction motor uses FPGA, which has implemented sensorless SMO for PMSM drives. It is robust and has a high performance. BLDC motor.	
Extended Kalman Filter (EKF)	Rotor position and speed can be estimated with sufficient accuracy in both steady and dynamic states Achieves a rapid convergence.	Intensive calculations
Applications	The BLDC motor without position and speed sensors has attracted wide attention. Extended Kalman filter will be employed to estimate the motor state variables by only using measurements of the stator line voltage and current. When applying the extended Kalman filter, it is necessary to solve some specific problems related to the voltage and current waveforms of the BLDC motor. EKF will be designed and implemented for the estimation of speed and rotor position of BLDC motor, so the motor could run at low speed with reasonable accuracy.	
Model Reference Adaptive System (MRAS)	It is also used in cases of estimating the resistance value of the stator and rotor when the sensorless control system is in the transient state, such as operating under a wide variation of the load moment or the change in the speed command. The scheme of an active power MRAS is based on the identification of rotor resistance, the evaluation of which is effective, over a wide range of variations and can be applied in real time Field Oriented Control (FOC).	One of the advantages is the high speed of adaptation. It is relatively easy to be implemented in a quick adaptation for a large application area.
Applications	For some problems concerning the control of multifunctional manipulators (industrial robots) with high-speed continuous movements, highly interconnected and non-linear, whose model is known, approaches based on the Model Reference Adaptive System (MRAS) method of control are possible and useful. A generalized MRAS control assures the convergence to a suitable reference model for a class of processes. Model reference adaptive systems (MRAS) are used to identifies the secondary resistance under any load and any speed in induction motor, also in BLDC motor.	

Results and Discussion

What control methods are used for the BLDC motor? It's a question that seeks for an answer for anyone starting to study the BLDC motor and its control. Confusion increases with the number of methods used. The paper tends to make a summary of control methods, advantages, disadvantages of each, as well as a brief information on their use without indicating what is the principle on which each method is based. From the literature review it is shown that for BLDC motor can be used all kinds of control methods from those with sensors to methods without sensors, from traditional methods to intelligent ones. This means that any kind of performance we want through the BLDC motor can be provided, as we can switch from one method to another that compensates for

the shortcomings of the former.From the methods based on the correct mathematical model of the motor, to methods that even allow inaccuracies of the model to those that do not need a mathematical model at all.

Table 8. Advantages and problems of intelligent control methods (Xia, 2012; Gamazo-Real et. al., 2010; Levine, 2010; Singh et. al., 2015; de Barras Ruano, 1992; Wang et. al. 2003).

Intellıgent Control	Advantages	Problems
Fuzzy logic Control	Requires less calculation, good reasoning skills, It has good durability and adaptability.	There is no ability for new rules, and very poor learning skills
Applications	Automobile and other vehicle subsystems, such as automatic transmissions, ABS and cruise control, Air conditioners; Cameras; Digital image processing, Rice cookers; Dishwashers; Elevators; Washing machines and other home appliances; Pattern recognition in Remote Sensing; Hydrometeor classification algorithms for polarimetric weather radar; Fuzzy logic has also been incorporated into some microcontrollers and microprocesors.	
Artificial Neural-Network Control	It has very good ability to solve structured uncertainty and system concerns. It learns very well. The ability to perform arbitrary nonlinear mappings. Allowing traditional control schemes to be extended to the control of nonlinear plants. This can be done without the need for detailed knowledge of the plant. The ability to create arbitrary decision regions means that they have the potential to be applied to fault detection problems. The use of ANNs is the duty of control managers, deciding which control algorithm to employ based on current operational conditions.	Requires more computing capacity and more memory space, but lacks good reasoning skills. .
Applications	Robots are nonlinear, complicated structures. Robotics was one of the first fields where ANNs were applied. It is still one of the most active areas for applications of artificial neural networks. ANNs have also been applied to sensor failure detection and diagnosis. The use of neural networks, in the three different capacities of identifiers, pattern recognizers and controllers, to detect, classify and recover from faults in control systems. Neural networks can also provide, significant fault tolerance, since damage to a few weights need not significantly impair the overall performance.	
Genetic Algorithm	Can optimize online and offline settings to get a better performance out of control.	Requires longer computation time and more memory space
Applications	GAs is applied in many different areas, such as signal processing, game playing, robotics, image segmentation, scheduling and control engineering. Application of GAs in Control Engineering, PID Control, Optimal Control, Robust Control, System Identification, Online Adaptive Identification and Control.	

Conclusion

The BLDC motor is the motor with with the highest increase in propagation in various applications because it provides very good and excellent properties, such as linear mechanical characteristic, lower losses, higher torque density and higher power density, noiseless operation, etc. The feature that has always attracted attention is the very high efficiency compared to other AC and DC motors of the same power. Experimentally tested and as written in the literature reference, the BLDC motor has a less moment of inertia than the IM motor. Its impact appears to be on the dynamic response with smaller starting currents, shorter stabilization time and faster stopping. For this reason the BLDC motor is more suitable especially in variable speed electric drives. Using this motor brings a higher performance.

On the other hand, electronic schemes greatly influence the use of control methods. For BLDC motors sensor methods or sensorless control methods, traditional methods, advanced methods and intelligent methods can be used. But a combination of methods can be realized not only of the same nature, but also of different natures to take benifits of the advantages of each of them, such as traditional method with intelligent method, etc. The type of control method is selected according to the requirements that must be met by the electric transmission with BLDC motor.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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Statistical Modelling of the Compressive Strength of Mortar Based on Cement Blended with Mineral Additions by the Method of Experimental Design

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Abstract: This experimental study aims to study the mechanical behaviour of a mortar based on cement blended with mineral additions (pozzolana, limestone and slag), knowing that the mechanical strength of a mortar is closely related to its composition. The use of the three mineral additions simultaneously, presents a high number of factors affecting the mechanical resistance and requires a very large number of experiments and the obtained data analysis becomes much more complex. In order to optimise the number of tests and to achieve a such satisfactory analysis, a statistical approach known as an "experimental design" was used. The experimental methodology has been established to assess the compressive strength of mortars at 2, 7, 28 and 60 days, by the elaboration of an experimental design for a set of cement mixtures, the level of the three additions (factors), slag, limestone and pozzolana at rates varying from 0% to 35%, provided that a fixed dosage of 35% is maintained for all combinations to form a binary, ternary and quaternary cement in accordance with cement standard requirements CEM II/B. This statistical approach allowed us to evaluate by a numerical analysis the effect of each addition alone as well the meaning of the double or triple interaction resulting from the association of two or three additions at a time. In addition, it has enabled us to establish a representative model that permitted to estimate and predict the mechanical behaviour of any composition in the experimental program with tolerable errors. The obtained results lead to a satisfactory numerical modeling of the compressive strengths, in particular at the age of 28 days, with a trend curve of a an acceptable determined coefficient of R^2 equal to 0.87.

Keywords: Compressive strength, Mortar, Mineral additions, Statistical analysis, Experimental design**.**

Introduction

The cement industry has been transformed by the use of mineral wastes such as silica fumes, fly ash and blast furnace slags as cement-based additions through the economic, environmental and functional benefits (Kerbouche, 2009), whose purpose to value this waste, knowing that these mineral additions have interesting hydraulic and pozzolanic properties.

The properties of a cement are closely related to its composition, therefore the behavior of mortar with mineral additions that are influenced by the nature, hence the diversity of the additions in their chemical, mineralogical

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composition and their reactivity property, which differs from one to another, either active or not (Paillere et. al., 1977).

This influences the properties of a mortar differently with respect to the effect size of such addition and the significance of the interactions among them according to the type of the binary, ternary or quaternary cement type.

The majority of studies going in one direction pointed a trend towards the use of mineral additions. It is in this development action that we studied binary, ternary and quaternary cements, combining clinker with three additions, when analysis of the results remains very complex. On the other hand, a practical and computerized statistical approach called "experimental design" (Jacques et. al., 2013) which minimizes the number of tests, optimizes the mixtures and allows a modeling of the studied response, it is an experimental method whose use is very advanced in many areas.

In addition, this approach has proved satisfactory in several works in the field of materials (Caré *et al.*, 2000). This method of experimental design has been adopted for the study of the mechanical response of a mortar based on blended cement in the present research work.

Materials

In this experimental program local materials were used. The clinker obtained from Ain Kebira's cement factory (from Sétif is from Algeria). The gypsum from a depository quarry in Djemila (Sétif- Algeria). Granulated blast furnace slag is a by-product of the El-Hadjar (Annaba- Algeria) iron driven from a steel complex. The natural pozzolana from the Beni-Saf deposit (Ain T'emouchent- Algeria) quarry. The limestone used in the study is obtained from the region of Sétif east of Algeria. The standardized sand for mortars confection, was used according to the European standard (NF EN 933-1, 1999; NF EN 933-2, 1999). The chemical composition of the various base materials used is shown in Table 1.

Table 1. Chemical composition of the materials used

	SiO_2	Al_2O_3	CaO	Fe_2O_3	MgO	SO_3	K_2O	CL	Na_2O
Clinker(C)	21,38	4,25	65,55	5,32	1,72	0,58	0,35	0,005	0.35
Gypsium(G)	10.05	2.99	26.90	1.55	3.86	30.33	0.41	0.007	0.05
Pozzolana(P)	40.00	18.80	15.90	9.00	5.23	2.00	2.26	0.012	0.41
Slag(S)	29.00	11.30	46.00	1.35	8.12	1.98	0.48	0.047	0.67
Limestone(L)	15.20	2.34	78.70	1.73	1.04	0.56	0.32	0.003	0.15

The physical properties of the various materials used are presented in Table 2.

Table 2. Physical properties of materials used

Materials	Specific density (g/cm^3)	Bulk density (g/cm^3)	Fineness (cm^2/g)
Clinker (C)	3.22	1.04	3490
Gypsum (G)	2.50	0.91	3500
Pozzolana(P)	2.62	0.95	3900
Limestone(L)	2.68	0.97	3800
Slag (S)	2.79	0.98	3215

Experimental Procedures

Experimental design

We have chosen a mixture of three quantitative factors (A, B and C) which represent three mineral additions (Pozzolana, Limestone and slag), the delimitation of the range of variation of the chosen factors is limited to a percentage maximum level of 35% in the mixtures as replacement of a CEMII-B cement. Clinker and gypsum

remain unchanged at 65 % amount. Thus, a plan of mixture of types I (plan network) is considered in such case, according to the following construction (Cohen, 1989).

Table 3.Construction of the experiment plan

Factors	Name	Unit	Type	Minimum	Maximum
A	Pozzolana (P)	%	Mixture	0	35
B	Limestone (L)	%	Mixture	0	35
C	Slag(S)	%	Mixture	0	35
				Total =A+B+C = 35 %	

Mechanical responses

The mechanical properties are to be measured for the variation of the factors mainly, the compressive strength of the mortars tested at the age of 2, 7, 28 and 60 days and designated as R_{C2}, R_{c7}, R_{c28} , and R_{c60}

Mixtures Plan

In order to optimize the number of tests, and consequently the number of mixtures to be prepared, which correctly meet our expectations, we used a practical and computerized statistical approach called "experimental design", carried out using software (Expert Design). the number and the composition of the mixtures are chosen by the experimental plan with arrangement in convenience to our purpose (Table 4).

Table 4.Composition and designation of prepared cements (% by weight of cement).

Designation of cement		Composition of cement mixtures (%)				
Type of cement	Name Mix	Clinker (C)	Gypsium (G)	Pozzolana (P)	Limestone (L)	Slag (S)
Binary	CB1	60	5	35	0	0
	CB2	60	5	0	35	0
	CB3	60	5	0	0	35
Ternary	CT1	60	5	7	0	28
	CT2	60	5	0	7	28
	CT3	60	5	0	28	7
	CT4	60	5	28	7	0
	CT5	60	5	28	0	7
	CT6	60	5	7	28	0
	CT7	60	5	21	14	0
	CT8	60	5	0	21	14
	CT9	60	5	0	14	21
	CT10	60	5	21	0	14
	CT11	60	5	14	0	21
	CT12	60	5	14	21	0
Quaternary	CQ1	60	5	21	7	7
	CQ2	60	5	7	21	7
	CQ3	60	5	7	7	21
	CQ4	60	5	14	14	7
	CQ5	60	5	14	7	14
	CQ6	60	5	7	14	14
	CQ7	60	5	12	12	12

Results and Discussion

Tests of the compressive strength measured at the age of 2.7,28 and 60 days, on prismatic test specimens ($4 \times 4 \times 16$) in accordance with European standard (EN 196-1, 2005) were prformed. The results are reported in table 5, below

Table 5. Results observed of the mechanical strengths of mortars tested at the age of 2.7,28 and 60 days

Type of cement	Designation (Mix)	Mineral additions %			Compressive strength			
		P	L	S	RC_{2J}	RC_{7J}	RC_{28J}	RC_{60J}
Binary	CB1	35	0	0	10.16	20.12	31.68	35.89
	CB2	0	35	0	9.83	20.32	28.07	29.99
	CB3	0	0	35	11.01	22.29	39.48	44.78
Ternary	CT1	7	0	28	11.68	24.23	37.81	46.64
	CT2	0	7	28	11.30	23.40	37.82	43.98
	CT3	0	28	7	9.93	20.54	31.03	39.56
	CT4	28	7	0	9.82	20.91	30.91	36.23
	CT5	28	0	7	10.12	21.02	33.58	37.36
	CT6	7	28	0	10.33	23.19	26.57	30.82
	CT7	21	14	0	11.18	23.79	34.13	38.49
	CT8	0	21	14	11.18	21.59	33.49	33.26
	CT9	0	14	21	12.55	24.33	34.95	41.49
	CT10	21	0	14	8.79	20.64	36.33	41.04
	CT11	14	0	21	11.58	21.68	35.27	39.44
	CT12	14	21	0	11.13	21.90	29.89	33.10
Quaternary	CQ1	21	7	7	9.80	20.38	34.51	36.36
	CQ2	7	21	7	11.47	22.87	35.08	34.08
	CQ3	7	7	21	10.37	24.20	36.18	42.46
	CQ4	14	14	7	10.59	22.85	35.11	39.30
	CQ5	14	7	14	10.44	21.83	34.92	43.58
	CQ6	7	14	14	10.55	23.54	36.80	43.00
	CQ7	12	12	12	10.88	24.54	35.55	39.57

The Early Compressive Strength at 2days

Through the analysis of Figure 1, which represents the variation of the compressive strength measured for the mortars studied, the best strength of 12,5 MPa is recorded for ternary composition (slag - limestone) with a dominant percentage due to slag of 21% compared to a rate of 14% for limestone, this is due to the positive interaction of slag and limestone, as long as the limestone acts by its nucleation and condensation role which improves the microstructure at a young age and on the other hand the early reactivity of the slag which positively affects the microstructure and improves the resistance, some authors report that with the addition of limestone, there is an increase in mechanical resistance at young age due to the accelerating effect and the filling effect; the filler effect of limestone. It should be noted that for a thinness of 300 to 350 m²/kg, only the filling effect is considered (Amouri, 2009).

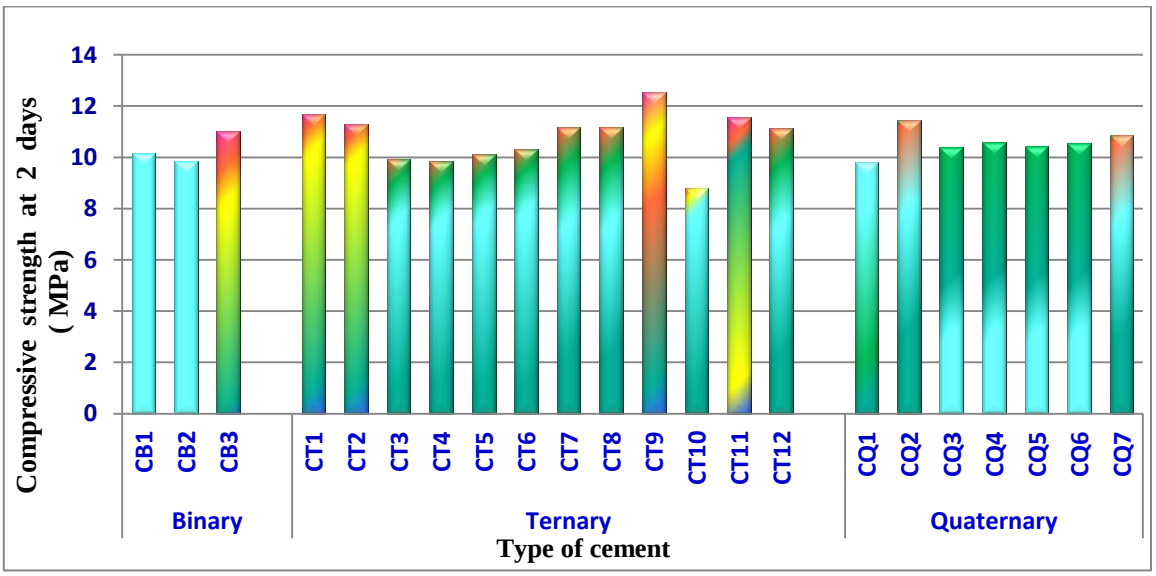

Figure 1. Variation of the compressive strength results of the mortars at the age of 2 days.

Nevertheless, the limestone becomes less beneficial beyond a rate of 14% and plays a detrimental role with a rate higher than 21% for all types of ternary and quaternary compositions. Noting that combinations (slag-pozzolane) are acceptable in all compositions. Overall the slag which remains the best addition that has a considerable effect at young age compared to pozzolana and limestone which are less beneficial in binary compositions with rates up to35%.

The Compressive strength results at 7 days

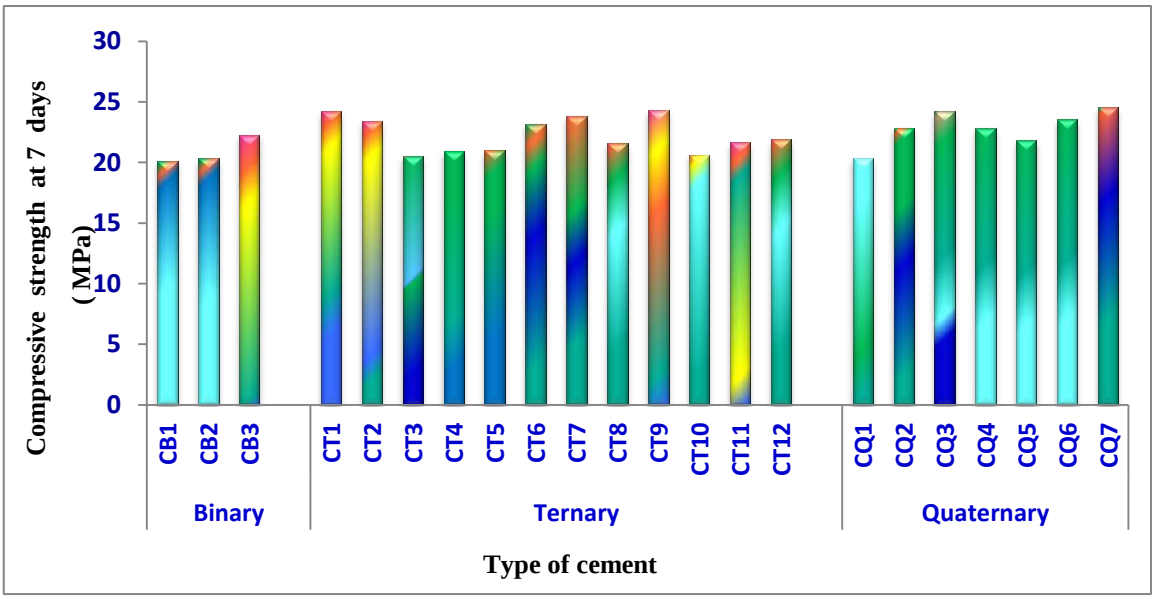

Figure 2. Variation of the compressive strength measured of the mortars at the age of 7 days.

The results of the compressive strength measured at the age of 7 days shown in Figure 2 show that the variation of the compressive resistances follows the same trend as that of the 2-day resistances, preserving the dominance of the slag effect, either in the binary compositions, or by double interaction with pozzolana or limestone with rates lower than 14% in ternary and quaternary compositions. Noting that the evolution of resistance is important and resistances are evolved from 100 to 80% compared to resistances at the age of 2 days.

The Compressive Strength Results at 28 Days

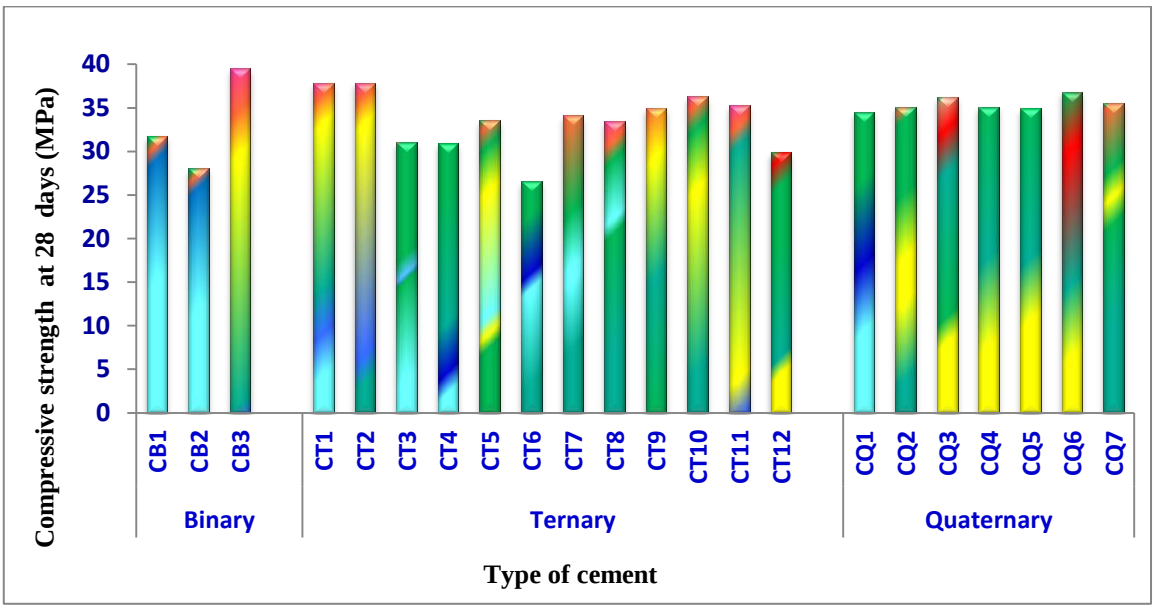

Figure 3. Variation of the compressive strength measured of the mortars at the age of 28 days.

Figure 3, which represents the variation of the compressive strength measured at 28 days, shows the best resistance of 39.48 MPa for binary composition with 35% of the slag replacement. This shows that the reactivity of the slag is in its advanced state for better participation in the formation of hydrates and their beneficial arrangement in the microstructure. Typically, between 7 and 28 days, resistance–is similat to that of control (Tokyay, 2016).

On the other hand, the lowest resistances are recorded for limestone with a rate of 35% for binary composition and 21 and 28% for ternary compositions with values of (28.07, 26.57 and 29.89 Mpa) respectively, which represents values below the guaranteed strength for cement II/B type.It should be noted that the reactivity of pozzolana begins to increase at the age of 28 days and manifests binding properties (Miller, 1993). . Noting the significant effect of the interaction (pozzolane-limestone) with limestone levels less than 21% and the effect of the double interaction (pozzolana-Slag) which sows better performances for all compositions. For the quaternary compositions it is noted that all the studied combinations ensure a guaranteed resistance greater than 30 MPa.

The Compressive Strength Results at 60 Days

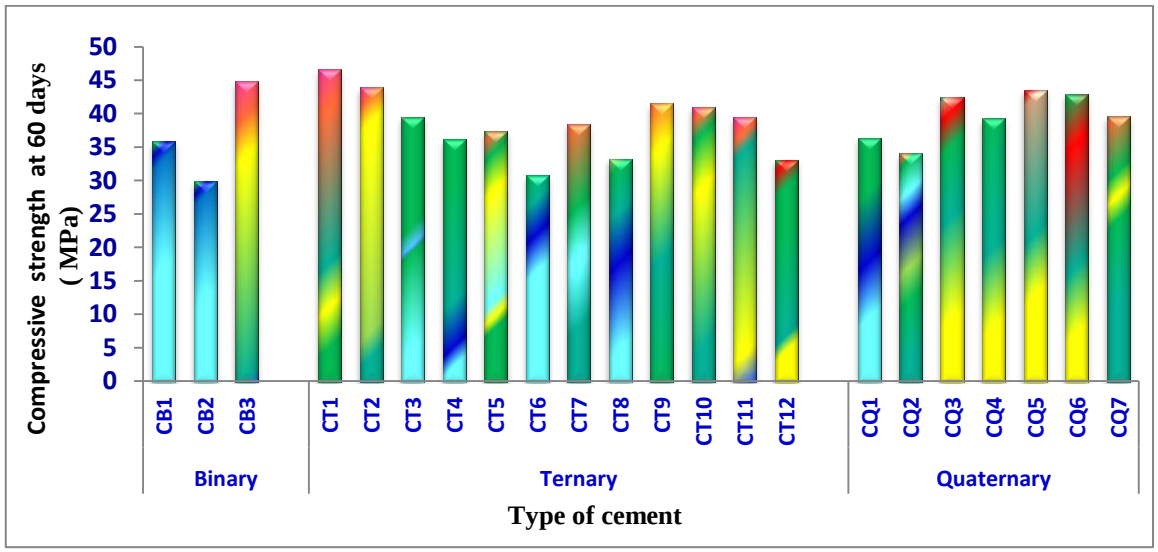

Figure 4. Variation of the compressive strength measured of the mortars at the age of 60 days.

Through the analysis of Figure 4, which represents the variation in compressive strength measured for the mortars studied at age 60 days, the best resistance values of 44.78 and 46.64 Mpa are recorded respectively for a binary composition of 35% of the slag and a ternary composition (slag – pozzolane) with a dominant percentage of the slag of 28% compared to a rate of 7% for the pozzolane, this is due to the positive interaction of the (Pouzzolane-slag), which reflected the reactivity of the two additions and the maturity of the microstructure. This is the case for a study (Kerbouche *et al.*, 2009) which concluded that the natural beni-saf pozzolane contributes positively in the long term.

At the age of 60 days the evolution is less important, nevertheless that all the registered resistances exceed 30 MPa which represents the threshold of the resistance guaranteed for a Cement II/B, with the exception of the binary composition with 35% of the limestone which remains below the guaranteed resistance.

Modeling Of The Compressive Strength

Model Summary Statistics for Compressive strength

The modeling of the mechanical behavior relative to the results measured by the experiment program consists in the choice of a model which represents a trend in the curve with a correlative coefficient of (R^2) better and close to 1. This reflects good convergence with minimal deviations between the results predicted by the model and those measured experimentally. The statistical results are reported in the following Table 6.

Table 6. Model Summary Statistics for Compressive strength

Model	R-Squared (R^2)			
	$\mathbf{RC_{2i}}$	$\mathbf{R_{C7i}}$	$\mathbf{RC_{28i}}$	$\mathbf{RC_{28i}}$
Linear	0.252	0.226	0.755	0.704
Quadratic	0.43	0.575	0.843	0.744
Special Cubic	0.483	0.576	0.868	0.754
Cubic	0.599	0.731	0.893	0.780

Modeling of the Compressive Strength at 2 Days

Table 7. Equation of the Compressive strength model at 2 days of age (Équation 1)

$\mathbf{RC_{2i}}$ =	0.29	* P
	+ 0.27	* L
	+ 0.316	* S
	+ 0.00399	* P * L
	- 0.000757	* P * S
	+ 0.0042	* L * S
	- 0.000428	* P * L * S
	- 0.000118	* P * L * (P-L)
	- 0.000177	* P * S * (P-S)
	- 1.76E-05	* L * S * (L-S)

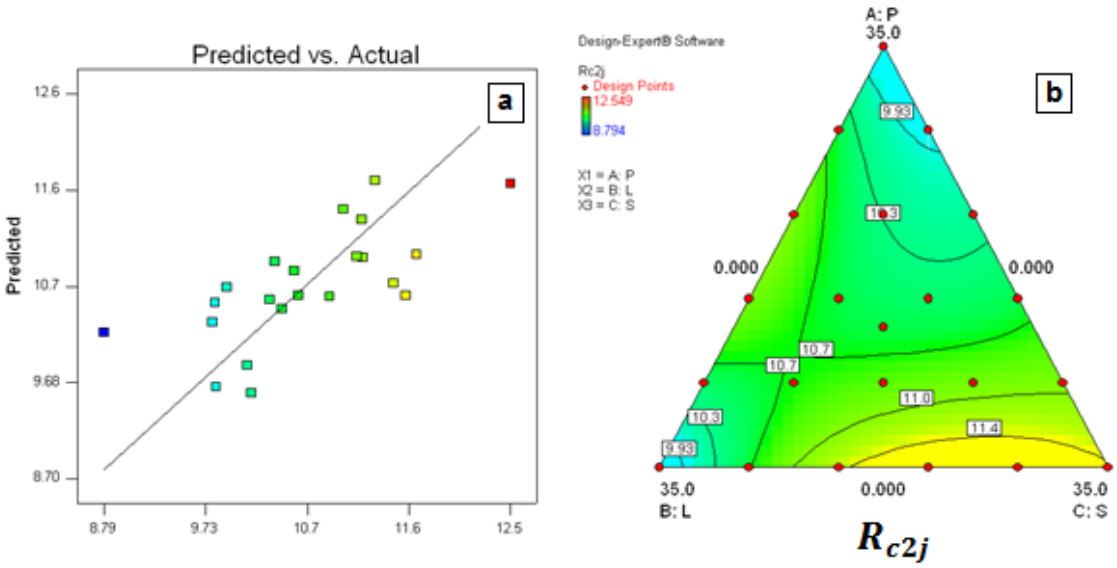

Figure 5. Compressive strength at 2 days a) Correlation between observed values and the model, b) Variation of compressive strength according to the model.

The suggested model records a coefficient of determination (R^2 = 0.599) for the cubic trend curve Figure 2. (a), but this coefficient remains unsatisfactory and the suggested model remains unrepresentative, no good correlation between the expected results and those actually achieved and which are very distant, with very large differences, given these results, in this case we cannot adopt this modelling which proves to be unsatisfactory.

Based on the results presented in a triangular diagram (Figure 5). It is noted that the 2-day compressive strength is relatively greater for binary cement with slag and ternary and quaternary cement with slag dominance, which is decisive in short-term resistance compared to the lowest results recorded at the level of binary cements; limestone and pozzolane). Since the correlation coefficient is quite low, the interpretation and analysis of the results at this age of 2 days can only be considered as indicative and not predictive.

Modeling of the Compressive Strength (7 Days)

Table 8. Equation of the Compressive strength model at 7 days of age (Équation 2)

$\mathbf{RC_{7j}}$ =	0.586	* P
	+0.578	* L
	+0.64	* S
	+0.00833	* P * L
	+0.000584	* P * S
	+0.00517	* L * S
	+0.00012	* P * L * S
	-0.000221	* P * L * (P-L)
	-0.00029	* P * S * (P-S)
	-0.000247	* L * S * (L-S)

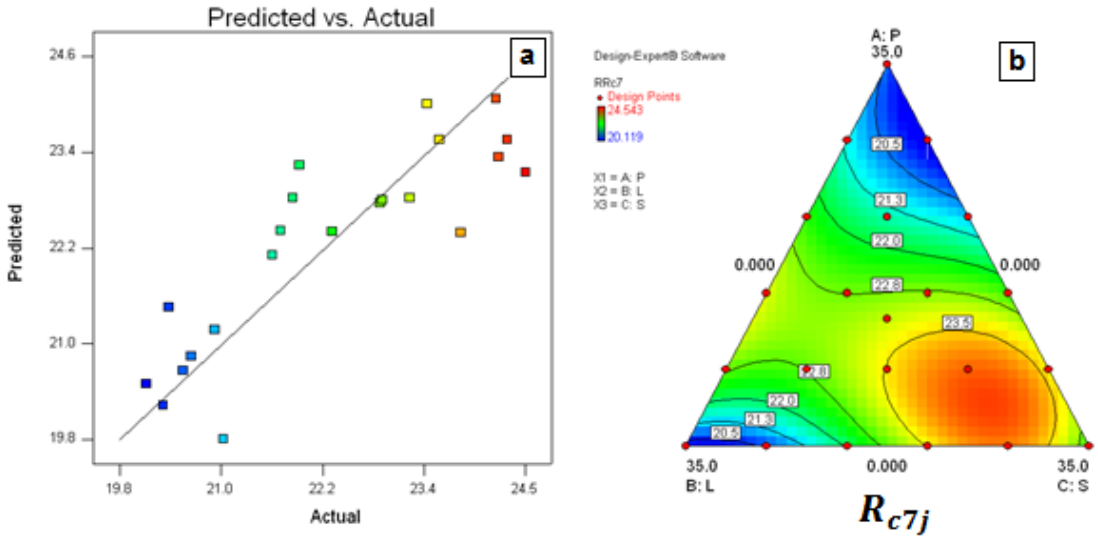

Figure 6- Compressive strength at 7 days: a) Correlation between observed values and the model, b) Variation of compressive strength according to the model.

The proposed model is a cubic model that takes into consideration the triple order interactions with side effects, this model is represented by equation 2, with an adjusted trend curve with a satisfactory coefficient of determination R^2 = 0,731 Figure 6 (a), which reflects a good correlation between expected and observed results with non-significant differences, which supports the effectiveness of the model which can be adopted with satisfaction.

Figure 6 (b) explains the variation in compressive strength at the age 7 days for the results obtained and expected. It is noted that through the predictions of the model it is possible to develop better values of compressive strength for quaternary cements with slag dominance. For binary compositions, pozzolana and limestone do not develop as good resistance to young age compared to Slag. The interaction is better between the (slag-pozzolana) and (slag-limestone) with low levels of pozzolana and limestone.

Modeling of the Compressive Strength (28 Days)

Table 9. Equation of the compressive strength model at 28 days of age (Équation 3)

$\mathbf{RC_{28j}}$ =	0.916	* P
	+0.781	* L
	+1.11	* S
	+0.00477	* P * L
	-0.000179	* P * S
	+0.00503	* L * S
	+0.00114	* P * L * S

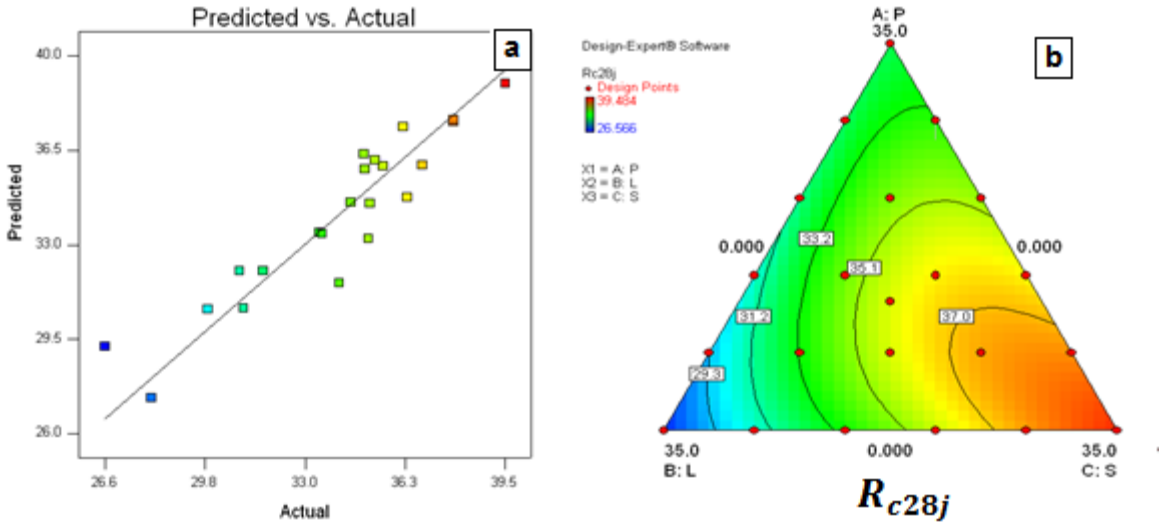

Figure 7. Compressive strength at 28 days : a) Correlation between observed values and the model, b) Variation of compressive strength according to the model.

The model proposed and represented by Equation 3 is a cubic model, which is limited to the consideration of triple simple order interactions (P-L-S). This model shows a satisfactory correlation between the expected results and those actually obtained illustrated by a trend curve Figure 7 (a) with a coefficient of determination (R^2 = 0.868), the model can be adopted with good satisfaction.

Figure 7 (b) shows the variation of compressive strength at the age of 28 days for the results obtained and those expected. The analysis of the expected and proposed results of the model is similar to the analysis made for the actually measured results, it is noted that the resistance becomes very important around the top (c) corresponding to the slag addition, which develops the best resistance the case of a binary cement and a significant interaction with limestone and pozzolane where the slag is dominant the case of ternary or quaternary cements, which explains the significance of the effect of the slag at this age. In addition, it can be noted that resistance in the vicinity of the pozzolane is acceptable for binary, ternary and quaternary cements. On the other hand, near the limestone tip, low resistance develops for ternary and quaternary cements, in particular a resistance lower than the resistance guaranteed for an CEM II/B in the case of binary cement with limestone.

Modeling of the Compressive Strength (60 Days)

The suggested model for 60-day compressive strength is represented by equation 4, it is a specific cubic model, which takes into account triple interactions, this model shows a satisfactory correlation illustrated by a trend curve Figure 8 (a) with a coefficient of determination (R^2=0.754), the model can be adopted with good satisfaction. Figure 8 (b) shows the variation in compressive strength at the age 60 days for both the results obtained and those expected. The analysis of the expected and proposed results of the model is similar to the analysis made for the actually measured results.

Similarly, the reading of the results and the analysis of the variation of the compressive strength at the age of 60 days, the significance of the effects of each addition as well as the double and triple interaction between different additions, remains similar to reading done for compression resistance at the age of 28 days with a regular and less important evolution of resistance at the age of 60 days.

Table 10. Equation of the Compressive strength model at 60 days of age (Équation 4)

RC_{60j} =	1.03	* P
	+0.865	* L
	+1.31	* S
	+0.00538	* P * L
	+4.16E-05	* P * S
	+0.00415	* L * S
	+0.00107	* P * L * S

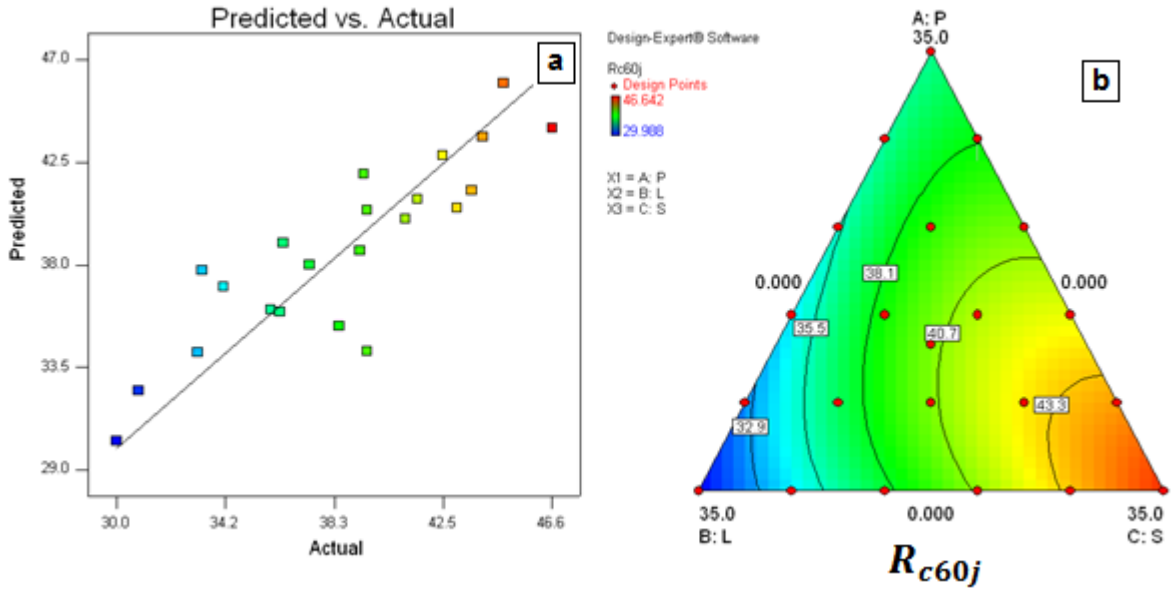

Figure 8. Compressive strength at 60 days a) Correlation between observed values and the model, b) Variation of compressive strength according to the model.

Conclusion

The results obtained from this study allow the following conclusions to be drawn:

The experimental design analysis could lead to a modelling which would give a relatively acceptable satisfaction to the analytical design and the explanation of the phenomenon studied in this case the mechanical response particularly in terms of estimation of the effects of the additions and the quantification of interactions, thus the delimitation and localization of the zones of amplification of the resistance which allows a good understanding of the mechanical behavior of a quaternary and ternary cement which resides complex without this tool.

With regard to the prediction of the results, it is found that the models estimated values close to those of the experiment, in particular for the characteristic compressive strength at 28 days, when the model was very close to the real phenomenon with very small differences.

However, it cannot be denied that there is a divergence in the results expected by the model, resulting in large differences and a very low coefficient of determination in the case of the 2-day compressive strength, This leads us to carry out complementary experiments for the refinement of the results.

This confrontation allowed us to estimate with tolerance the degree of conformity of these models with the real phenomenon (the mechanical response) of a quaternary cement, ternary and binary compositions. Thus, the model obtained will always be imperfect but it does not prevent that it can serve as an indicator in terms of analysis and prediction.

Finally, it could be concluded all compositions belonging to the field of study limited to a rate of addition of 35%, are acceptable in regards to mechanical performances with the exception made for the compositions with limestone percentage higher than 21% that show lower strength in comparison with almost tested mixtures.

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Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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Enhancement the Biological Behavior of Titanium Dental Implants by Laser Pulses Treatment

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Abstract: The long-term success of dental implants largely depends on rapid healing with safe integration into the jaw bone. Geometry and surface topography are crucial for the short and long-term success of dental implants. This work aim to enhancing clinical performance of titanium dental implants by laser Pulses treatment to provide bone in a faster and improved osseointegration process. The results show that using different manufacturing processes (machining and powder technology) produced topographical differences. The topographical change observed from powder technology method was more than the machined one. Also Strong titanium oxide layer was observed after laser pulsed resulted in improving surface roughness and topography and it was the method of choice for complex surface geometries providing energy focused on one spot especially in the inside of implant thread. The release of Ti ion rise in first three days and after that released of Ti ions begins to stabilize after laser treatment. Finally, the histological view of implant samples after 4weeks of implantation, showed active bone formation in all implant surface which give clear indication of tissue acceptance and the appearance of mature bone was observed after laser treatments at short implantation periods.

Keywords: dental implants, osseointegration, powder technology, laser pulsed, histological view.

Introduction

The long-term success of dental implants largely depends on rapid healing with safe integration into the jaw bone. Geometry and surface topography are crucial for the short and long-term success of dental implants. Implant surfaces have been developed in the last decade in a concentrated effort to provide bone in a faster and improved osseointegration process. Osseointegration, defined as a direct structural and functional connection between ordered,living bone and the surface of a load-carrying implant, is critical for implant stability, and is considered a prerequisite for implant loading and long-term clinical success of endosseous dental implants. Osseointegration of titanium implant surfaces is dependent upon both physical and chemical properties (Johansson et. al., 2005). Surface properties of biomaterials are important parameters influencing cellular reactions towards artificial materials. The properties of dental implant surfaces are extremely important in influencing the healing process leading to osseointegration and ultimate clinical success of the implant. Surface morphology modulates the response of cells to a dental implant, and surfaces with defined microstructures may be useful for enhancement of the stable anchorage (Al Hasani, 2020).

These modifications may subsequently influence conformational changes in the structures and interactive natures of adsorbed proteins and cells. Furthermore, within the complexities of an in vivo environment containing multiple protein and cellular interactions, these alterations may differentially regulate biological events. Modifications to the implant surface chemistry may lead to alterations in the structure of adsorbed proteins and have cascading effects that may ultimately be evident at the clinical level (Kilpadi et. al., 1994).

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The laser technology for surfaces preparation already has numerous industrial applications. This process results in titanium surface microstructures with greatly increased hardness, corrosion resistance, a high degree of purity with a standard roughness and thicker oxide layer. Biological studies evaluating the role of titanium ablation topography and chemical properties showed the potential of the grooved surface to orientate osteoblast cell attachment and control the direction of ingrowth. A number of laser-based techniques have been applied (Al Hasani, 2020). Besides the prompt intense heating of the surface, excimer laser illumination may further enhance the sterilising effect in consequence of the high dose in the UV range. The laser technique has several advantages, add no chemicals and can be used in routine manufacturing. Only the valley and parts of the flank of the implant threads was laser treated while the remaining part was left as-machined (Cooper, 2000). The idea behind this design is that the flack portion of the implant thread, which might have the higher risk to expose to the Microorganism and plaque, is characterized by a relatively smooth surface to minimize the incidence of peri-implant, whereas the valley part of the implant threads has the rougher surface (Frenkel et. al. 2002). Manufacturers recommend the use of Nd: YAG laser for soft tissue periodontal procedures such as debridement of diseased epithelial linings, gingivoplasty, crown lengthening, vestibuloplasty, gingivectomy and reduction of drug-induced gingival hypertrophy (Cochran, 1999; Eriksson et. al. 2001). Many of these procedures involve removal of soft tissue in areas adjacent to teeth which may have amalgam restorations in close proximity to the working area. Accidental laser exposure to such restorations is a distinct possibility. With the development of modern medical lasers; laser therapy has gained an increasing role in the wide spectrum of treatment modalities. Also in oncology, laser techniques have become interesting alternatives in radical tumor resection and to palliative tumor treatment methods. Due to the great variability of induced tissue reactions from microsurgical precise coagulation and cutting to voluminous coagulation or tumor vaporization, the Nd: YAG laser is the most important surgical laser (Bauerle, 2000; Palmquist, 2010).

The possibility of transmitting its light through flexible fibers allows wide variation of applications and tissue effects. Even if this laser is mostly known for its ability of volume coagulation, which is due to its large optical penetration depth, it shows a reaction depth which can be varied in the widest range of all medical lasers by using the appropriate parameters (Cernavin et. al., 1999; Daikuzono et. al., 1985). Many research focus on improvement of titanium surface by laser treatment In 2003 M. Bereznai et al. modified the titanium surface by excimer laser irradiation of titanium samples in order to improve their surface characteristics so as to facilitate biointegration, and to enlarge the effective interfacial area of bone–implant contact, holes were ablated by laser pulses of ns or sub-ps length. X-ray photoelectron spectroscopy analysis of the laser-polished titanium surface revealed that laser treatment led to a decrease in surface contamination and in thickening of the oxide layer (Bereznaia et. al., 2003). In 2006, Milan Trtica et al. used the interaction of an Nd:YAG laser, operating at 1064 or 532 nm wavelength and pulse duration of 40 ps, with titanium implant. The surface damage thresholds were estimated to be 0.9 and 0.6 J/cm^2 at wavelengths 1064 and 532 nm, respectively. The titanium implant surface modification was studied by the laser beam of energy density of 4.0 and 23.8 J/cm^2 (at 1064 nm) and 13.6 J/cm2 (at 532 nm). Generally, both laser wavelengths and the corresponding laser energy densities can efficiently enhance the titanium/implant roughness. This implant roughness is expected to improve its bio-integration (Trtica et. al., 2006). In 2008 Rafael Silveira Faeda et al. evaluated by using a biomechanical test, the force needed to remove implants with surface modification by laser (Nd:YAG) in comparison with implants with machined surfaces. Surface characterization showed that a deep and regular topography was provided by the laser conditioning, with a great quantity of oxygen ions when compared with the MS (Faeda et. al. 2009).

Method

Samples Preparation

Preparation of implant samples involved using two different methods in order to make comparison between them and to study the effect of manufacturing process on the surface roughness which may affect the biological behavior of the implant in the body by elimination of healing period (rapid osseointegration). The first method involved the use of commercial pure titanium rod with high purity (99.8 %). While the second method included the use of powder technology in order to produce the implant screws. In this method the raw material used was pure titanium powder (from Aldrich Chemical Company) purity (99.8%). the compaction process accomplished by hydraulic press machine with maximum applied load 15 ton for five minutes and then the load released gradually. The samples were then removed carefully from the die resulting compacted rods with 20 mm in diameter were then sintered in a furnace (local manufacturing) under controlled atmosphere using argon gas at 1000^{o}C for two hours. After the sintering process the resulting samples with diameter (20 mm) then converted into a pin shape with diameter (3mm) using a wire cutting machine. The final implants screws were obtained by

machining the titanium pins using lathe. The final implant samples whether produced from commercial pure Ti powder or rod have the dimensions; 2.8 mm in diameter ,8mm in length.

Laser Pulses Surface Treatment

The titanium implant surface was activated by using laser pulses. The technique generates short pulses of light of single wavelength, providing energy focused on one spot. It is rapid, extremely clean, and suitable for the selective modification of surfaces. The Nd:YAG system was employed type (Nd:YAG LASER ,made in Korea maximum power 1000mJ,pulse duration 6ns). The implant Samples were irradiated by focusing the laser beam using a quartz lens of 12 cm focal length. During the irradiation process, the laser was operated in the fundamental transverse mode with power energy 1000mJ, pulse duration 6ns, at frequency 2Hz and wave length 1064nm. The angle of incidence of the laser beam with respect to the surface was 90^{o}. The irradiation was carried out in air, at standard relative humidity. Finally, the resulting implant samples were organized as shown in (Table 1).

Table1. Implant samples numbers

Sample	Number
Sample produced from Ti powder	1
Sample produced from Ti rod	2
Sample produced from Ti powder treated with laser	3
Sample produced from Ti rod treated with laser	4

Testing and Characterization

Experimental work also involved implant testing and characterization that have been done after laser surface treatment procedure to examine implant samples and to ensure the safety performance of the implant inside the body in which the implantation process have been done, the characterization involves; microstructure observation using scanning electron microscope (SEM), surface chemical composition analysis using Energy-dispersive spectroscopy EDS. The EDS device was coupled with SEM and the inspection was done at the same time of SEM observation. the topographic change after the surface treatments as well as the amount of roughness using Atomic Force Microscope (AFM), ion release test. The metal ion release from the implant material occurs as a direct consequence of the corrosion process. Release of metal ions can cause local and systemic health problems, due to the ions diffusion through the whole body. The ion release of titanium implant samples was performed by static immersion test in which The samples were exposed to a corrosive solution with minimum relative motion between samples and solution. Each sample was placed in a separate container with a medium that simulates biofluids. Hank'ssolution. The samples incubated at 37°C using a water path and thermostat. The immersion time used was 7 days; certain amount of solution was removed every day to conduct the release of ions. The type and concentration of ions released from the metallic implant materials was determined using Inductively Coupled Plasma optical emission spectrometry ICP-OES. Finally, vivo testing in which twenty males of New Zealand rabbit weighing 2-2.5 kg were used. The age of them was from 10 -12 months. The rabbits were kept in standard cages and had free access to tap water, and fed with standard pellets. Before the implantation surgery the implants were sterilized by placing each two implants in a single air tight plastic sheet then the implants were autoclaved at 121^{o}C and 20 bars for 30 minute, also all instruments were autoclaved at 121^{o}C a20 bar for 30 minute.

Figure1. The tibia bone

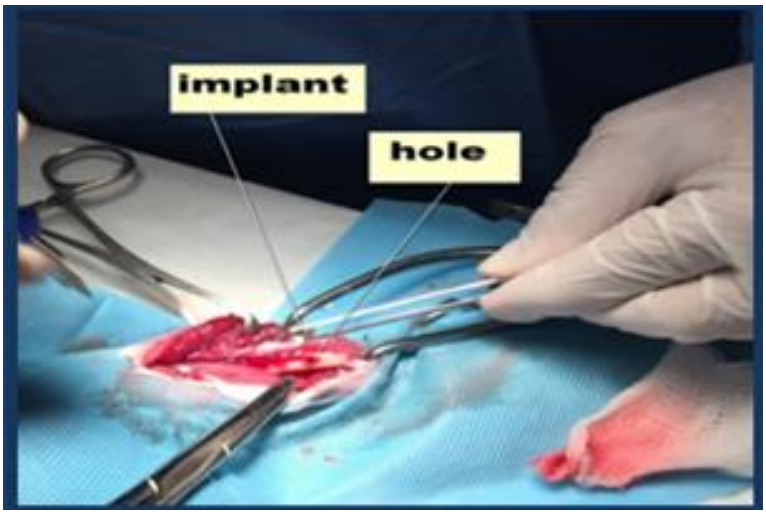

Figure2. Hole in bone.

Anesthesia was induced by intramuscular injection of Ketamine hydrochloride 50mg (1ml/kg body weight) Xylazine 20 %(0.1 ml/kg body weight). The surgery was performed under sterile and gentle surgical technique. Both tibias of each rabbit were shaved from the inner side and the surgical towels were placed around the operation site, then the skin was cleaned with alcohol and iodine then apiece of cotton was damped with iodine and left on the shaved skin for five minute. Incision was made on the medical side of the legs about 3 cm in length to expose tibia bone the skin and fascia were reflected the periosteom was carefully reflected as shown in (Figures1, 2).

Drilling was done using round bur with intermittent pressure and continuous cooling of normal saline at a rotary speed of 1500 RPM and reduction torque 16.1. The enlargement of the hole was made gradually with spiral drill from 2.2 mm to 2.5mm till a hole with about 2.7mm was obtained as shown in (Figure 2) .The operation site was cleaned with copious amount of saline to remove bone sheared then the implant was removed from the plastic sheet and placed in holes with slight spiral movement until 5mm was completely inserted in bone as shown in (Figure 3) finally histological testing with optical microscope have been done.

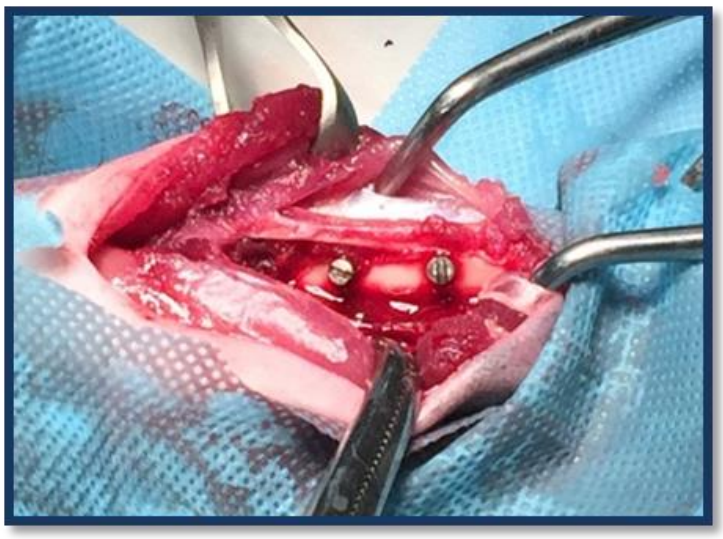

Figure3. Iimplants in tibia.

Results and Discussion

Microstructure Characterization

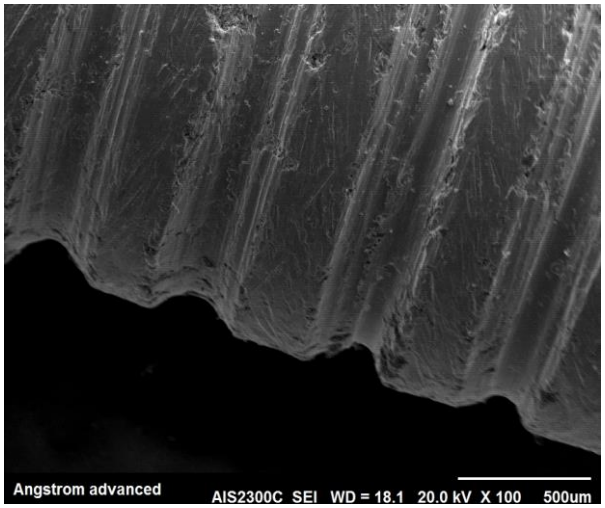

Figure 4. SEM image of sample 1.

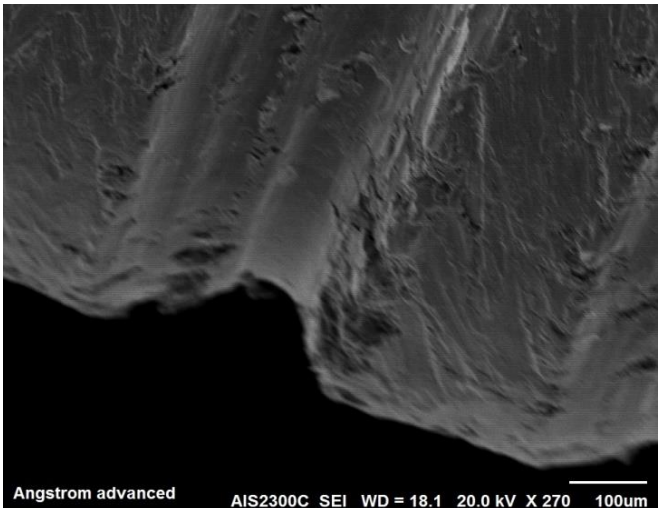

Figure5. SEM image of sample 1 in other magnification.

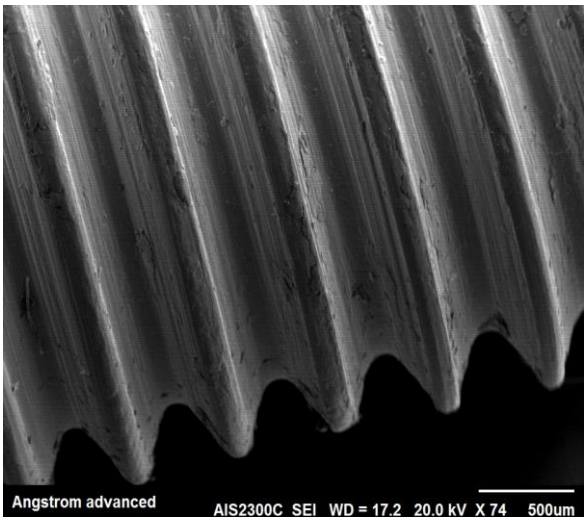

Figure 6. SEM image of sample 2.

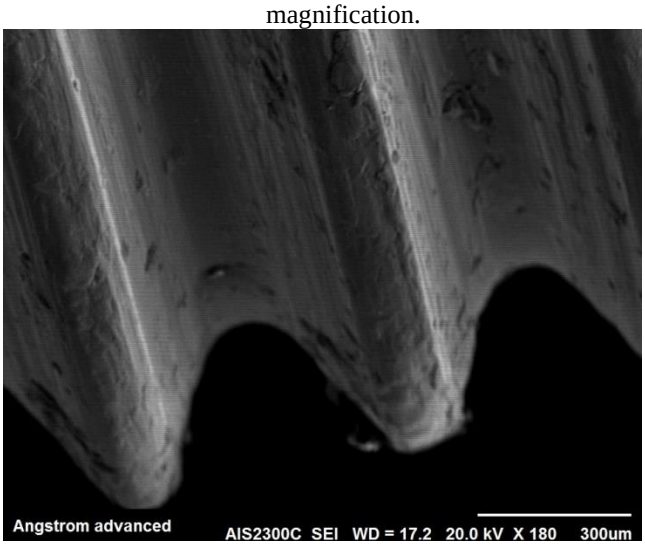

Figure 7. SEM image of sample 2 in other magnification

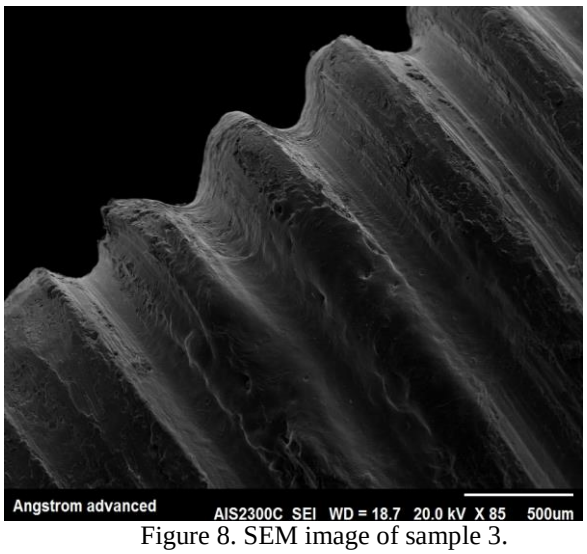

Figure 8. SEM image of sample 3.

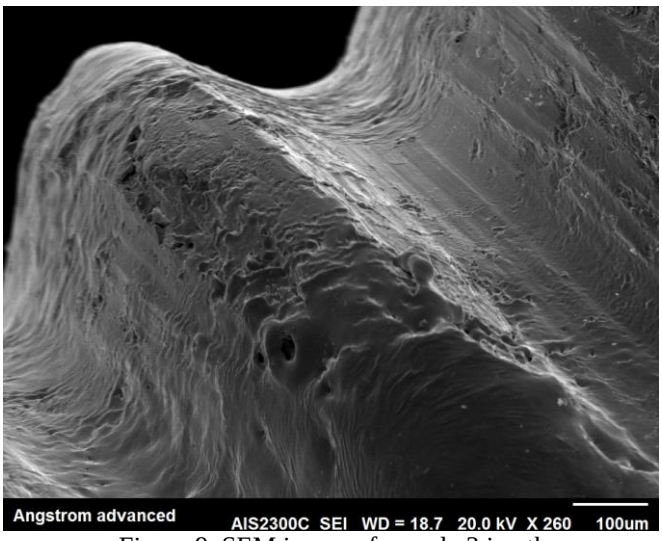

Figure 9. SEM image of sample 3 in other magnification

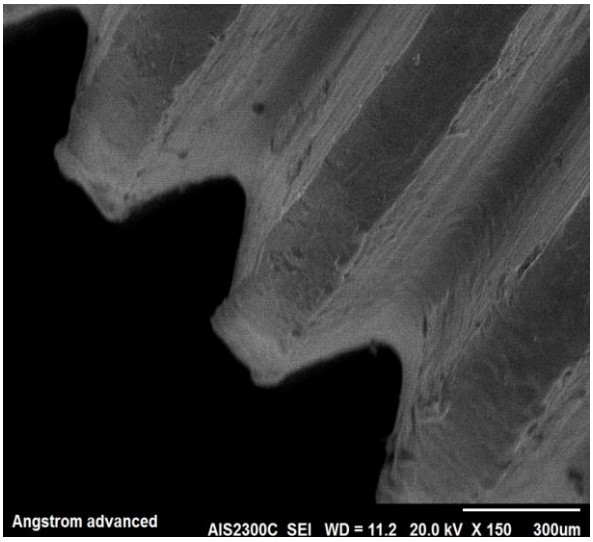

Figure 10. SEM image of sample 4.

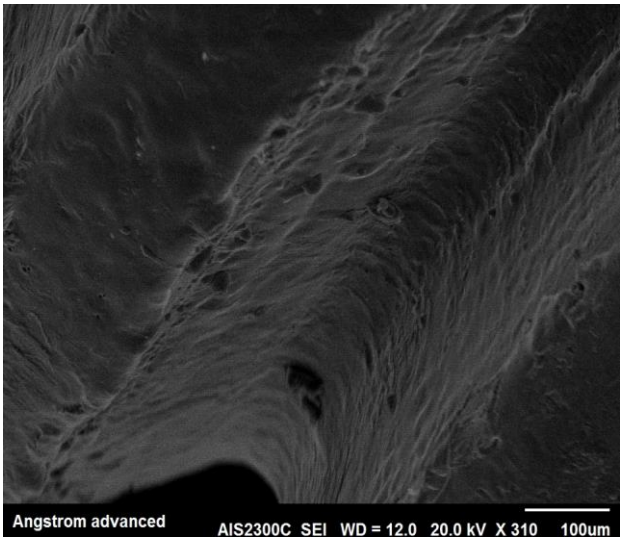

Figure 11. SEM image of sample 3 in other magnification

Scanning electron microscope was conducted implant samples, (Figures 4 and 5) show the surface morphologies of sample (1) and sample (2), these two samples differ in manufacturing process but both of them are without laser treatment. No morphological differences were observed among the implants surfaces except for some inconsiderable morphological differences as a result of the manufacturing process .For sample (1) produced by powder technology it obvious to have a degree of porosity which result in roughen surface than sample (2) which was produced by turning .The tool marks created by the turning process made the surface anisotropic with clear directional surface irregularities .Therefore ,it was possible observe that sample (2) surface similar to some commercial dental implants available from various companies. The microstructure observation of the laser group demonstrate that the laser pulses energy used ($1J/cm^2$) was appropriate to make the surface damages and the laser beam created a deep and regular morphological pattern as seen in(Figures 8, 9, 10 and 11) which illustrated the SEM image of samples (3 and 4). It is clearly recognized that the laser pulses have caused remarkable surface topographical changes, From (Figures 8, 9) of sample (3) easy to distinguish the laser pulses effects on the samples surface topography than the (Figures 10, 11) of sample (4). This is because sample (3) was produced by powder technology which resulted in more initial surface roughness and topographical irregularities than the other methods. Laser pulses can be altered to be more effective to change the surface topography under given laser pulse energy. The benefit of using laser treatment for implant samples prepared by powder technology process is to facilitate the creation of microstructural surface roughness in the inner part of implant's thread. It is believed that the inner part of thread is more in bone formation than the outer part. From the microstructure observation of laser samples it is concluded that the technique is a suitable choice for complex surface geometries. The technique generates short pulses of light of single wavelength, providing energy focused on one spot especially in the inside of implant thread. It is rapid, extremely clean, and suitable for selective modifications of surfaces and allows the generation of complex microstructures/ features with high resolution.

Energy-dispersive Spectroscopy EDS

Elemental analysis or surface chemical characterization of implanted a sample have been made before and after surface treatments using interaction of some sources of X-ray excitation and the sample by energy - dispersive spectroscopy (EDS). This test was done in order to identify the effect of laser treatments on the implant surface chemistry. EDS graph of the samples (1, and 4) in (Figures 12 and 13) show a large peak of titanium element without any peaks of other elements which refer to samples with high degree of purity and the manufacturing process will not affect or result in a change of the surface chemical composition. Elemental analysis of the titanium sample treated with laser showed that oxygen contents are high, the increasing in oxygen content implied that possible oxidation of the titanium sample took place. Presence of titanium oxide on the implant surface can be considered very desirable for many reasons, firstly the composition of the oxides, including their distribution, can resist corrosion of the implant sample secondly the titanium oxides can influence implant surface adhesion properties and finally the oxidation of a titanium implant can lead to local hardening and improvement of the wear resistance. There are some differences observed in the EDS graphs. These are due to the using of different manufacturing process that has been employed. Finally it is found that manufacturing

process (powder metallurgy)resulted in increasing oxygen content at the surface and therefore improving the oxide layer that have been formed after laser pulses.

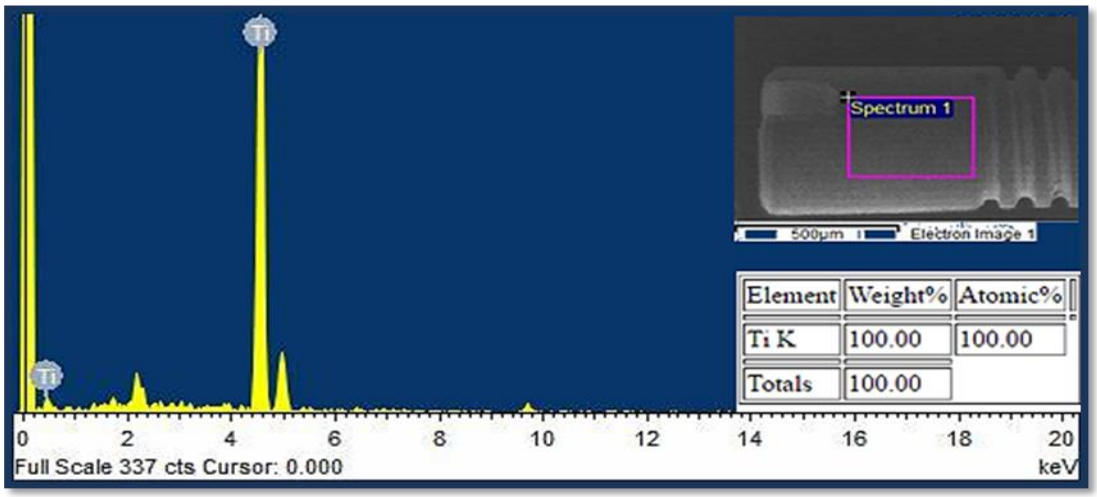

Figure12 .EDS graph of sample (1).

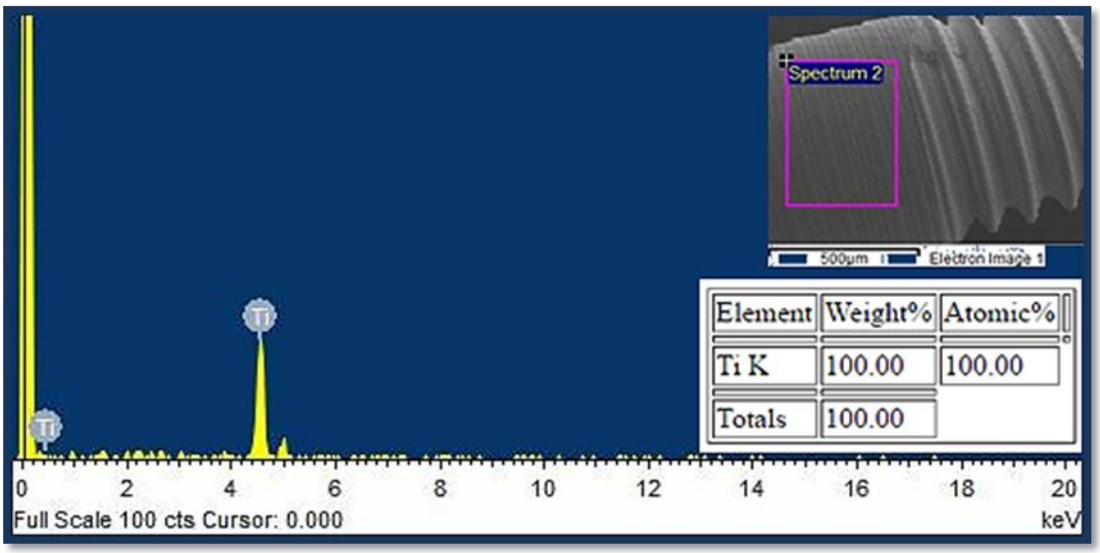

Figure13. EDS graph of sample 2.

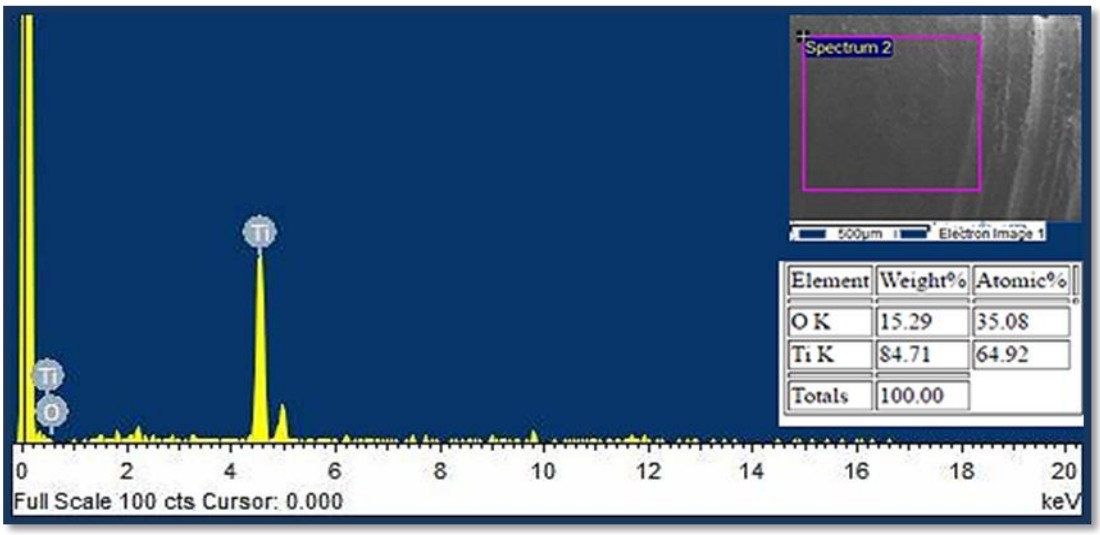

Figure14. EDS graph of sample 3

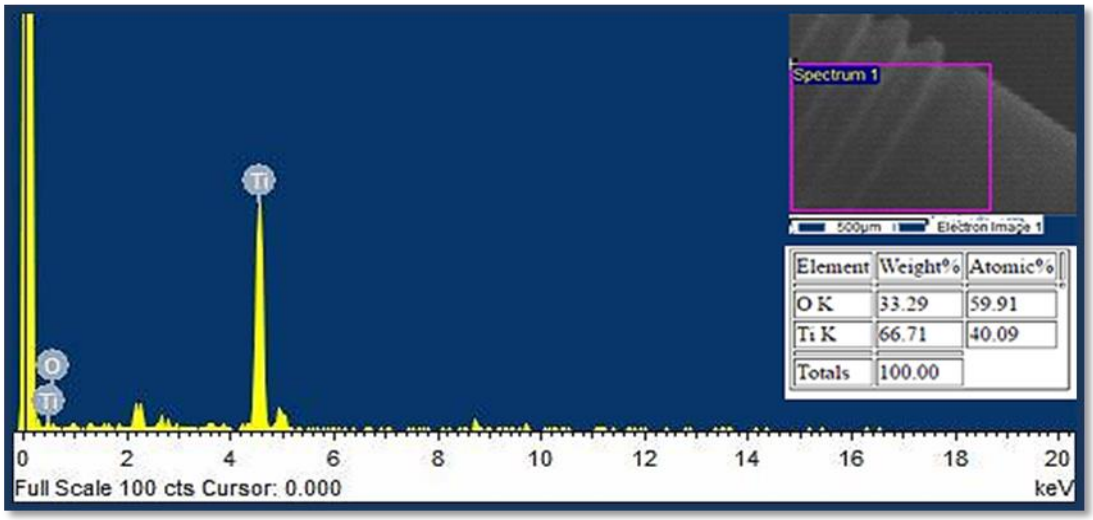

Figure15. EDS graph of sample 4

Surface Roughness:

Surface roughness has been identified as an important parameter for implants and its capacity for being anchored in bone tissue. Surface topography was displayed by Atomic-force microscopy (AFM) in which images of three-dimensional shape (topography) of a sample surface at a high resolution was obtained. This is achieved by scanning the position of the sample with respect to the tip and recording the height of the probe that corresponds to a constant probe-sample interaction. (Figure 16) displays the roughness value of the sample (1). This sample was produced by powder technology process without any surface treatment have higher roughness (845.36 nm) than sample (2) in (Figure 17) , produced by machining without any surface treatment (531.7nm). Hence the powder technology process produced samples with higher surface roughness compared to the machining process. The use of laser pulses will also effect on the surface roughness of implant samples as illustrated in (Figures 18 and 19) shows that the samples changed their roughness values either raised or reduced after the laser pulses. This is due to the formation of a strong oxide layer refer that all samples have the same response to the laser irradiation and the slight differences in the roughness values were due to the change in surface heating rate that resulted from the manufacturing process employed which caused a considerable change structural surface properties.

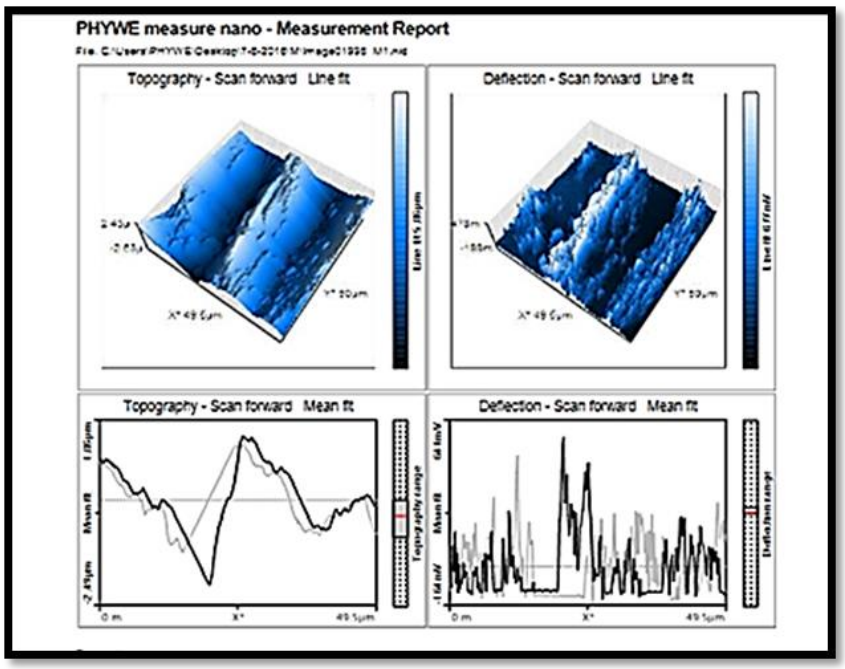

Figure 16.AFM chart of sample 1.

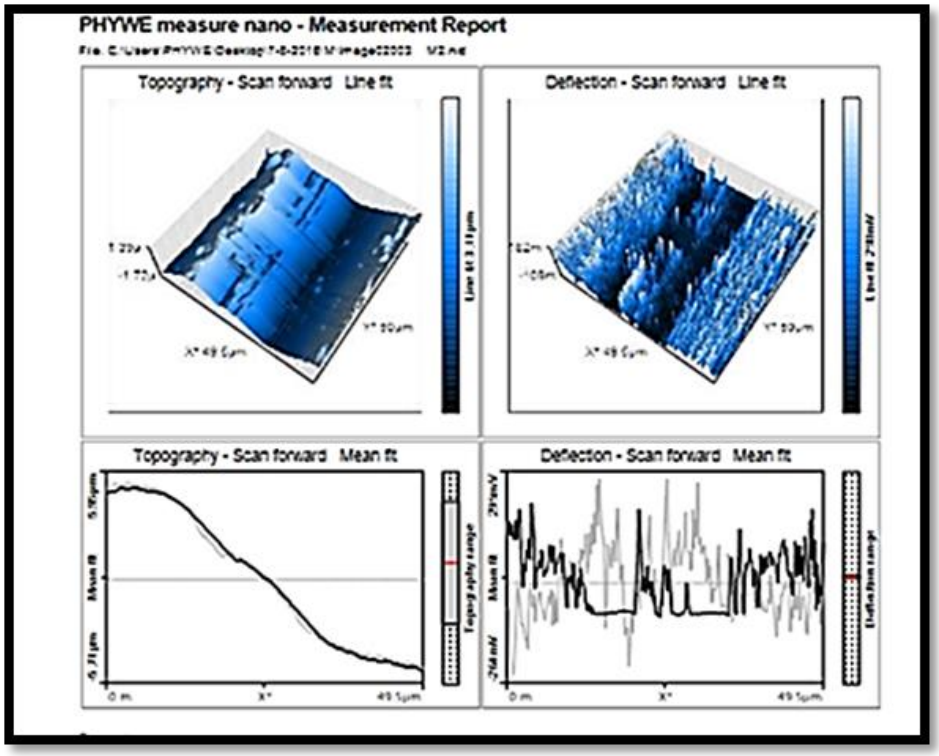

Figure17.AFM chart of sample 2.

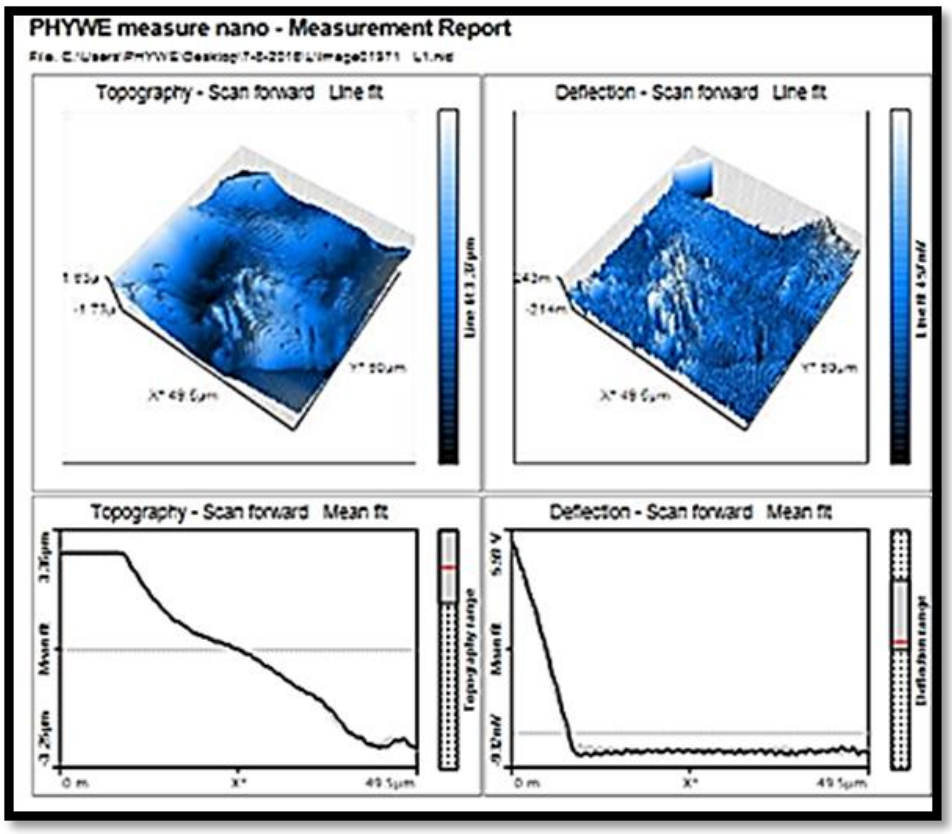

Figure 18.AFM chart of sample 3.

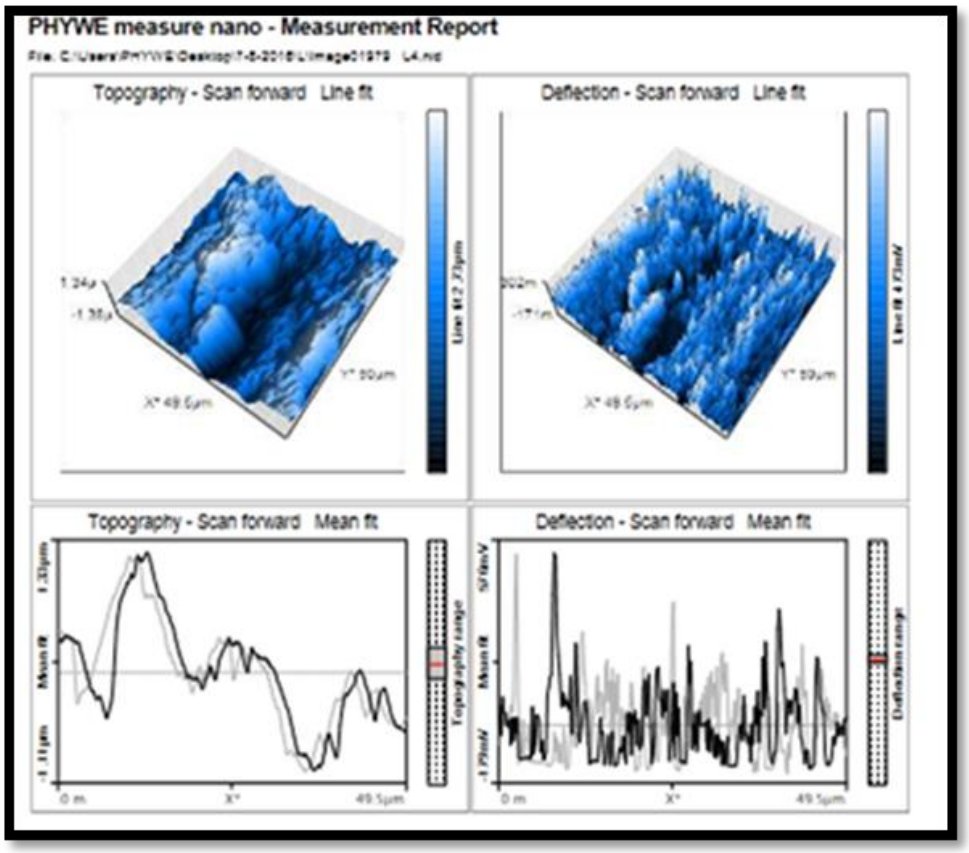

Figure 19.AFM chart of sample 4.

Ion Release Analysis:

Ions are released from implant materials as a direct consequence of the corrosion process. Release of metal ions can cause local and systemic health problems due to the ions diffusion through the whole body. The amount of Titanium ions that have been released from all samples in Hank's solution was measured. It was found that the surface oxide films on titanium implant play an important role as an inhibitor of ion release also the regeneration time of the surface oxide film after disruption governs the amount of released ion. Low concentration of dissolved oxygen, inorganic ions, proteins, and cells may accelerate the metal ion release. It is obvious that the behavior of metal ion release into biofluid is governed by the electrochemical rule and the released metal ions do not always combine with biomolecules to show toxicity because the active ions immediately combine with a water molecule or an anion near the ion to form an oxide, hydroxide, or inorganic salt. Thus, there is only a small chance that the ion will combine with biomolecules to cause cytotoxicity, allergy, and other biological influences and this was not observed in the current titanium samples. From the results of ion release analysis, it was found that all samples in all groups have similar ion release behavior when the samples are immersed in Hank's solution for seven days as illustrated in (Figure 20), it is observed that the release of Ti ion rise in first three days and after that release of Ti ions begin to stabilized. This was due to the fact; when the metal is immersed inside the body consequently their ions begin to be released from the surface by adsorption process. At the same time these ions will combine with other molecules in the environment and desorb at other surface so that the amount of released ions is increased with increasing immersion time until the adsorption- desorption equilibrium is reached thus the amount of released ion will be fixed.

Histological Analysis

Modifications of the implant surface have benefits regarding the response of the surrounding bone tissue, accelerating the healing process and improving the quality of the newly formed bone. Osseointegration is related to micro geometric features, such as the degree of surface roughness, and to factors such as the physical and chemical properties of surfaces. Rough surfaces were found to stimulate osteoblastic gene expression and to enhance bone formation and bone implant fixation. From The histological view of implant samples after 4weeks

of implantation, it was found that there are active bone formations in all implant surfaces which gives clear indication of tissue acceptance.(Figure 21) shows histological view of sample (1) prepared by powder technology method without surface treatment and shows new bone trabecullae (BT) filled thread area and reversal line separate between old and new bone which refers to the new bone have been formed in a thread region as show in (Figure 22) .

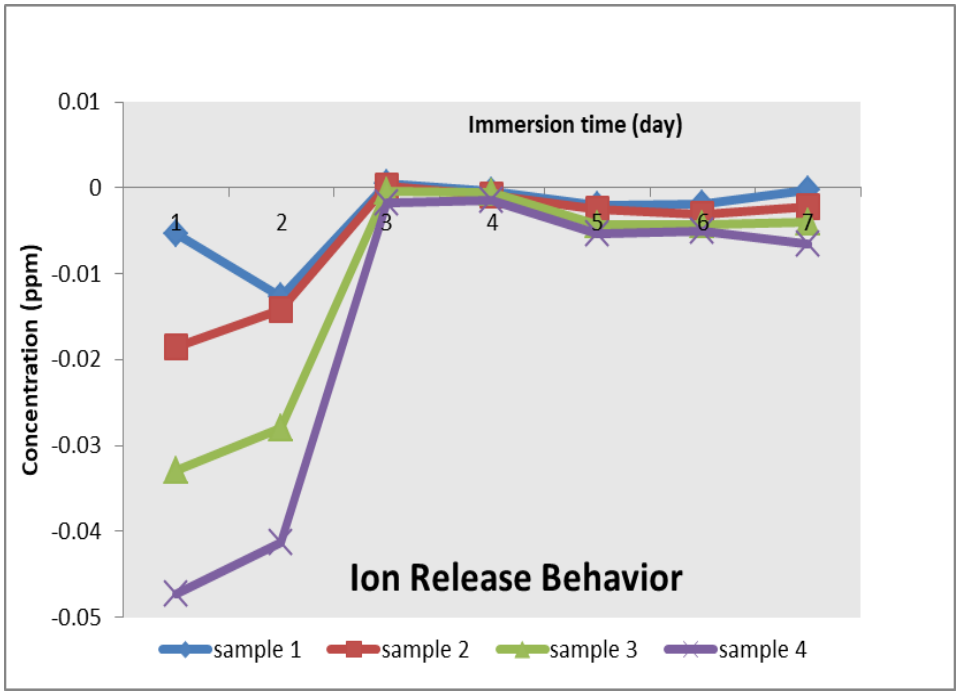

Figure.20. Release amounts of Ti ions in Hank's solution.

While in sample (2) prepared by machining process as shown in(Figure 23) more bone trabeculea formation is seen with large number of osteocyte preosteocytes (POC) and blood vessels (BV) as shown in (Figure 24). This indicates that the deposition of bone was still continued and therefore the bone formation in sample (1) was faster than sample (2) due to the differences in production method. Thus the powder technology method will produce a pores surface which yielded greater bone formation than smoother one due to their larger area in contact with the bone tissue as well as it present intercommunicating porous structure allowing the formation of three dimensional osseointegration networks. When the implant sample was laser pulsed, a strong oxide layer will form on the implant surface resulting in improving the adhesion between the implant surface and bone thus good osseointgration was obtained. This was observed in samples (3) and (4). The microstructural view of sample (3) which produced by powder technology method then treated with laser show dense bone filled thread area as in (Figure 25) bone trabecullae filled thread area with large osteocytes (OC) surrounded by osteoblasts (OB), and osteoclasts (OCL). While, in sample (4) the microstructural view shows mature bone filled thread area with small osteocytes (OC), osteoblasts (OB) lined Haversian canal (HC).The appearance of mature bone in the (3) rather than (4) is due to the stability of oxide layer in sample (3) which was more than sample (4). It is largely affected by the surface nature that resulted from the manufacturing process. From the laser treatment it was found that increasing in oxide layer stability result in the improving oseointegration as well as enhancing the bone formation process.

Conclusion

Using different manufacturing processes (machining and powder technology) produced topographical differences. The topographical change observed from powder technology method was more than the machined one. Strong titanium oxide layer was observed after laser pulsed resulted in improving surface roughness and topography and it was the method of choice for complex surface geometries providing energy focused on one spot especially in the inside of implant thread. The release of Ti -ion rise in first three days and after that released of Ti- ions begin to stabilize. The histological view of implant samples after 4weeks of implantation, showed active bone formation in all implant surface which give clear indication of tissue acceptance and the appearance of mature bone was observed in polymer coated samples at short implantation periods

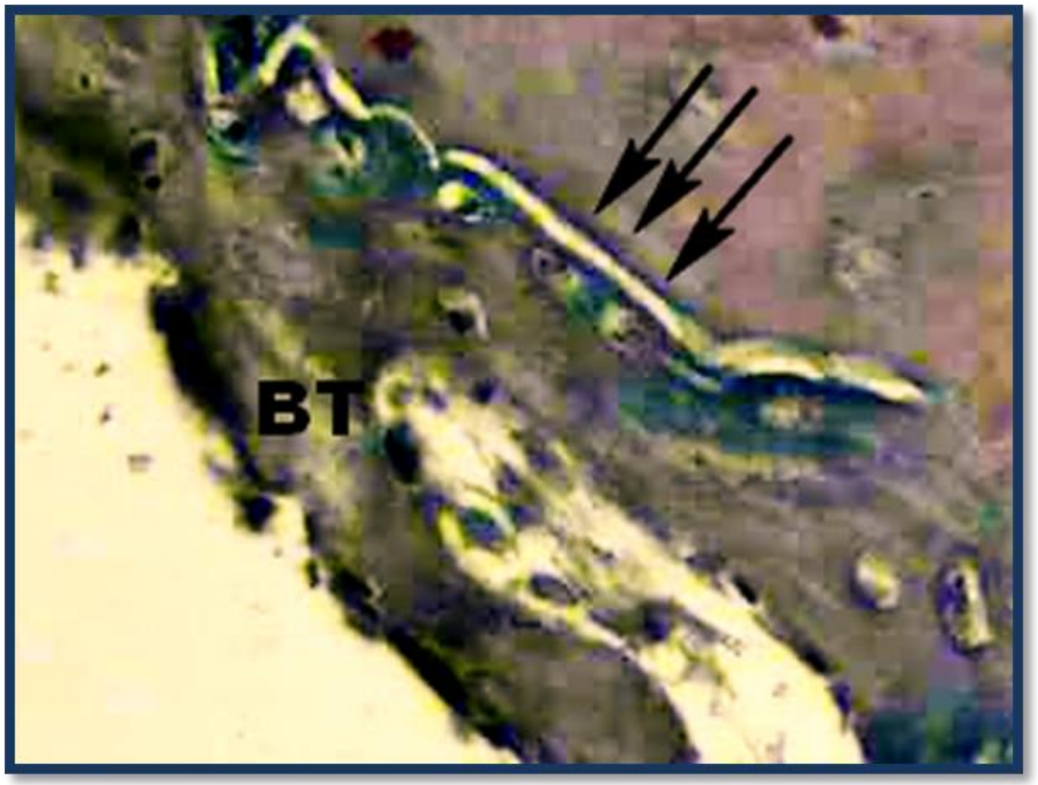

Figure21. Histological view of sample (1) show new bone trabecullae (BT) filled thread area and reversal line separate between old and new bone (arrows).H&E X10

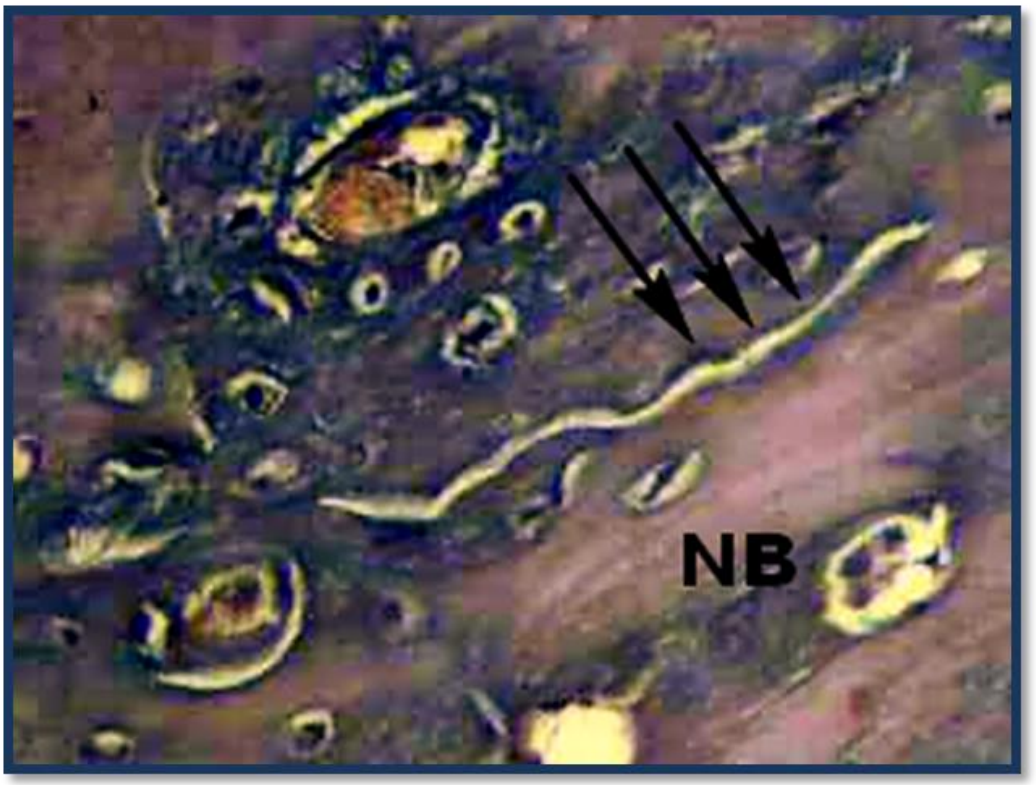

Figure 22. Magnifying view of sample (1) show new bone formation (NB) in thread region which separate from old bone by reversal line (arrow). H&E X40.

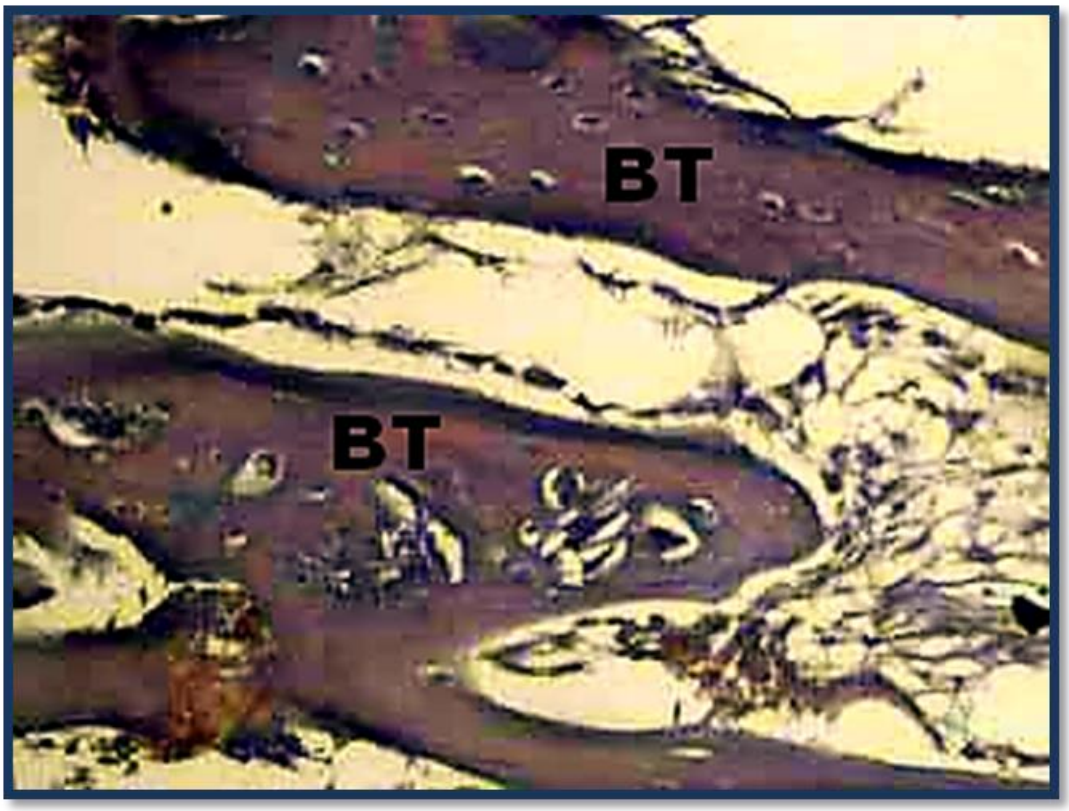

Figure 23. Histological view of sample (M4) show new bone trabecullae (BT) in thread region . H&E X20

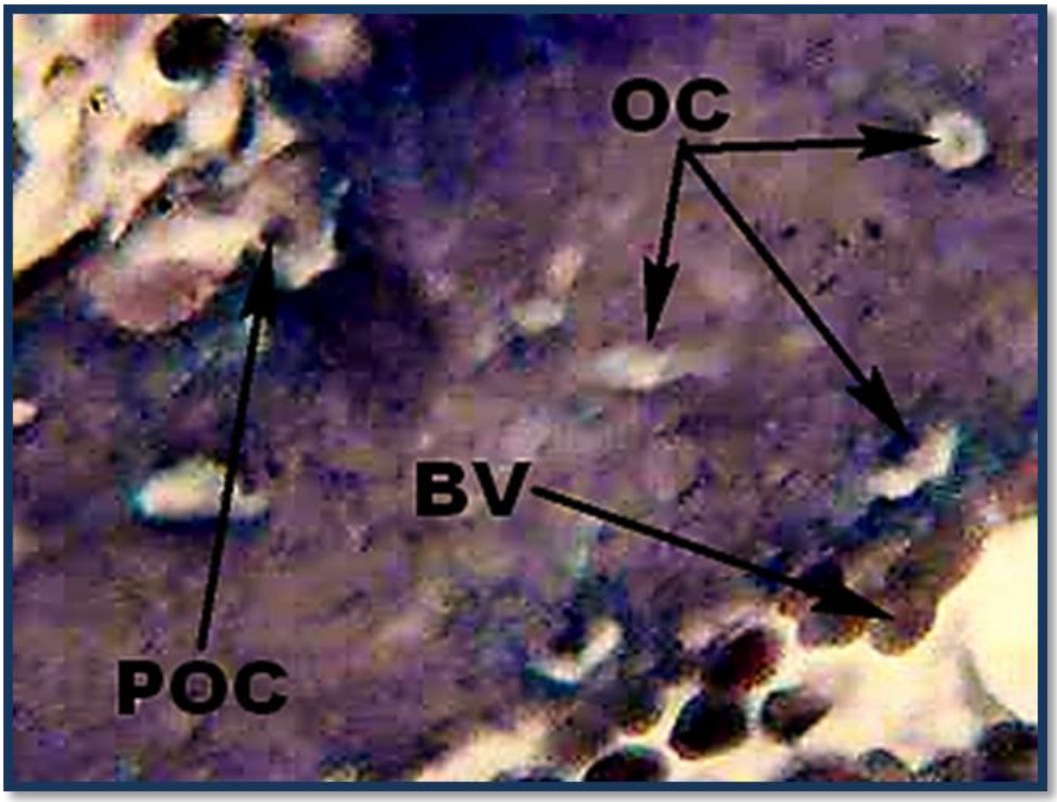

Figure 24. Magnifying view of sample (M4) show new bone formation with octeocytes (OC) , preosteocytes (POC) and blood vessels (BV) .H&E X40

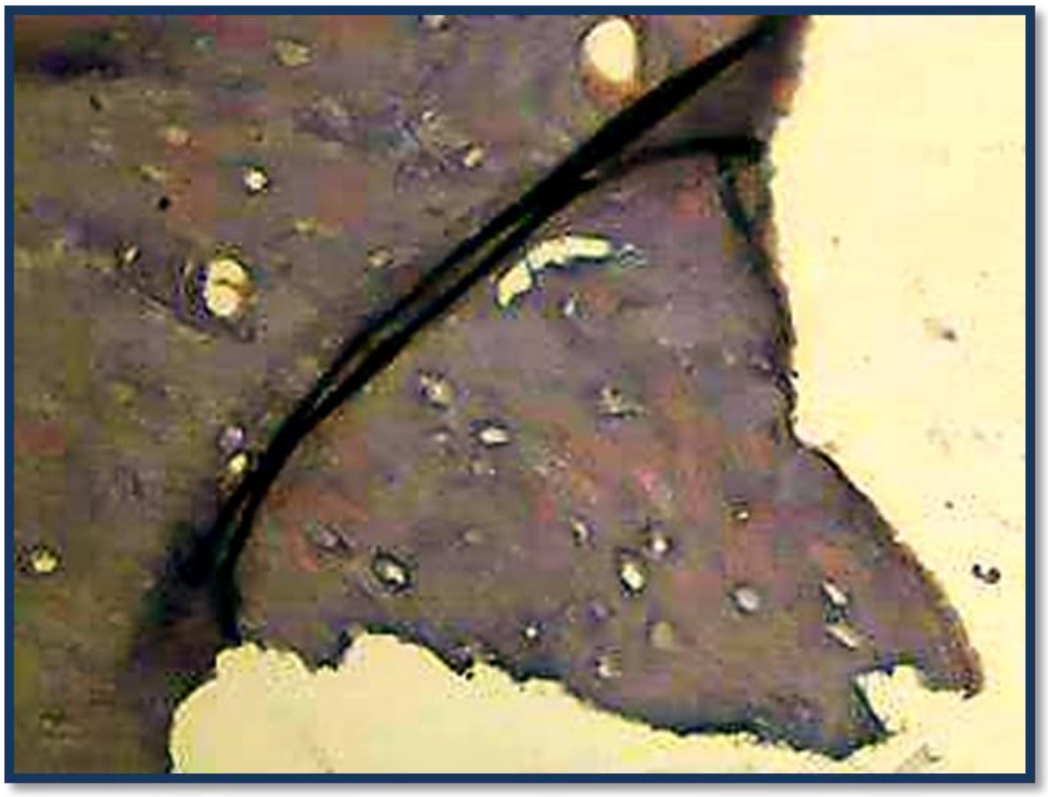

Figure 25. Histological view of sample (L1) show dense bone filled thread area .H&E X20

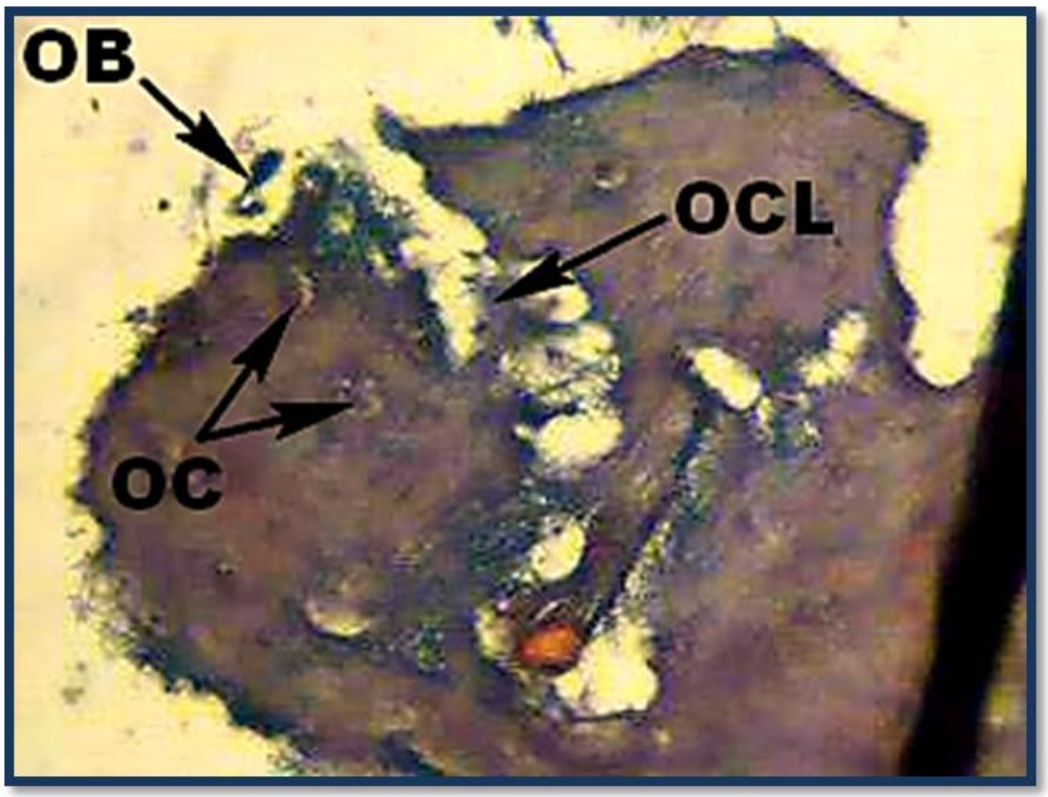

Figure 26. Histological view of sample (L1) show bone trabecullae filled thread area with large osteocytes (OC) surrounded by osteoblasts (OB) ,and osteoclasts (OCL).H&E X20

Figure 27. Histological view of sample (L4) show v .H&E X10

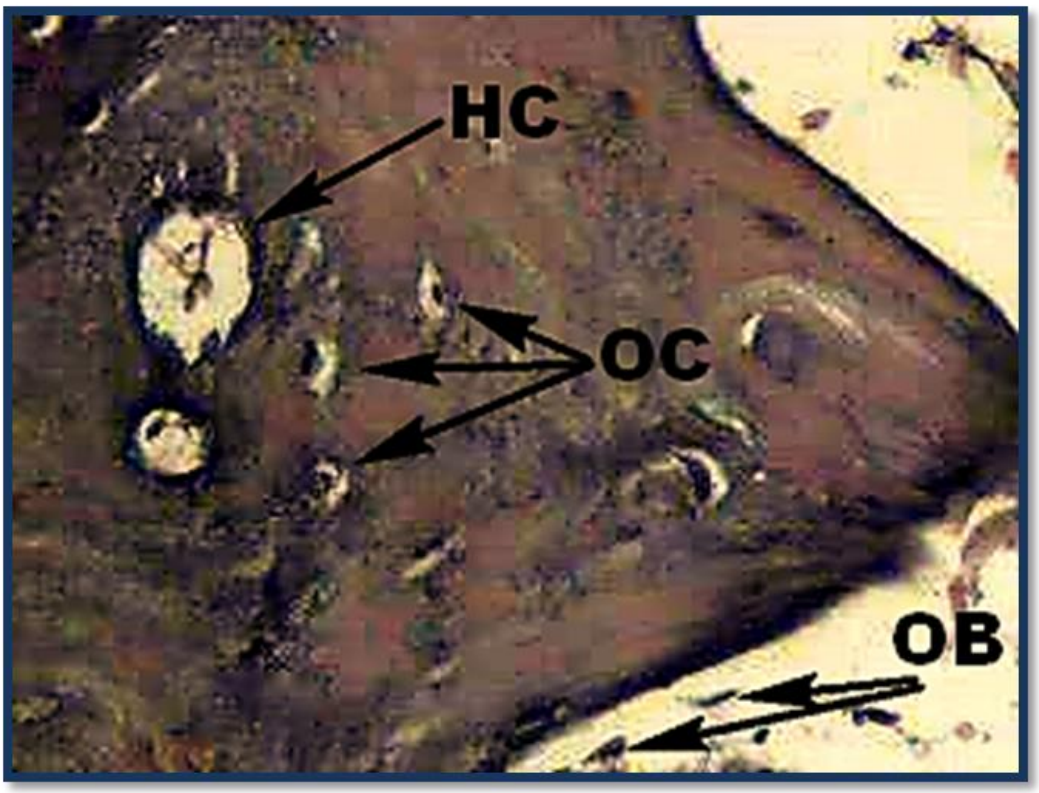

Figure 28. Magnifying view of sample (L4) show small osteocytes (OC) , osteoblasts (OB) lined Haversian canal (HC) .H&E. X20

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Recommendations

After possible results gets from the experimental work, many recommendations may be possible for future; like using laser pulse as surface activation process for other types of metallic implant, using the laser treatment to precipitate elements or oxides at the surface of implant samples.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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The Use of Shredded Plastic Water Bottles in Soil Stabilization

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Abstract: Please Soil stabilization is a mechanical or chemical procedure to improve the physical properties of weak soil. In this research, a mechanical process of using shredded plastic water bottles has been investigated in soil stabilization. To achieve the objective of this research, two types of clayey soils have been selected based on their plastic indices. The initial mechanical properties of the two soils have been determined using ASTM standard procedures. A plastic water battles were shredded into small pieces with dimension 1.0 cm in length and 2.0 – 3.0 mm in width. The shredded plastic was added to the clayey soil at 6 different percentages by dry weight of the soils 0.5%, 1.0%, 1.5%, 2.0%, 2.5%, and 3.0% with 0.5 increment. Standard compaction and unconfined compression test were conducted on soil plastic mixtures at the 6 different percentages. It was found that the addition of shredded plastic to the clayey soils reduced both the maximum dry density and optimum moisture content for the two types of soils. However, a significant increase in unconfined compression test was noticed due to the addition of shredded plastic waste. The highest increase was noticed at 1.5% by dry weight of the soil. Additionally, the failure strain was decreased due to the addition of the plastic waste.

Keywords: Soil stabilization, Plastic waste, Unconfined compressive strength, Optimum moisture content.

Introduction

Disposal of municipal and industrial waste materials has become a major environmental and financial problems in the entire world due to the huge amount of generated and accumulated waste such as plastic waste, ceramic waste, waste rubber tires, etc. resulted from the rapid urbanization and industrialization. Plastic waste materials are considered the most common waste materials. Such material is generated in substantial quantities and considered the humans' daily life most usable material category. A recent study was conducted in 2019 has evaluated the impacts of plastic pollution on the sustainability of seafood value chain reported that the average waste generation was estimated at 15.4 billion fragments per day (Awuchi et. al. 2019). Another study reported that 1.5 billion units of tires are generated throughout the globe approximately (Thomas et. al., 2016) Another study reported that 8-12% of the annual total generated municipal and industrial wastes are plastics which almost represent 190 million tons (Wong et. al., 2015). In 2008 a study was conducted in Australia which reported that plastic wastes comprise 16% of the municipal waste stream which stands for 2.24 million tones (Bajracharya et. al., 2016). The increase of production of wastes and plastics in particular was influenced by many elements such as population growth, the wide variety of applications, and the low production cost (Meran et. al., 2008). Plastics wastes contain several types, however, the main contributor to the large volume of plastic wastes are polyethylene end products (Wong et. al., 2015). Polyethylene is used to comprise many products such as polyethylene terephthalate (PET) which include plastic bottles, high-density polyethylene (HDPE) which include the leaning agents and laundry detergents, polyvinyl chloride (PVC) which include trays for sweets and plastic packing, low-density polyethylene (LDPE) which include the shopping bags, etc. In Kurdistan/Iraq the main components of waste materials are considered to be polyethylene products. In 2012 a

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study was performed to study the effect of using waste polyethylene production on mechanical properties of concrete reported that more than 5000 tons of polyethylene is produced as waste materials every day in Duhok city (Hanna et. al., 2012). Even while plastics have several benefits, they are posing negative effects on the health and environment since most of these products are not biodegradable. This is why efficient recycling and reusing of these materials is considered one of the most important elements addressed by most of the countries nowadays.

To maintain and preserve the environment from the negative impacts of plastic waste materials, several researchers have conducted studies to obtain efficient methods that can minimize the pollution of these materials such as recycling and reusing these products in civil engineering applications. A study was performed in 2018 which found out that using plastic wastes as an alternative to stabilize the soil used for road construction is considered an effective method (Tatone, et al., 2018). Cement and lime are considered the two traditional materials used to enhance the geotechnical properties of weak soils and they're widely used in soil stabilization (Sherwood, 1993; Yadav et. al., 2016; Yadav et. al., 2018). Many studies have been performed and proved the effectiveness of using these materials as soil stabilizers (Bell, 1996; Rout et. al., 2012; Rasul et. al., 2015). Still, numerous researchers are trying to discover alternatives to cement and lime such as plastic, tire chips, etc. since high usage of cement and lime can make them unsustainable in terms of cost (Obo et. al. 2014).

In 2011, a study was performed to study the effect of fibers on some engineering properties of cement and lime stabilized soils and reported that using plastic wastes as a soil stabilizing material can enhance the foundation layers of pavement (Khattab et. al., 2011) which can enhance the properties of soils and decrease the amount of waste. The usage of plastics in the shape of discrete fibers in considered one method of integrating this material in soil stabilization since it tends to behave similar to fiber-concrete soils when merged with soil (Yetimoglu et. al., 2003). To verify the effectiveness of improving soils properties by using plastic waste materials as discreet fibers, many studies have been conducted. (Ziegler et. al., 1998; Babu et. al., 2011; Mondal, 2012; Ahmadinia et. al., 2012; Peddaiah et. al., 2018; Hassan et. al., 2021) All these studies reported that the use of plastic wastes in soil stabilization will enhance the properties of the soils such as UCS, CBR. As a result, the aim of this research is to evaluate the adaptation of a mechanical process using shredded plastic water bottles on soil stabilization.

Experimental Program

Selection and Classification of Tested Soils

The chosen soils for this research were selected to be clay. Two types of clay soils were selected which are high-plasticity clay soil (CH) and low-plasticity clay soil (CL). The physical properties of the two soils were determined by conducting several laboratory tests such as particle size distribution, Atterberg's limit test, Proctor compaction test, and specific gravity test. All the tests which were performed according to the ASTM standards.

Plastic Waste Material and Preparation of Samples

The plastic waste materials (PWM) were introduced in this research by gathering some polyethylene terephthalate (plastic water bottles) since they represent the most common used type of the plastic wastes in the daily life. To use the plastic water bottles wastes were used to play the role of fiber stabilizers. To achieve this object, PWM were cut and shredded into a 1cm size in length and 1-2mm size in width. Figure 1 represent a sample of the used PWM. The prepared PWM were distributed into six groups which each reflect a percentage of the dry weight of the soil. The fiber pieces were applied at 0.5%, 1%, 1.5%, 2%, 2.5%, and 3% of dry weight of the clayey soils. Afterwards, each soil was divided into seven different portions. Each portion was mixed with one of the PWM percentages based on the dry weight and the last sample portion represented the 0% fiber content to present the native soil outcomes. Subsequently, proctor compaction test was performed in accordance with the ASTM D698 using the different prepared fiber samples to obtain the maximum dry density and optimum water content and to understand the influence of PWM on these two parameters. Consequently, remolded samples were prepared at 95% relative compaction and using the optimum water content obtained in the unconfined compression mold. Leave one blank line after each heading and two blank lines before each heading. (Exception: leave one line between consecutive headings.) Please margin all headings to the left. Leave one blank line after each heading and two blank lines before each heading. (Exception: leave one line between consecutive headings.) Please margin all headings to the left.

Figure 1: PWM sample

Laboratory Tests

To evaluate the effect of the PWM on the clay soils, different types of tests were required to be conducted. As mentioned earlier, to classify the clay soils and obtain the raw physical properties of the tested soils particle size distribution, Atterberg's limit, Proctor compaction, and specific gravity tests were performed. After preparing the different needed samples, the strength of the prepared samples and the effect of the PWM on the unconfined compression strength was acquired by conducting Unconfined Compressive Strength Test. The test was conducted based on ASTM D2166 procedures. The test was performed on the remolded samples. All the data were collected and analyzed. All the tests were performed at American University of Sharjah laboratory.

Results and Discussion

The Effect of the PWM on Compaction Parameters

Figure 2 and Figure 3 depicts the effect of PWM on the compaction parameters mainly maximum dry density and the optimum water content. It is clear from the figures that as the percentage of the PWM is increasing, the maximum dry density and the optimum water content of the different mixtures tend to decrease as the curves tend to get lower and shift to the left. This outcome can be justified based on the fact that PWM has less density than the clay soil and it will replace the soil in the mold which will lead to lower the maximum dry unit weight. Moreover, the PWM doesn't not absorb water which will lead to reduce the optimum water content as illustrated in Figure 4 and Figure 5.

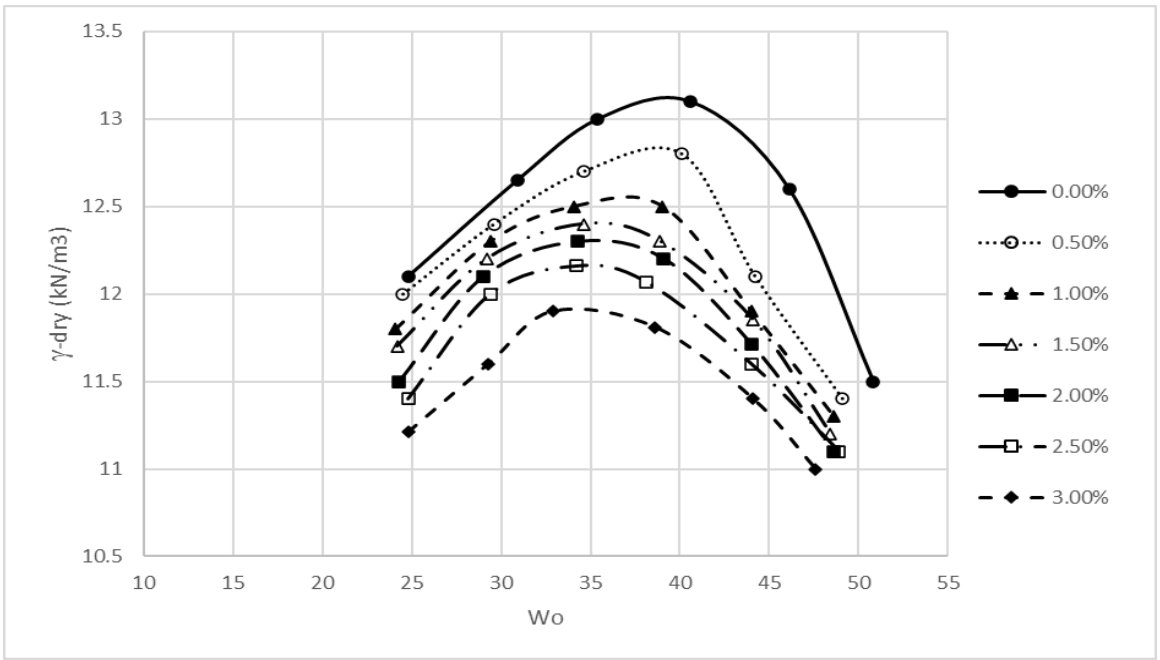

Figure 2: Compaction curve for CH soil.

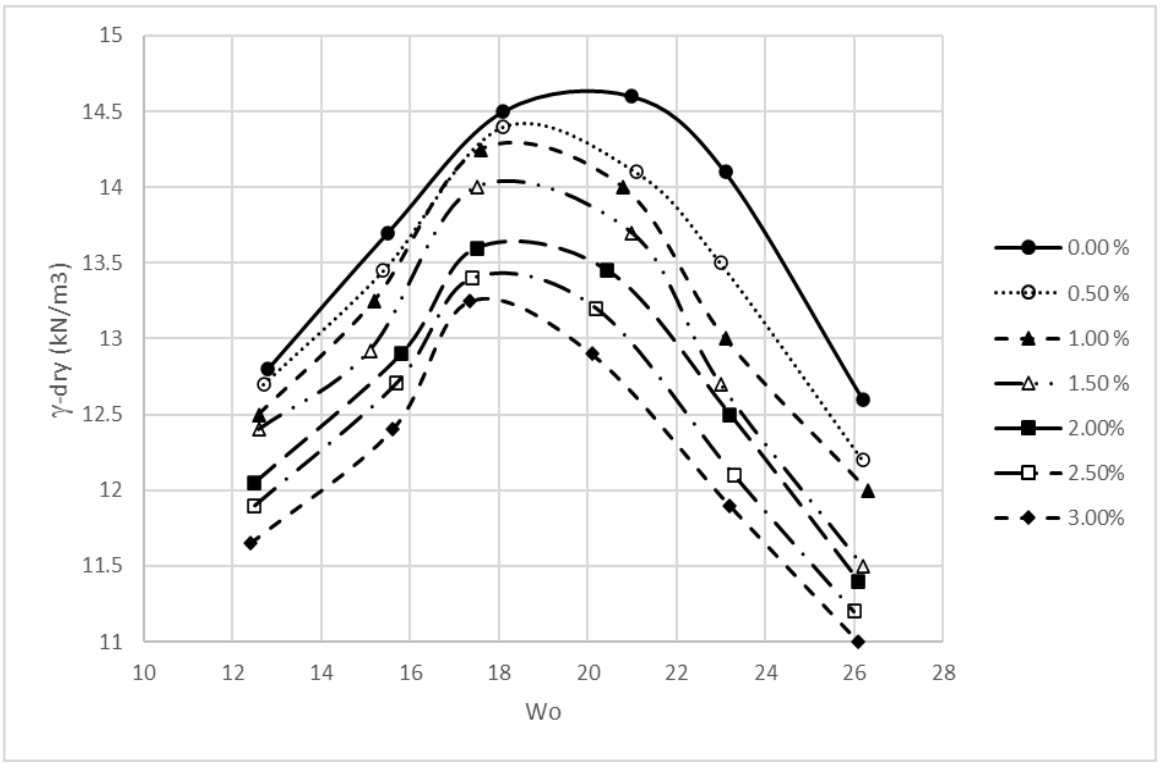

Figure 3: Compaction curve for CL soil.

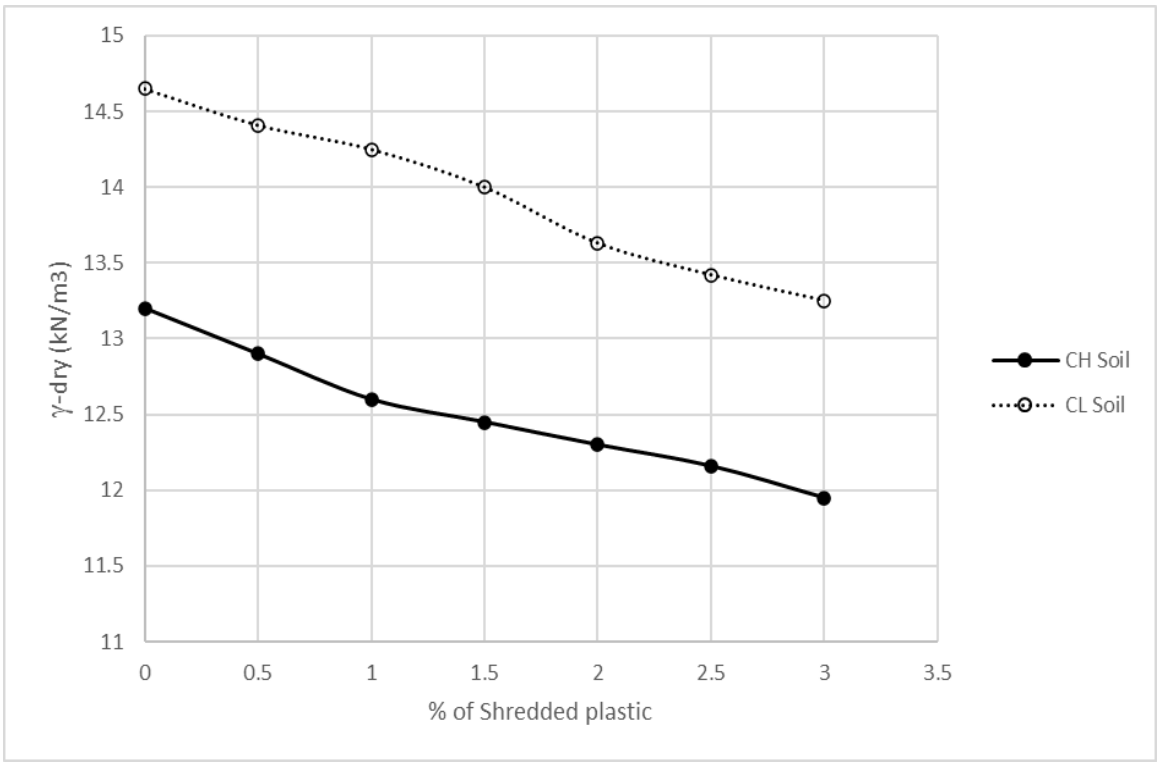

Figure 4: Maximum dry density with respect to the percentage of shredded plastic waste added.

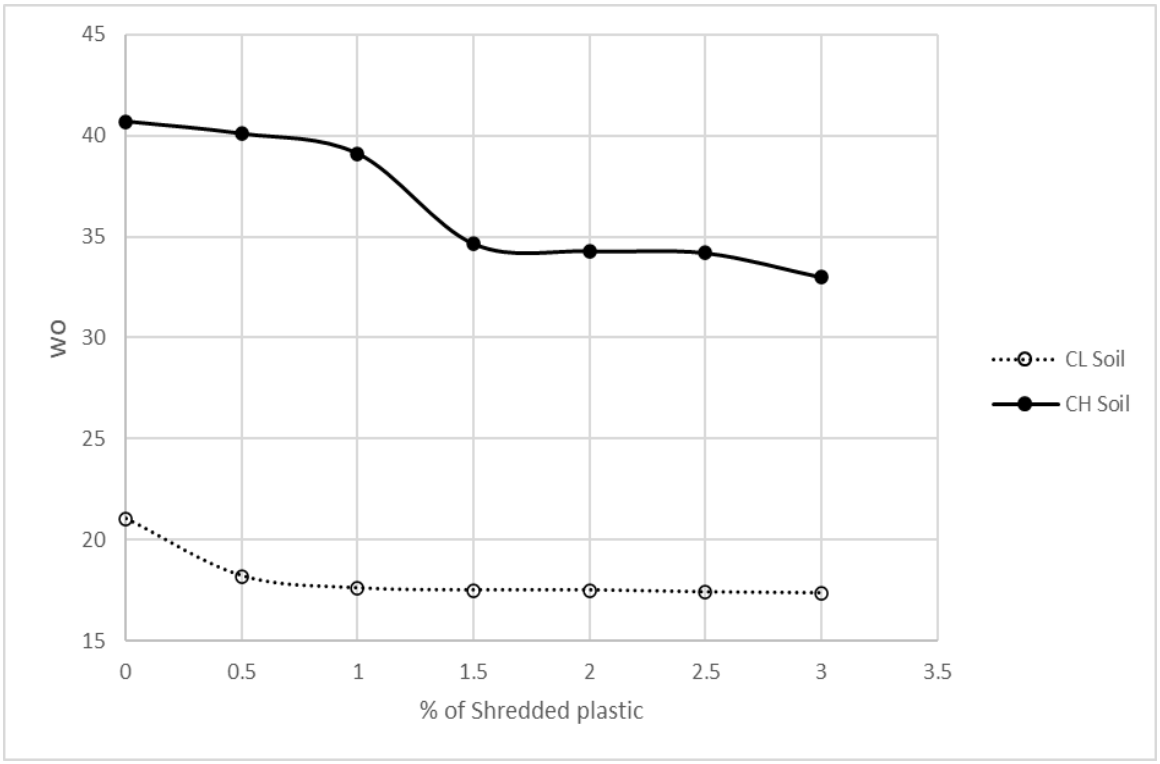

Figure 5: Optimum water content with respect to the percentage of shredded plastic waste added.

The Effect on the PWM on the Unconfined Compression Strength

Figure 6 represents the influence of PWM on the unconfined compression strength. It's clear that the addition of PWM led to a noticeable improvement in the unconfined compression strength of both soils up to a specific percentage which is 1.5%. This could be attributed to the fact that the added PWM formed a deep contact with the soil while keeping in mind that some of the fiber will intersect to the failure plane which will result in increasing the unconfined compression strength. The results reported that this trend is applicable up to 1.5%. Afterwards, increasing the percentage of PWM in the soil mixture will cause a reduction in the strength of the soil which is logical as the presence of additional PWM in the soil will reduce the cohesion since clay particles are being replaced with plastic even while considering the contact with the remaining clay soil.

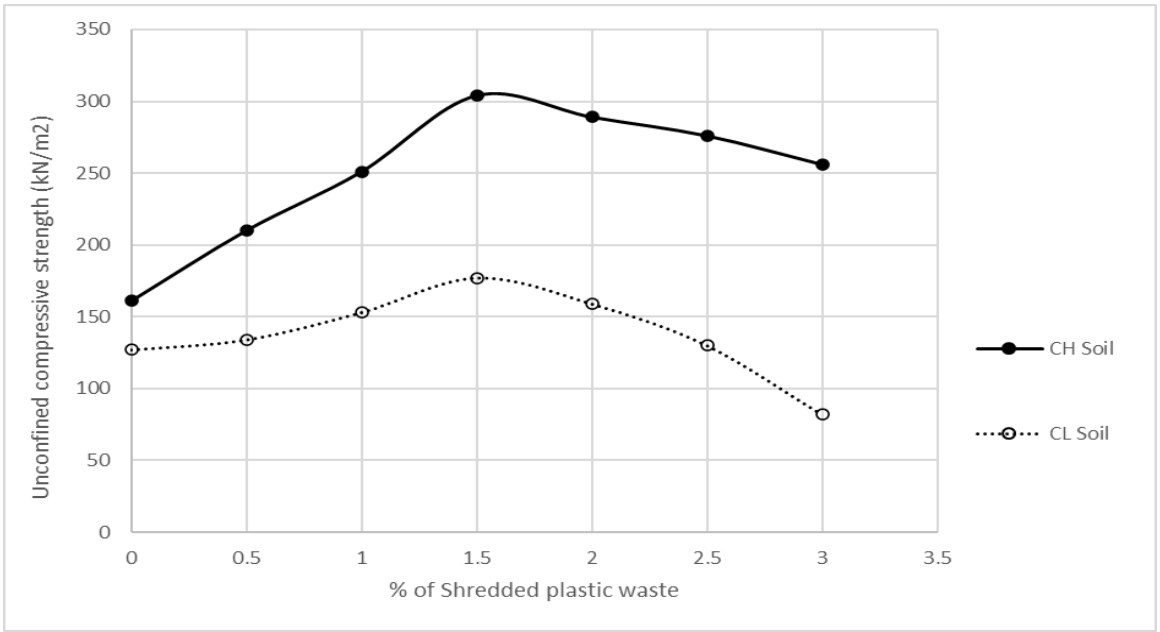

Figure 6: Unconfined compression test.

The Effect on PWM on Failure Strain

Figure 7 illustrates the impact of PWM on the failure strain of the soil. It's clear that the increase in the percentage of the PWM in the soils lead to decrease the percentage of the anticipated failure strain. This is primarily due to the fact that the nature of the added PWM is considered to be non-cohesive which will directly result in decreasing the failure strain and hence, the failure of the samples will occur at lower strain values.

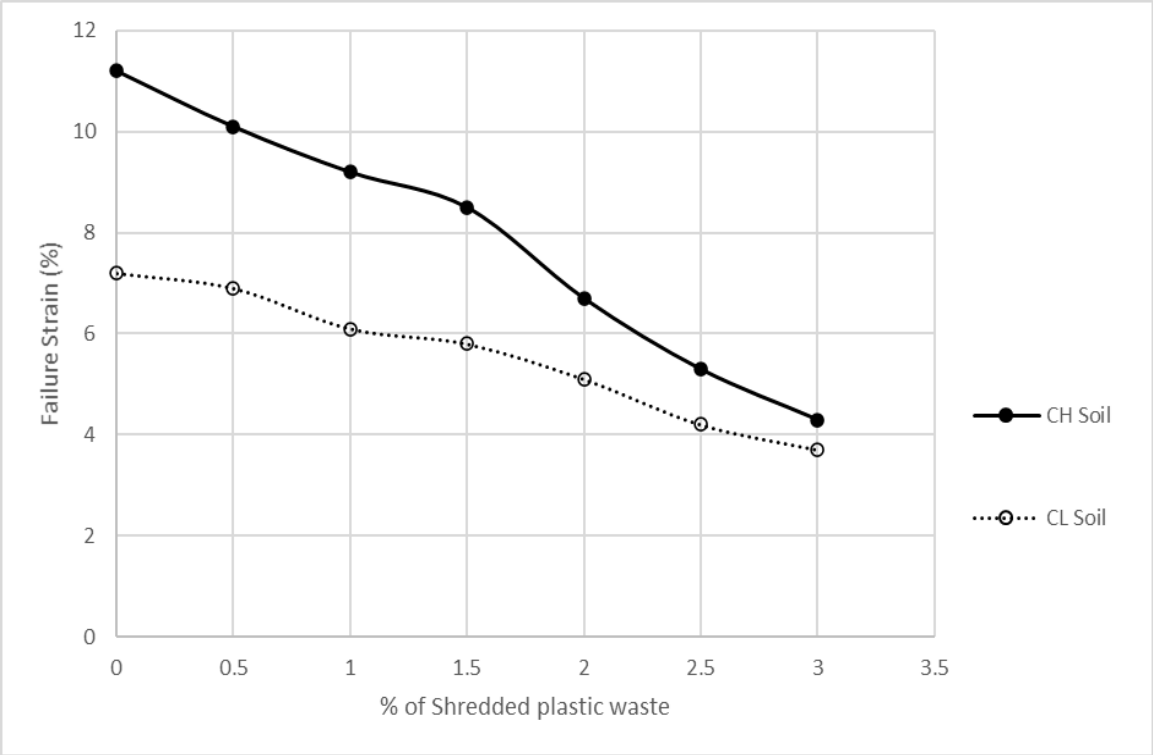

Figure 7: Percentage of failure strain with respect to the percentage of shredded plastic waste.

The Effect on the PWM on the Modulus of Elasticity

Figure 8 depicts the effect on the modulus of elasticity resulted from the addition of different percentages of PWM to the selected soils. It's obvious that increasing the percentage of PWM led to increase the value of the elastic modulus for both soils up to a specific percentage which is 1.5%. The reason behind this trend lies in the fact that the added PWM developed a deep contact causing the improvement in the modulus of elasticity and hence, an improvement in the strength of the mixture. Yet, the results showed that this trend is valid up to 1.5% of the added plastic material. After that, any additional increase in the PWM to the soil will tend reduce the strength of the soil as the presence of more PWM in the soil will decrease the cohesion of the soil since clay particles are being replaced with plastics which will reduce the overall cohesion of the clay soils.

Conclusion

The major conclusion of this research obtained from the several conducted tests are presented in this section.As the percentage of the added shredded plastic waste is increasing, the maximum dry density and the optimum water content of the different samples tend to decrease.The addition of shredded plastic waste up to 1.5% led to a noticeable improvement in the unconfined compression strength of both soils.Increasing the percentage of the shredded plastic waste in the soils led to decrease the percentage of the anticipated failure strain.Increasing the percentage of shredded plastic waste led to increase the value of the elastic modulus for both soils up to a specific percentage, which is 1.5%. Higher percentages more than 1.5% of the shredded plastic waste in the soil increase will decrease both the unconfined compressive strength and the modulus of elasticity.

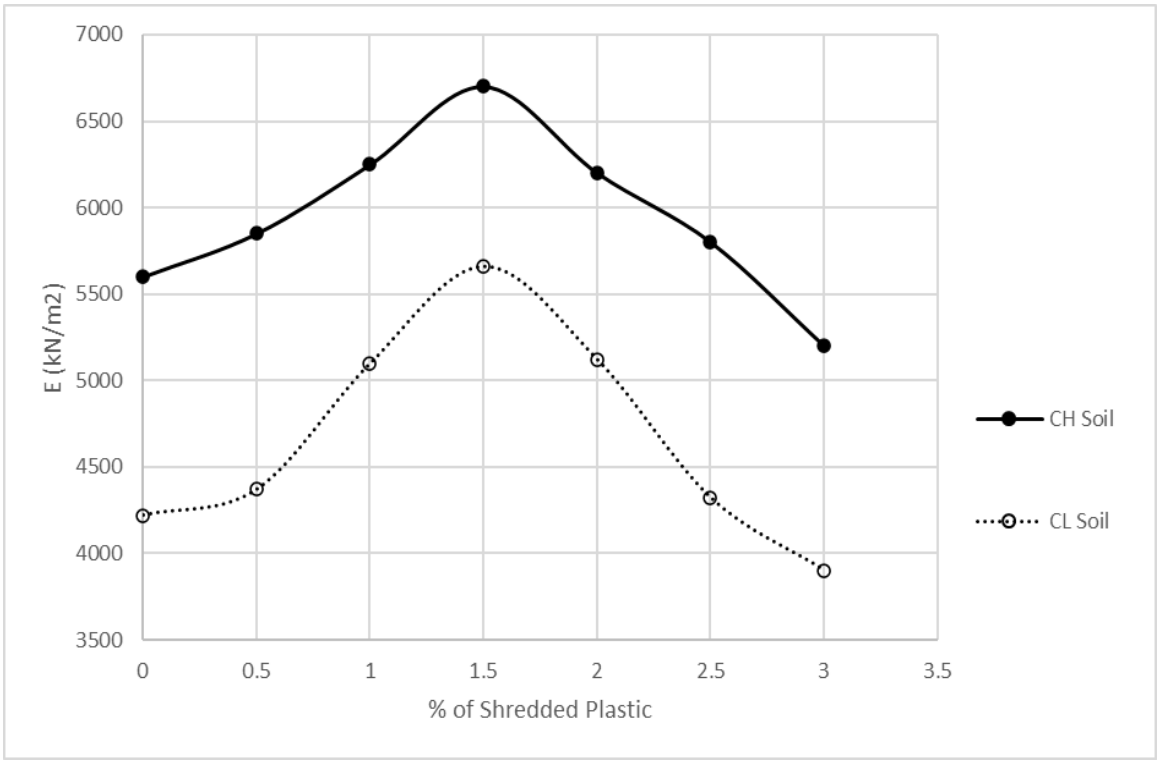

Figure 8: Modulus of elasticity with respect to the percentage of shredded plastic waste.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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The Review of Algerian Building Seismic Code(RPA) in Seven Points Compared to American and European Codes

Boulaouad ABDERRACHID
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Abstract: The first Algerian seismic code named "Règles Parasismiques Algériennes" (RPA, 1981) was established after the terrible 1980 Chlef earthquake (M 7.3), which caused a great disaster. Since this catastrophic event a continually reviewed versions, in particular after the 2003 Boumerdes earthquake (M 6.8) which caused an immense hazardous loss in human lives and construction damages (2000 seath) persons killed). This harmful event urged on to a serious review leading to the last and present version of such standard earthquake (RPA, 2003) with fundamental modifications concerning many important fields. The points revealed in the present review research study are the classification of sites, design methods, design spectrum, ductility concept, behavior factor, self-steady structures and dual systems (frames and walls). The outcome of the study here in is summarized as a brief review that could be a contribution to enrich the Algerian seismic regulation (RPA) with a focus on these seven important points selected as they seem to present some anomalies or deficiencies detected and treated on the basis of two main parameters. Firstly, we consider the damage observed after the 2003 Boumerdes earthquake; later in the second step, a comparison is made with other codes practiced over the world alike the European EC8 or the American Uniform Building Code, 1994 (UBC 94) or the 2000 NEHRP Provisions.

Keywords: Algerian seismic code (RPA), Design methods, Spectrum, Behavior factor, Dual system.

Introduction

In countries subjected to frequent severe earthquakes, such as Algeria, attention must be focused on seismic design, and seismic codes must be frequently revised to be more improved. The first Algerian seismic code named "RèglesParasismiquesAlgériennes" (RPA) was born only one year after the terrible 1980 Chlef earthquake (M 7.3), which caused a great disaster (big damage and loss of about 3500 lives). Since that, this code is continually reviewed. Recently, other earthquakes have occurred in some regions of Algeria, particularly the 2003 Boumerdes earthquake (M 6.8) which killed more than 2000 persons and caused an immense economic loss. This event egged on to serious review of the seismic design code leading to the last and present version of this regulation known as "RPA 2003" with fundamental modifications concerning many important fields (Algerian Ministry of Inhabitants, 2003).

This paper is a brief review of the Algerian seismic regulation (RPA) with a focus on seven important points which have been selected as they seem to present some anomalies or deficiencies which are detected and treated

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on the basis of two main parameters: the damage observed after the 2003 Boumerdes earthquake and the comparison with other codes over the world such as the European EC8 (Code, 2005).

The points concerned by this study are: site classification, design methods, response spectrum, ductility concept, behavior factor, self-steady structure and dual system (frame and wall).

Site Classification

The RPA classifies the soils in only four categories of sites according to their mechanical properties whereas the EC8 classifies them in seven categories according to the average shear wave velocity if it is available or the number of blows required for a standard penetration test (SPT) if not. Table 1 gives a comparison between the two cited codes concerning the site classification.

Table 1. Site classification according to RPA and EC8 codes

Eurocode8 Category	site	RPA 2003 Category	site
A	rocky site	S1	rocky site
B	firm site	S2	firm site
C	deep site of moderately dense sand and gravel or moderately stiff clay		
D	sol site of medium to poor density without cohesion	S3	loose site
E	sol site with a superficial layer of alluvium resting on a more steep material.		
S1	site composed of or containing a clayey layer more than 10 cm thick.	S4	very loose site
S2	liquefiable soil site of sensitive clay or other soil not mentioned previously.		

One can note that the RPA classification is not accurate. More categories of sites must be added for a better identification of instable or liquefiable soils.

Design Methods

During strong motions, the forces and displacements induced by seismic excitations can exceed the elasticity limit of structural elements causing, thus, nonlinearities which may lead to collapse. In the classical method, known as force-based (FB) or acceleration-based (AB) method, these nonlinearities are taken into account by a reduction of the forces derived from an elastic analysis procedure while the displacements are approximately checked at the end (Pinho et. al., 2007).

The Algerian seismic code (R.P.A.), amongst others, is based on the conventional (FB or AB) method which uses the acceleration spectra (Algerian Ministry of Inhabitants, 2003). After the terrible Northridge 1994 earthquake and similar further earthquakes (Kobe 1995, Kocaeli 1999 and Boumerdes 2003), this classical approach proved to be unsuccessful in the prevention of earthquake consequences. The use of more perfect approaches that clearly takes into account the nonlinearities of structures became necessary (Pinho et. al., 2007). In this perspective, the "Performance Based Seismic Design" was recently developed and is more and more used for three reasons:

It seems to be more realistic and accurate than the conventional method as it takes directly into account the displacement and permits the evaluation of the behavior expected on each structural element. It is more economical as it provides a structure that meets the requirements for the several limit states. It may be a good alternative to the nonlinear time-history (exact) method which is practically complex as it is governed by difficult conditions and tools.

This procedure consists to compare the capacity of a structure with a target displacement derived from a pushover analysis. The nonlinearities of materials are taken into account by a combination of the nonlinear static (pushover) analysis and the response spectrum approach. The applications of such an approach are: the capacity spectrum method of ATC 40 (ATC, 1996), the nonlinear static procedure of FEMA 356 (American Society of Civil Engineers, 2000) and the N2 method (Fajfar, 1999) implemented in the Eurocode8 (Code, 2005). In these

methods, the pushover analysis of a multi-degree-of-freedom (MDF) model is combined with the response spectrum analysis of an equivalent single-degree-of-freedom (SDF) system.

The most important steps of a simplified method are given in (Berra et. al. 2019). This new design concept uses the displacement as a key parameter in damage control on the basis of performance objectives which associate security with economy. This procedures is very effective for application to seismic rehabilitation of structures and is gradually extended to the design of new constructions. So, it is very relevant to the evaluation of the Algerian housing stock which consists mainly of Reinforced Concrete (RC) self-steady frames. A large part of this stock may not satisfy the limits imposed to such constructions by the "RPA 2003" code as they have been constructed before its advent. This new procedure must be incorporated in the RPA which does not refer to it.

Response Spectrum

In the RPA, the response spectrum called "normalized acceleration spectrum" Sa/g isgiven by the following equations:

$$\frac{S_a}{g} = \begin{cases} 1.25A\left[1+\frac{T}{T_1}\left(2.5\eta\,\frac{Q}{R}-1\right)\right] & if \quad 0 \le T \le T_1 \quad (1a) \\ 3.125\,\eta\,A\,\frac{Q}{R} & if \quad T_1 \le T \le T_2 \quad (1b) \\ 3.125\,\eta\,A\left(\frac{Q}{R}\right)\left(\frac{T_2}{T}\right)^{\frac{2}{3}} & if \quad T_2 \le T \le 3.0\,s \quad (1c) \\ 3.125\,\eta\,A\left(\frac{Q}{R}\right)\left(\frac{T_2}{3}\right)^{\frac{2}{3}}\left(\frac{3}{T}\right)^{\frac{5}{3}} & if \quad T \ge 3.0\,s \quad (1d) \end{cases}$$

where: A, T, T1, T2, Q, R and η represent, respectively, the acceleration coefficient of zone, the fundamental period, the characteristic periods, the quality factor, the behavior factor and the damping correction factor given in terms of the damping ratio ξ, by Eq. 2:

$$\eta = \sqrt{7/(2+\xi)} \ge 0.7 \quad (2)$$

First of all, one can note that the four overloaded equations (Eqs. 1a, 1b, 1c and 1d) of the RPA are very complex compared with the three simple equations (Eqs. 3a, 3b and 3c) of the UBC 94 (Chopra, 1995) and the two equations (Eqs. 4a and 4b) of the NBCC 95 (Chopra, 1995) for example. The acceleration spectra A/g of UBC 94 (for soil profile S1) and NBCC 95 (for zonal velocity ratio υ = 0.4) are given, respectively, by the following:

$$\frac{A}{g} = \begin{cases} Z + T_n & if \quad 0 \le T_n \le 0.15\,s \quad (3a) \\ 1 & if \quad 0.15 \le T_n \le 0.39\,s \quad (3b) \\ \frac{0.39}{T_n} & if \quad T_n \succ 0.39\,s \quad (3c) \end{cases}$$

$$\frac{A}{g} = \begin{cases} 1.2 & if \quad 0.03 \le T_n \le 0.427\,s \quad (4a) \\ \frac{0.512}{T_n} & if \quad T_n \succ 0.427\,s \quad (4b) \end{cases}$$

Where Z is the seismic zone factor and Tn the natural period of an SDF system (Chopra, 1995). On top of that, the present formulas of the RPA usually lead to a negative slope of the first branch (i.e. range of short periods)

while it must be a positive one as it is the case in either seismic design spectra or computed ones (Fig. 1). This anomaly has been already highlighted by Berra and Boulaouad (Berra et. al. 2019).

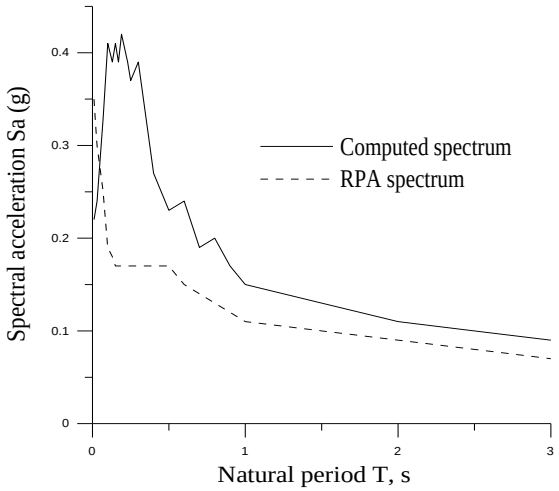

Figure 1. (a) RPA spectrum and Computed one

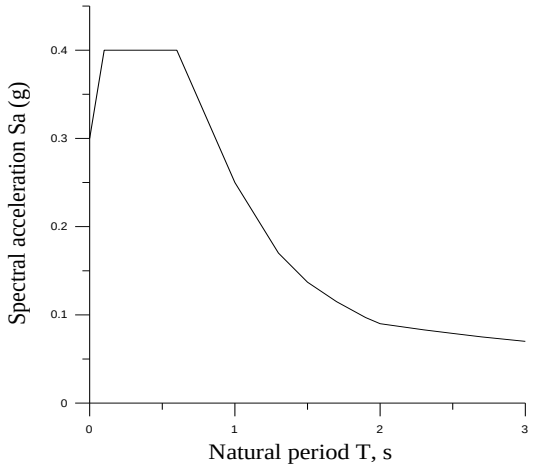

Figure 1. (b) EC8 Type I spectrum

The third and last defect which may be observed is the fact that the RPA code gives one and only design spectrum for all regions of Algeria whereas it must give specific spectra for particular regions such as the district of Algiers the capital which is often subjected to strong motions and groups most people of the state.

Ductility Concept

The Eurocode 8 gives 3 classes of structures corresponding to 3 levels of ductility: low, medium and high (Code, 2005). The RPA comments about ductility are general and vague without any specification of levels or classes. But, according to the requirements imposed to the construction, only one level is considered corresponding, likely, to the third class of the EC8 (high level). On top of that, the RPA gives one and only value of ductility for a multistory structure, not taking into account the reduction of ductility in elevation.

Behavior Factor

In order to account for the inelastic behavior of the structure, the seismic codes have introduced the well known behavior factor, noted R (or q in the Eurocode 8). This factor is also called reduction factor too as it is used to reduce the earthquake load. The values attributed to this parameter are subject to the following comments: They are given arbitrarily without any scientific basis. They depend only on the Lateral Loading Resisting System (LLRS) type of the building. They are often higher than those given by other codes. In the case of frame structure with masonry for example, the value given in the EC8 is 1.5 while it is 3.5 in the RPA. Consequently,

they seem to be overestimated as shown in Figure 2 where a comparison is made between the values given by the RPA, the ATC 40, the FEMA 356 and the time history (TH) methods (Fig. 2). This fact has been confirmed by the damage observed on this type of structure after the 2003 Boumerdes earthquake and lately by the works of Berra and Boulaouad (Berra et. al. 2019). Last but not least, they do not take into account the particularity of some regions of high sensibility to earthquakes, such as Algiers, where the life-safety criterion takes precedence over the economical one. In such a case, the incursion in the plastic domain must be strictly limited and consequently R must be reduced.

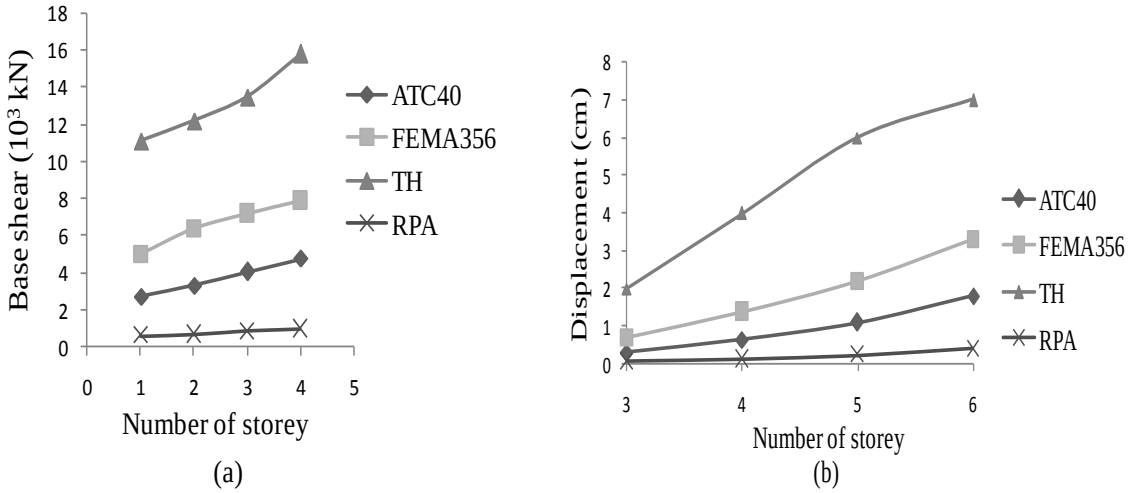

Figure 2. RPA, ATC, FEMA and exact methods: (a) base shear and (b) displacement

Self-Steady Structure

During the Boumerdes 2003 earthquake, a large proportion of the self-steady structures collapsed or were severely damaged (Figure 3). The lesson learned from this relevant information is that the Algerian seismic regulation must be revised so that the use of such structures must be prohibited in zone of very high seismicity (zone 3) and their number of stories restricted to 3 or 4 in the other zones. The type of structure recommended instead of the self-steady frame is the combined system (wall and frame).

Figure 3. Shear collapse due to the interaction between masonry and frame in Boumerdes town.

Dual System (Frame and Wall)

The RPA does not give any indication concerning the proportion of the different elements. Attention must be focused on the proportion of walls to insure a minimum of stiffness.

Conclusion

In order to improve the Algerian seismic code (RPA) which presents many deficiencies, seven points have been selected and treated on the basis of two main parameters: the damage observed after the 2003 Boumerdes earthquake and the comparison with other codes. Relevant observations have been made and beneficial suggestions have been given. Other items can be pointed and treated in the same manner.

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Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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