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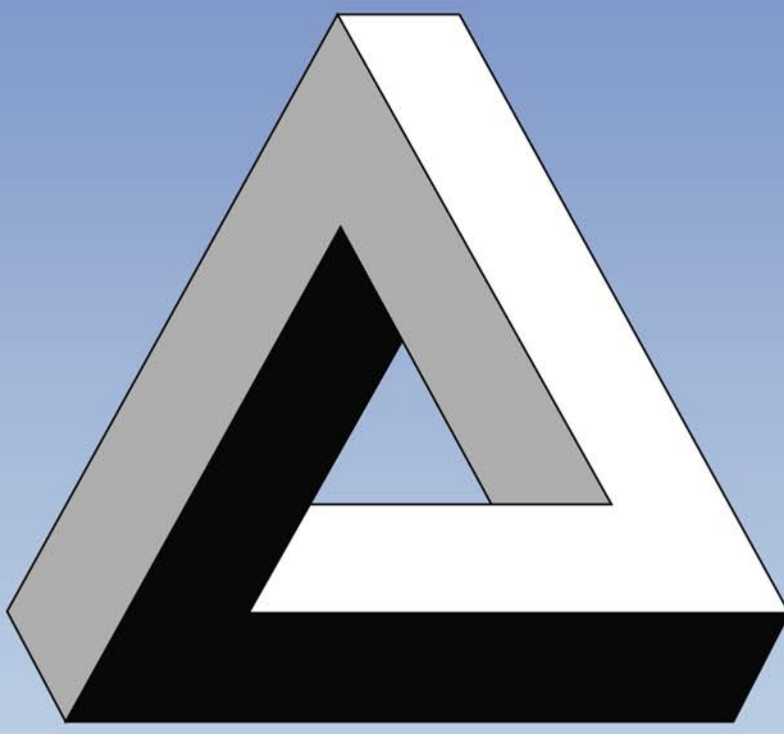

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INFLUENCE OF SUPERPLASTICIZER ON THE RHEOLOGY OF COMPOSITE MORTARS

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Abstract- Two series of samples were prepared, a control mortar and composite mortars mixed with plastic waste. A superplasticizer powder and a superplasticizer liquid were used to define the rheological properties of each mixture. The water/cement (W/C) ratios were constant, while the percentages of plastic waste varied from 2, 5, 10 and 15%. Both fresh and mechanical properties were assessed. This research demonstrated the crucial importance of the choice of superplasticizer in the formulation of composite mortars. These factors have a direct influence on the rheological and mechanical performance of mortars, making it possible to design formulations adapted to the requirements of modern construction.

Keywords: Composite mortars, Plastic waste, Superplasticizer, Rheology.

1-Introduction

According to a World Bank report, Algeria generates around 3.7 million tonnes of plastic waste every year, a significant proportion of which ends up in landfill sites or in the natural environment [1]. Faced with this problem, researchers and engineers are increasingly turning their attention to innovative solutions for managing and recovering this waste. One promising solution is to incorporate plastic waste into construction materials such as composite mortars. This approach not only reduces the amount of waste sent to landfill, but also produces construction materials that are potentially more durable and economical [2]. Indeed, the reuse of plastics in composite mortars offers an efficient recycling solution while improving certain characteristics of the materials, such as lightness, flexibility and energy absorption capacity [3]. The main aim of this study is to assess the effectiveness of incorporating plastic waste into composite mortars in Algeria. There are several reasons for this choice. Firstly, plastic waste management is becoming a growing concern in Algeria, where recycling infrastructures remain insufficient to deal with the volume of waste generated [4].

Secondly, Algeria's construction industry is expanding rapidly, increasing demand for innovative and sustainable building materials. By incorporating plastic waste into composite mortars, it is possible to meet this demand while reducing environmental impacts. In addition, previous studies have shown that incorporating recycled plastics into mortars can improve certain mechanical and physical properties of the materials, such as resistance to cracking and durability in aggressive environments [5]. However, these studies have often been carried out in contexts different from that of Algeria, where climatic conditions, the types of waste available and construction standards vary. Specific research is therefore essential to assess the effectiveness and suitability of these materials in the Algerian context. In summary, this innovative approach to managing plastic waste by incorporating it into composite mortars aims to provide empirical data on the performance of these materials and to make recommendations for their use in the Algerian construction sector. The aim of this approach is to help solve the problems associated with waste management and improve the durability of construction materials in the country. This study highlighted the crucial importance of the choice of superplasticizer in the formulation of composite mortars. These choices have a direct influence on the rheological and mechanical performance of mortars, making it possible to develop formulations tailored to the requirements of modern construction.

2- Materials and test methods

2.1- Materials

● Cement: a CEM II / 42.5 cement from the Groupe Industriel des Ciments d'Algérie 'GICA' cement works in accordance with Algerian standard NA442-2023 [6]. This cement is suitable for the manufacture of mortars and all reinforced concrete works. The dosage of this cement is 350kg/m^3. Its chemical and mineralogical composition of the clinker is given in Table 1.

● Sand: the sand used is quarry sand, the grain size of which was determined by sieving. The chemical and physical characteristics of this sand are given in Tables 1 and 2 respectively.

● Plastic waste (PW): This consists of collected plastic caps ground into powder with a diameter of less than 0.5 mm. The physical characteristics are presented in table 2. It is incorporated by mass substitution into sand with contents ranging from 2, 5, 10 and 15%.

● Superplasticizer: two types of superplasticizer were used.

- *A liquid superplasticizer* (SPL): this is a SIKA ViscoCrete-625 superplasticizer from the SIKA BULDING TRUST company in Oran, which complies with standard NF EN 934-2 [7]. This additive makes it possible to produce concretes and mortars with very low W/C ratios. The physical and chemical characteristics of the superplasticizer are given in tables 1 and 2 respectively.

Table 1: Chemical and mineralogical analysis of cement, SPP, SPL and sand

Elements	Cement (%)	Superplasticizer (SPP) (%)	Superplasticizer (SPL) (%)	Sand (%)
CaO	59.93	0.88	-	-
SiO_2	18.73	93.35	-	29.15
Al_2O_3	4.38	0.29	-	-
Fe_2O_3	3.31	0.34	-	0.56
SO_3	2.63	-	$\leq 4\%$	-
K_2O	0.67	-	-	-
Na_2O	0.23	-	-	-
MgO	1.62	-	-	-
SO_4	-	0.97	-	-
$CaCO_3$	-	3.18	-	70.45
CO_2	-	-	-	-
CaO free	-	-	-	-
C3S	59.9	-	-	-
C2S	8.82	-	-	-
C3A	6.01	-	-	-
C4AF	10.06	-	-	-

- *A powder superplasticizer* (SPP): this is an AETERNUM 3 superplasticizer from the TEKNACHEM company in SIDI BELABES. This new-generation carbon and silicate-based powder additive, infused with active nano-micro silicates, which it combines with high pozzolanic activity, ensures rheology, fluidity without segregation and impermeability. This additive makes it possible to produce concretes and mortars with very low E/C ratios. The physical and chemical characteristics of the superplasticizer are given in Tables 1 and 2 respectively.

Table 2 : Physical characteristics of cement, sand, SPP, SPL and PW

Physical properties	Cement	Sand	SPP	SPL	PW
Blaine specific surface area (cm²/g)	3308	-	1000 - 2000	-	-
pH	-	-	10	5	-
Consistency	-	-	powder	fluid	-
Sand equivalent under piston	-	85.12	-	-	-
Absolute density (g/cm^3)	3.16	2.72	0.4-0.6	1,08 ± 0,015	-
Apparent density (g/cm^3)	-	1.41	-		0.95
Absorption coefficient(%)	-	18	-	-	Ins.

2.2- Test method

In order to determine the consistency of each composition, it was decided to keep the same spread (60%) and therefore the same W/C ratio. Only the percentage of superplasticizer varied. Mechanical strength was assessed by measuring compressive strengths. For each mortar composition, three samples were subjected to a compression test 28 days after casting. The composition of the mortars is given in Table 3.

Table 3 : Composition of different composite mortars

Mix mortars	Cement (g)	Sand (g)	SPP (%)	SPL (%)	PW (g)	E/C
MRSPL	650	1300	-	0.5	-	0.5
MCSPL2	650	1274	-	1	26	0.5
MCSPL5	650	1235	-	1.35	65	0.5
MCSPL10	650	1170	-	1.65	130	0.5
MCSPL15	650	1105	-	1.95	195	0.5
MRSPP	650	1300	1.95	-	-	0.5
MCSPP2	650	1274	2	-	26	0.5
MCSPP5	650	1235	2.3	-	65	0.5
MCSPP10	650	1170	2.6	-	130	0.5
MCSPP15	650	1105	3	-	195	0.5

3- Result and discussion

Figure 1 illustrates the effect of superplasticizer in the fresh state of the various composites. It can be seen that to achieve the same W/C ratio with constant workability, the addition of the superplasticizer powder SPP must be increased by around 3% for the MR reference mortar and around 2% for the other composite mortars compared with the liquid superplasticizer SPL. In order to achieve a W/C ratio of 0.5, SPP requires a high silica content due to its fineness, which is comparable to that of cement. Also, the amount of silica is high, which favours an increased content of superplasticizer (silicate and carbon). The higher the PW content, the greater the demand for superplasticizer. Despite being insoluble and inert, PW encourages greater use of superplasticizer [8].

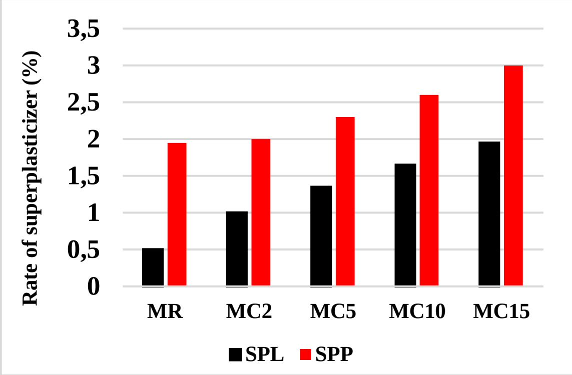

Figure 1: Effect of superplasticizers on fresh composite mortars

Figure 2 shows the mechanical strength as a function of the level of plastic waste and the nature of the superplasticizer. It can be clearly seen that the incorporation of SPP increases the compressive strength compared with the introduction of SPL. The high silica content in SPP generates a pozzolanic reaction in mortars, which increases compressive strength. Researchers have shown that powdered superplasticizers with a high silica content can increase strength [9-10], and as the PW content increases, strength tends to decrease regardless of the addition of the superplasticizer. A number of studies show that PW influences the porosity of mortars and that an optimum level should be specified for each type of formulation [11].

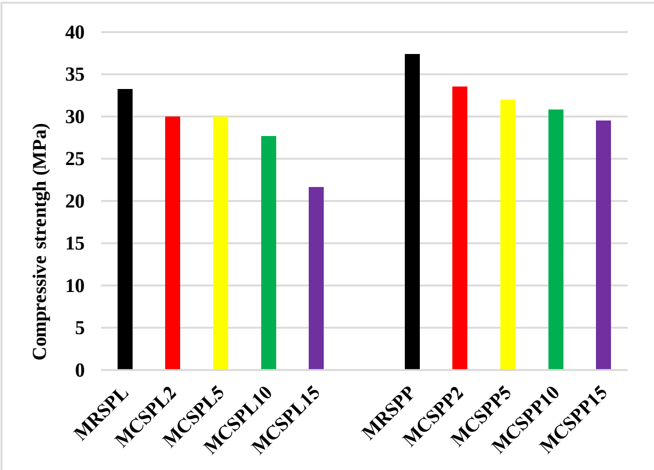

Figure 2: Compressive strength of composite mortars as a function of superplasticizer

4 - Conclusion

After simple and rapid testing, it was found that superplasticizer powder (SPP) would increase the mechanical strength of composite mortars. The level of PW in composite mortars has a direct influence on the porosity of the mortar. With a PW content of 15%, the mortar reaches 29 MPa, which is very favourable for construction mortars.

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EFFET DE LA FUMÉE DE SILICE SUR LA DURABILITÉ DES BÉTONS À BASE DE GRANULATS MULTI-RECYCLÉS

EFFECT OF SILICA FUME ON THE DURABILITY OF MULTI-RECYCLED COARSE AGGREGATE CONCRETE

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Résumé - Ce travail de recherche vise à étudier la durabilité des bétons fabriqués avec des granulats grossiers multi-recyclés. Quatre générations de béton ont été préparées : un béton témoin (NAC) contenant 100 % de granulats grossiers naturels (NCA) et trois générations de bétons recyclés (RAC1, RAC2 et RAC3). Dans chaque génération, le NAC est totalement remplacé par des granulats recyclés (RCA). Au cours de l'étude, il a été constaté que le multi-recyclage du béton entraîne une diminution significative de ses propriétés. Par conséquent, l'utilisation de 10 % de fumée de silice a été proposée pour améliorer ses performances. Les RCA sont pré-saturés avant leur utilisation afin d'obtenir la même ouvrabilité pour tous les bétons étudiés. La durabilité des bétons a été évaluée par des essais de perméabilité à l'eau, d'absorption d'eau et de diffusion des ions chlorures. Les résultats montrent que la perméabilité à l'eau et l'absorption d'eau du béton augmentent avec le nombre de cycles de recyclage, en raison de la structure plus poreuse, de la haute capacité d'absorption des RCA et de porosité de la matrice RAC. En outre, les bétons recyclés présentent une pénétration élevée des ions chlorure par rapport au béton témoin, cette pénétration augmentant avec le nombre de cycles de recyclage. Enfin, il a été observé que l'ajout de fumée de silice améliore la durabilité des bétons à base de granulats multi-recyclés.

Mots - clés : Granulat recyclé, Multi-recyclage, Perméabilité, Absorption d'eau, diffusion des ions chlorures

Abstract- This research work aims to study the durability of concretes made with multi-recycled coarse aggregate. Four generations of concrete were prepared in this study: a control concrete (NAC) with 100% natural coarse aggregate (NCA), and three different generations of recycled concrete (RAC1, RAC2 and RAC3). NAC is completely substituted by RCA in each generation. During the course of the work, it was observed that the multi-recycling of concrete involves a significant decrease in its properties. Therefore, the use of 10% silica fume was suggested to correct its performance. The RCA are pre-saturated before their use to achieve the same workability for all the studied concretes. the durability of the concrete was evaluated by conducting tests for water permeability, water absorption, as well as chloride ion diffusion tests. The results show that the water permeability and the water absorption of concrete increases with the increase in the number of recycling cycles due to the more porous structure and the high absorption capacity of RCA and the permeability of RAC matrix. Moreover, recycled concretes have high chlorine ion penetration compared to control concrete; the latter increases with the increase in recycling cycles. Finally, it was observed that the addition of silica fume leads to an improvement in the durability of the concretes made with multi-recycled aggregates.

Keywords: Recycled aggregate, Multi-recycling, Permeability, Water absorption, Chloride ions diffusion.

1-Introduction

In the future, when all concrete is recycled concrete, it will be necessary to recycle the recycled concrete [1]. According to studies on the replacement of natural aggregates with recycled coarse aggregates to produce concrete, both the durability and mechanical properties of concrete are affected. However, it is generally accepted that the use of recycled aggregates has a greater impact on the durability performance. The use of a more porous aggregate results in a more porous concrete matrix, thus increasing its fluid penetration capacity [2 & 3]. This same porosity is the main cause of the decrease in resistance to corrosion processes, such as carbonation and chloride penetration. Furthermore, the incorporation of recycled aggregates results in a lower performance of concrete in terms of carbonation resistance [4 & 5]. Similar behaviour has been observed for resistance to chloride penetration [6]. It can be concluded that the main reason for the lower durability of RAC is its higher porosity, which is directly related to the attached mortar constituting the RCA. Therefore, since the multiple recycling process is expected to produce RCA with an increasing amount of attached mortar, it is likely that the studied mixtures will show decreasing durability, depending on the number of recycling cycles that have produced the RCA that compose them.

The attached mortar is commonly acknowledged as the major vulnerability of RCA. Therefore, some studies have focused on the treatment of RCA, either by improving their properties using mineral addition [7 & 8], or by separating the attached mortar by mechanical, chemical or physical methods [9]. These various techniques are based on the difference in properties between NCA and cement paste, which has a weaker interfacial transition zone (ITZ) [10].

The innovation of this research lies in determining the durability properties of multi-recycled concrete, produced from the crushing of an original concrete with the same composition and properties as the reference concrete, thus eliminating the entropy due to this parameter. Each new concrete with recycled aggregates was made with RCA from a previous recycling cycle of concrete having exactly the same composition and constituents as the previous cycle, changing only the origin of the RCA.

2-Materials and method

2.1- Materials used

CEM II/A-L 42.5 N; Silica Fume with SSB = 22.5 m2/g; Sand of a fineness module 2.79; Natural limestone gravel 3.15/15; Three generations of recycled gravel 3.15/15.

2.2- Method

Four generations of concrete were prepared in this study: NAC with 100% NCA and three different generations of multi-recycled concrete. NCA is substituted by RCA with volume percentages 100% in each generation. The RCAs are pre-saturated before their use in order to achieve the same workability of all the concretes studied, while the NCA is used in the dry state. All concretes were manufactured with the same water/binder ratio (W/B = 0.57) and slump ratio (18 ± 1 cm). The proportions of different mixtures of concrete are reported in Tab 1.

Tableau 1 : formulation des différents mélanges
Table 1 : Composition of different mixtures (kg/m3)

Concrete	Cement	SF	Sand	NCA	RCA1	RCA2	RCA3
NAC	400		745	968			
RAC1	400		745		888		
RAC2	400		745			855	
RAC3	400		745				837
RAC1-SF	360	40	745		888		
RAC2-SF	360	40	745			855	
RAC3-SF	360	40	745				837

The aim of this work is to characterize the durability of concrete made with recycled coarse aggregate. The durability tests conducted are:

2.2.1 Water absorption by immersion

Water absorption by immersion measures its mass absorption capacity, expressed as the amount of water absorbed by a concrete sample. According to ASTM C642-06, the test involves placing 70x70x280 mm prismatic concrete samples, aged 90 days, in an oven at 105 °C and weighing them until a constant weight is achieved. The samples are then fully submerged in a water bath at 20 °C for 24 hours until the material is saturated.

2.2.2 Water permeability

Water permeability measures the migration of water through concrete under water pressure. Permeable concrete allows various external aggressive agents to penetrate. The water permeability test was conducted according to the NF EN 12390-8 standard. This test measures the depth of water penetration in a cylindrical sample with a diameter of 150 mm. Three samples were tested at 90 days of age. The samples were placed in the test device under a water pressure of 500 kPa (5 bars) for 72 hours. The surface of the sample exposed to the water pressure must be roughened with a wire brush. After 72 hours of applying the pressure, the samples were removed from the device, and each sample was then split into two halves using a splitting test. The depth of water penetration is measured with a calliper to the nearest millimetre.

2.2.3 Penetration of chloride ions

The penetration of chloride ions into concrete is determined using the permeability method according to ASTM C1202-12. The test is conducted on cylindrical samples with a diameter of 100 mm and a height of 50 mm at 90 days of age. The perimeter of the sample is coated with a waterproof paint (flintkote) to direct the diffusion of chloride ions in a single direction. Before each test, the samples are pre-saturated in water at 20 °C.

3-Results and discussion

3.1- Properties of aggregates

Fig. 1 represents the particle size analysis of the different types of aggregates and Tab 2 shows the properties of the different generations of coarse aggregates.

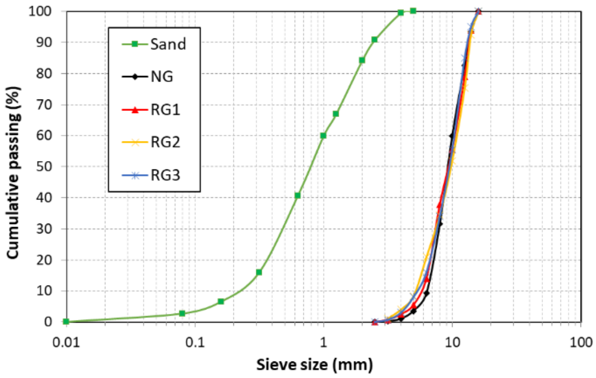

Figure 1 : Distribution granulométrique
Figure 1 : Particle size distribution

Tableau 1 : formulation des différents mélanges (kg/m^3)
Table 1 : Composition of different mixtures (kg/m^3)

	NCA	RCA1	RCA2	RCA3
Specific weight (g/cm3)	2.65	2.43	2.34	2.29
Attached mortar (%)		35	54	79
Water absorption (%)	0.63	6.5	10.1	13.7
Los-Angeles coefficient (%)	29	36	44	57
Fragmentation coefficient (%)	21	29	34	39

The mechanical properties of the RCAs deteriorate after each recycling cycle; this is due to the fragility of the mortar attached to the NCA [11]. In addition, these high values of the coefficients are characterized by a high sensitivity to wear and therefore the RCA are less resistant than the NCA.

3.2- Water absorption by immersion

3.2.1- Influence of multi-recycling on water absorption by immersion

Fig. 2 shows the influence of multiple recycling on the water absorption by immersion of the tested concretes at 90 days. According to the curves, an increase in the water absorption coefficient is observed as the number of recycling cycles increases. Following this trend, RAC3 had the highest water absorption (12%), while NAC had the lowest (4%). These results align with those reported by De Brito et al.[12] and Ozbakkaloglu et al. [13], who observed a progressive increase in the water absorption capacity of concrete as the substitution of natural aggregates with recycled aggregates increased. The adhered mortar on the aggregates is responsible for the increased water absorption capacity of recycled concrete aggregates due to its relatively higher porosity compared to natural aggregates.

3.2.2- Influence of silica fume on water absorption by immersion

According to Fig. 2, after the addition of silica fume, reductions of 26%, 19%, and 9% are observed for the first, second, and third recycling cycles, respectively. This decrease is attributed to the finer structure of silica fume compared to cement, which coats the surface of the recycled aggregates and reduces water absorption [14]. Silica fume can also help fill voids, leading to increased compactness and cohesion of the mix [15].

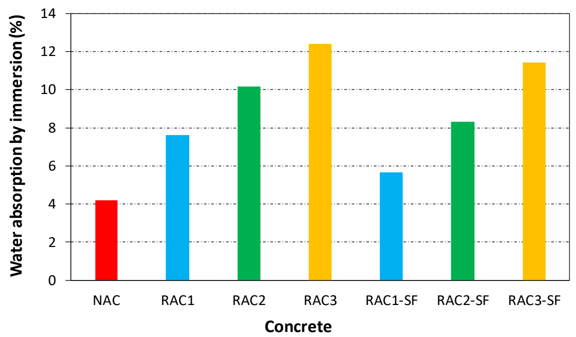

Figure 1 : Absorption d’eau par immersion des bétons

Figure 1 : Water absorption by immersion of concretes.

3.3- Water permeability

3.3.1- Influence of multi-recycling on water permeability

The water penetration depths under pressure, depending on the recycling cycle, are illustrated in Fig. 3. The results show that the water penetration depth is greater in concrete made with recycled aggregates from the third cycle. RAC1 exhibited a water penetration depth of 48 mm, while NAC showed a depth of 28 mm. RAC2 and RAC3 displayed average values of around 60 mm and 72 mm, respectively. It is evident that the increase in the number of recycling cycles leads to significantly higher water permeability. This increase is explained by the high absorption capacity of the recycled aggregates and the permeability of the concrete matrix.

3.3.2- Influence of silica fume on water permeability

The water permeability of the tested concretes is illustrated in Fig. 3. In general, permeability decreases after the addition of silica fume across all cycles. According to the observations from the diagram, water permeability decreases by 27% in the first cycle, and by 14% and 11% in the second and third cycles, respectively. This reduction in depth is due to the presence of silica fume, which fills the voids and pores with C-S-H, thereby blocking water penetration [16].

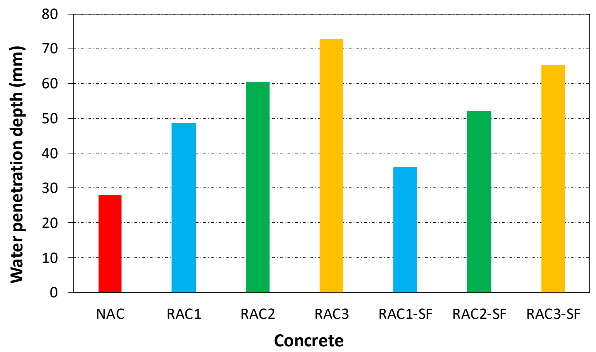

Figure 1 : Profondeur de pénétration de l'eau dans les bétons

Figure 1 : Water penetration depth of concretes

3.4- Water permeability

3.4.1- Influence of multi-recycling on chloride ions penetration

The results of the chloride ion penetration test at 90 days are presented in Fig. 4. The results indicate that the chloride ion migration coefficient increases with the number of recycling cycles. This increase is approximately 32% for RAC1, 61% for RAC2, and 96% for RAC3 compared to conventional concrete. This rise is directly linked to the concrete's porosity and grows linearly with each cycle due to the increasing amount of adhered mortar.

The total charge is significantly higher in recycled concretes and increases proportionally with the recycling cycle. This can be explained by the greater permeability of recycled concretes compared to conventional concrete [17].

3.4.2- Influence of silica fume on chloride ions penetration

Fig. 4 shows the influence of silica fume on the chloride ion permeability of the tested concretes at 90 days. Based on these results, a reduction in total charge is observed with the increase in the number of recycling cycles after the addition of silica fume. This reduction reaches 20%, 13%, and 8% for the first, second, and third cycles, respectively. This decrease in charge is due to the formation of C-S-H and the filling of cement paste pores by silica fume.

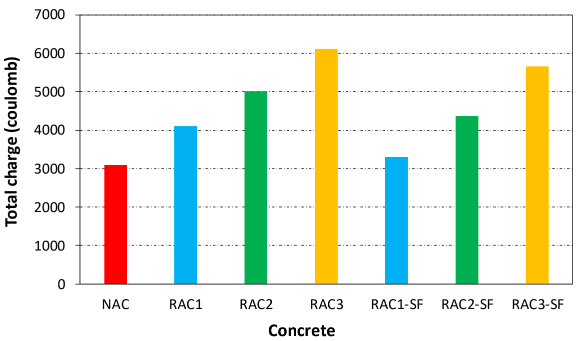

Figure 1 : Charge totale de pénétration des ions chlorure

Figure 1: Total charge of chloride ion penetration

4- Conclusion

According to this experimental study, the main conclusions we reached are:

1. RCA of each generation is characterized by higher absorption, lower density and reduced abrasion resistance compared to those of NCA.

2. The immersion water absorption and water permeability of concretes increases with increasing number of recycling cycles due to the more porous structure and high absorption capacity of RCA.

3. Recycled concretes exhibit higher chloride ion penetration compared to the control concrete, and this penetration increases with the number of recycling cycles.

4. The addition of silica fume enhances the durability stability of concretes made with multi-recycled aggregates.

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EFFET DE L'ÂGE SUR LA VARIABILITÉ DE LA MESURE DE LA RÉSISTANCE A LA COMPRESSION DU BÉTON

EFFECT OF AGE ON THE VARIABILITY OF COMPRESSIVE STRENGTH MEASUREMENT OF CONCRETE

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Résumé- *La résistance à la compression des bétons demeure un enjeu de grand intérêt dans le domaine de la construction. L'effet de l'âge de durcissement des éprouvettes influe sur le comportement et la fiabilité des structures en béton, ce qui impose de le prendre en compte dans les calculs de dimensionnement et la conception des pièces réalisées avec ce matériau. Il est également nécessaire d'intégrer ce paramètre dans l'élaboration des modèles de prédiction, ce qui justifie l'utilisation d'approches statistiques probabilistes basées sur la notion d'une probabilité acceptable. Un travail expérimental a été conduit pour étudier l'effet de l'âge sur la variabilité de la mesure des résistances à la compression du béton en utilisant des matériaux locaux. Des essais d'écrasement ont été réalisés sur des cubes d'arête 15 cm à différents âges (7 et 28 jours).Ces essais ont permis d'analyser comment l'âge des échantillons influe les résultats de la résistance à la compression, en tenant compte de l'évolution des propriétés du béton au fil du temps. Les résultats obtenus ont montré des écarts significatifs de résistance à la compression pour tous les âges étudiés.*
Cette variabilité souligne l'importance de considérer l'effet de l'âge dans les pratiques de dimensionnement et de conception des structures en béton. Pour prendre en compte la dispersion des réponses mesurées, le modèle statistique de Weibull à deux paramètres a été utilisé. Ce modèle permet de mieux comprendre et prédire la variabilité des résistances à la compression du béton, en tenant compte de l'effet de l'âge observé lors des essais expérimentaux.
Mots - clés : *Variabilité, Résistance, Compression, Weibull, Rupture*

Abstract- *The compressive strength of concrete remains a significant concern in the field of construction. The effect of the curing age of specimens influences the behavior and reliability of concrete structures, necessitating its consideration in the design calculations and the engineering of components made with this material. It is also essential to incorporate this parameter into the development of predictive models, which justifies the use of probabilistic statistical approaches based on the concept of an acceptable probability. An experimental study was conducted to investigate the effect of age on the variability of compressive strength measurements of concrete using local materials. Crushing tests were performed on 15 cm edge cubes at different ages (7 and 28 days). These tests allowed for the analysis of how the age of the samples affects the compressive strength results, taking into account the evolution of concrete properties over time. The results obtained showed significant variations in compressive strength for all ages studied. This variability underscores the importance of considering the effect of age in the design and engineering practices of concrete structures. To account for the dispersion of measured responses, a two-parameter Weibull statistical model was employed. This model facilitates a better understanding and prediction of the variability of concrete compressive strengths, considering the age effect observed during the experimental tests.*

Keywords: *Variability, Strength, Compression, Weibull, Failure.*

1-Introduction

Le béton est un matériau de construction largement utilisé en raison de ses propriétés de durabilité et de résistance [1]. Cependant, le béton peut subir une perte importante de sa force, ce qui pose un défi important [2–3]. L'âge du béton peut également influencer sa résistance, d'où l'importance d'étudier la relation entre l'âge du béton et sa résistance résiduelle à la compression. Dans cette étude on va étudier l'effet de l'âge sur la résistance à la compression des éprouvettes cubiques à 7 jours et 28 jours, en tenant compte de la variation de cette résistance à la compression en utilisant un modèle statistique. De nombreuses études ont été faites sur le béton durci à des âges différents afin de comprendre comment l'âge affecte la résistance et l'élasticité du béton au fil du temps. Selon la norme ASTM C192 [4], l'âge des éprouvettes pour les tests de compression ne doit être inférieur à 28 jours. Cependant, pour assurer le développement de la résistance du béton, il est recommandé de tester les spécimens à l'âge de 28, 90 et 180 jours [5].

Dans la littérature plusieurs études ont montrés que la résistance à la compression du béton évolue lorsque l'âge du béton augmente [6-7], cela est dû aux à l'hydratation continue des grains de ciment avec de l'eau et la diminution de nombre de défauts au fil du temps [8-9]. En outre, la résistance du béton est influencée par l'âge du béton et le type et la nature de granulats utilisés.

2- Matériaux et méthodes

2.1- Matériaux

Un ciment de type CPJ 42,5 provenant de la cimenterie d'Ain El Kebira, a été utilisé pour la confection des bétons d'étude. Ce dernier répond à toutes les exigences de la norme Algérienne (NA 442).

Trois fractions granulaires ont été utilisées pour la fabrication des bétons d'études. Ces granulats proviennent de la carrière Adrar Oufarnou (Bejaia). Ces agrégats sont des produits concassés de nature calcaires. Il s'agit d'un sable (0/3), d'un gravier (8/15) et d'un gravier (15/25).

Les caractéristiques physiques et mécaniques de ces granulats sont données dans le tableau 1 ci-dessous.

Tableau 1 : Les caractéristiques physiques et mécaniques des granulats utilisés

Table 1: The physical and mechanical properties of the aggregates used.

Caractéristiques	S (0/3)	G (8/15)	G (15/25)
Densité absolue (g/cm3)	2,45	2,62	2,55
Densité apparente (g/cm3)	1,51	1,48	1,45
Module de finesse	2,63	-	-
LA (%)	-	30	30
Nature	Calcaire	Calcaire	Calcaire

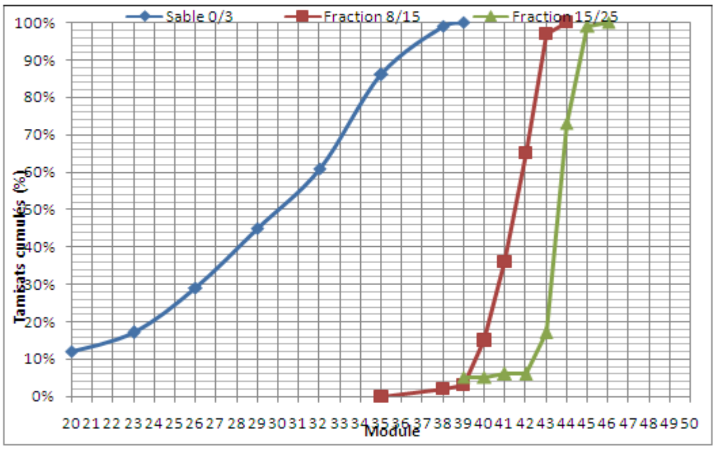

Figure 1 : Distribution granulométriques des granulats utilisés

Figure 1: Grain size distribution of the aggregates used.

2.2- Méthodes

Les bétons utilisés dans cette étude ont été fabriqués par la méthode de Dreux-Gorisse pour produire un béton normal. Les résultats de la composition sont donnés dans le tableau 2 ci-dessous.

Tableau 2 : Composition du béton selon Dreux-Goriss
Table 2: Concrete composition according to Dreux-Goriss

Constituants	Dosage des agrégats (%)	Dosage en (Kg/m3)
Sable (0/3)	35	609
Gravier (8/15)	31	555
Gravier (15/25)	34	571
Ciment	-	350
Eau	-	175

Les bétons ont été préparés et conservés conformément aux spécifications de la norme EN 206-1. Ces derniers ont été coulés et mis dans les moules cubiques d'arête 15 cm par vibration (aiguille vibrante). Les moules cubiques ont été stockés après coulage dans une chambre humide pendant 24 heures à 20 ± 1°C et à une humidité relative supérieure à 90 %. Après le démoulage les éprouvettes ont été conservées dans un bac rempli d'eau jusqu'à l'âge de l'essai.

Trois séries de 10 éprouvettes cubiques ont été confectionnées, soit au total 30 essais de compression afin d'évaluer la résistance à la compression par écrasement respectivement à 7 jours et 28 jours. Afin d'assurer une grande planéité des surfaces qui seront en contact avec les plateaux de la presse, les éprouvettes ont été préalablement surfacées pour engendrer le moins de frottement possible [10]. Les résultats de la résistance à la compression pour les différents âges sont illustrés sur les figures 2 et 3 ci-dessous.

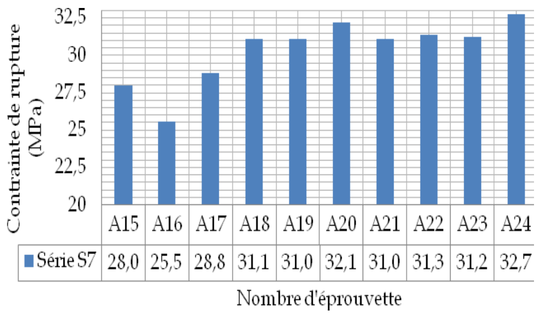

Figure 2 : Variation des résistances à la compression pour la série S7

Figure 2: Variation of compressive strengths for series S7.

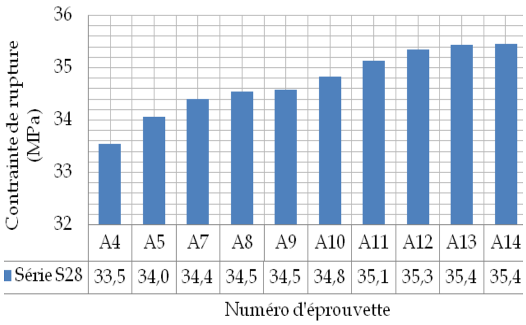

Figure 3 : Variation des résistances à la compression pour la série S28

Figure 3: Variation of compressive strengths for series S28

Selon les figures 2 et 3, la résistance à la compression varie au fil du temps, en raison de l'hydratation continue des grains de ciment avec l'eau présente dans le béton, ainsi que de la réduction du nombre de défauts. Il est également observé que des écarts significatifs subsistent, notamment pour la série S7, où la différence atteint environ 7 MPa. En revanche, cette variabilité tend à diminuer avec l'âge, atteignant environ 2 MPa pour la série S28.

Les résultats expérimentaux relatifs à la résistance à la compression montrent une variabilité significative en fonction de l'âge du béton. Cette dispersion résulte de la diminution des défauts internes et du processus de durcissement progressif du matériau. Pour modéliser cette variabilité, il est approprié d'utiliser un modèle statistique de type Weibull à deux paramètres, qui permet de mieux appréhender les fluctuations observées dans les mesures.

3-Analyse de la dispersion avec le modèle de Weibull

Le béton est un matériau fragile, la distribution des defaults est la principale cause de la rupture. Le modèle de Weibull est employé dans cette étude afin de prendre en compte la dispersion des résultats de mesure. L'objectif de cette statistique de Weibull est de déterminer un critère de rupture plus représentatif des constatations expérimentales, car ce critère permet de prendre en compte l'hétérogénéité du béton qui est la source principale de la dispersion des résultats de mesures [14].

Selon la statistique de Weibull, la probabilité de rupture est donnée par la formule (1) suivante :

$$P_r = 1 - exp\left[-\left(\frac{\sigma}{\sigma_0}\right)^m\right] \qquad (1)$$

Où :

σ est la contrainte de rupture, σ0 est le facteur d'échelle sans signification physique et m le module de Weibull : il est caractéristique de la dispersion et donc de la forme de la courbe.

La formule (1) peut s'écrire sous la forme (2) suivante :

$$1 - P_r = exp\left[-\left(\frac{\sigma}{\sigma_0}\right)^m\right] \qquad (2)$$

Et encore :

$$-ln\,(1 - P_r) = \left[\left(\frac{\sigma}{\sigma_0}\right)^m\right] \qquad (3)$$

On peut écrire encore la formule (3) sous la forme (4) suivante :

$$ln\,[-ln\,(1 - P_r)] = m\ln(\sigma) + m\ln(\sigma_0) \qquad (4)$$

On applique la méthode de régression linéaire sur la formule (4) en posant :

$X = \ln(\sigma_R)$ et $Y = \ln[-\ln(1 - P_R)]$

On obtient finalement la formule (5) suivante :

$$Y = mX + B \qquad (5)$$

4 - Résultats et discutions

En traçant Y en fonction de X pour chaque série d'éprouvettes, on obtient des droites de régression illustrées sur les figures (4 et 5) qui décrivent au mieux la tendance du nuage observé et nous permettent d'identifier les paramètres de Weibull correspondants à chaque série d'éprouvettes cubiques.

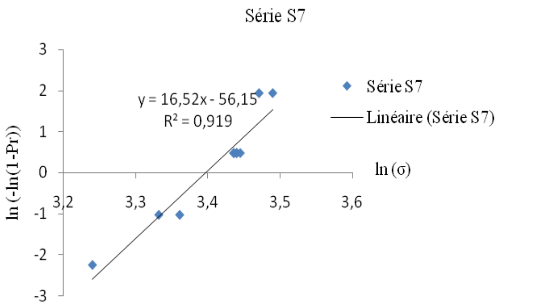

Figure 4 : Diagramme de Weibull pour la série S7

Figure 4: Weibull diagram for series S7

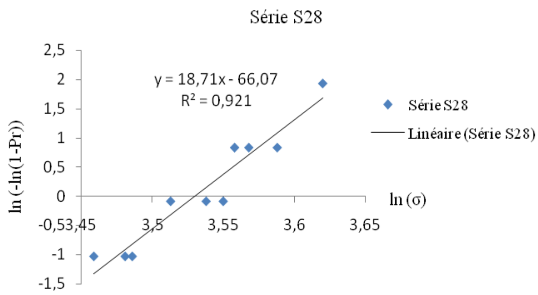

Figure 5 : Diagramme de Weibull pour la série S7

Figure 5: Weibull diagram for series S28

Les paramètres de Weibull pour chaque série sont donnés par le tableau 3 ci-dessous dessous.

Tableau 3: Weibull parameters for each series
Table 3: Concrete composition according to Dreux-Goriss

Eprouvette	R²	B	m	σ_0 = exp (-B/m)
S7	0,919	-56,15	16,52	29,931
S28	0,921	-66,07	18,71	34,167

Les résultats expérimentaux ont été comparés à ceux générés par le modèle de Weibull et cette analyse est illustrée dans les figures 6 et 7.

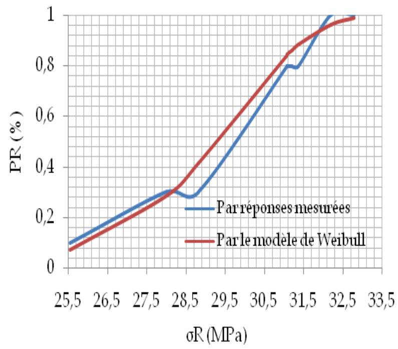

Figure 6 : Comparaison des résultats obtenus pour la série S7

Figure 6: Comparison of the results obtained for series S7.

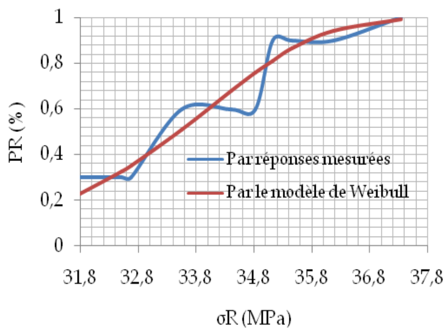

Figure 7 : Comparaison des résultats obtenus pour la série S28

Figure 7: Comparison of the results obtained for series S28

Les droites de régressions figures (4 et 5) obtenues permettront de décrire au mieux la tendance du nuage observé et permettront aussi d'identifier les paramètres de Weibull correspondant à chaque série d'éprouvettes.

La linéarisation des courbes, par la loi statistique de Weibull, montre une tendance linéaire et le module de Weibull (m) dans ce cas correspond à la pente de la droite de régression et varie en fonction de l'âge de l'éprouvette.

Pour l'ensemble des séries, le paramètre de Weibull (m) se situe dans la plage typique des bétons, allant de 5 à 50 [11]. Une valeur de (m) élevée indique une moindre dispersion des contraintes de rupture [12-13]. Dans le cas de la série S7, nous avons observé une valeur de (m) relativement faible, ce qui suggère une plus grande dispersion des résistances à la compression à un jeune âge, notamment à 7 jours.

Le coefficient de détermination se rapproche de 1 pour l'ensemble des séries, cela veut dire que le nuage de point se rapproche de la droite de régression.

Le modèle de Weibull une bonne adéquation pour les deux séries représentées, puisqu'il représente plus de 92 % de la variation de Y en en fonction de X.

Les résultats obtenus à partir du modèle de Weibull présentent une similarité marquée avec ceux issus des expériences (voir les figures 6 et 7), bien qu'un léger décalage soit observé. Cela indique que la formule dérivée du raisonnement appliqué est capable de modéliser la rupture des éprouvettes sous un chargement déterminé.

6 - Conclusion

Cette approche statistique probabiliste permet de fournir des prévisions plus fiables sur la résistance à la compression des bétons.

Elle contribue également à l'amélioration de la conception et de la durabilité des structures en béton, en permettant de mieux anticiper les variations potentielles dues à l'effet de l'âge.

Cette recherche met en lumière l'importance de l'intégration de modèles probabilistes dans l'ingénierie des matériaux et la construction afin de garantir des ouvrages plus sûrs et plus performants.

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MECHANICAL PROPERTIES OF CEMENT-STABILIZED CHLEF SAND REINFORCED WITH POLYPROPYLENE FIBER

PROPRIETES MECANIQUES D'UN SABLE DE CHLEF STABILISE AVEC DU CIMENT ET RENFORCE AVEC DES FIBRES DE POLYPROPYLENES

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Abstract - In recent years, stabilization and reinforcement techniques have been widely used in geotechnical engineering in order to improve soil`s geotechnical properties, it can be achieved through the addition of a proper amount of cementitious agents (cement, fly ash... etc), or the inclusion of oriented or randomly distributed elements such as fibers. Adding fibers to stabilized sand reduces the risk of shrinkage cracks and promotes overall structural integrity. This paper investigated the addition of polypropylene fiber to cement-stabilized sand to enhance the mixture's mechanical properties. sand-cement specimens were prepared with different cement content (Cc=2,5%; 5%;10%) and fiber content (Fc=0,1%; 0,2%; 0,3%). Direct shear tests were carried out at a moisture content of 10%, a relative density of 80%, and normal stress (50; 100; and 200kPa), the specimens were cured for 7 days at room temperature. The main findings showed an increase in shear strength, cohesion, and internal friction angle with the increase in cement and fiber content, the maximum shear strength of the mixture sand-cement-fiber was attained at a fiber content of 0,2% and then started decreasing with the augmentation of fiber content. in addition, the inclusion of fiber leads to an attenuation in the brittleness index and the dilative behavior of the fiber-reinforced cemented-sand.

Key-words: Stabilization; Reinforcement; Soil improvement; Shear strength; Sand

Résumé - Ces dernières années, les techniques de stabilisation et de renforcement ont été largement utilisées en ingénierie géotechnique afin d'améliorer les propriétés géotechniques des sols. Cela peut être réalisé par l'ajout d'une quantité adéquate d'agents cimentaires (ciment, cendre volante, etc.) ou par l'inclusion d'éléments orientés ou distribués de manière aléatoire, tels que des fibres. L'ajout de fibres au sable stabilisé réduit le risque de fissures de retrait et favorise l'intégrité structurelle globale. Cet article a étudié l'ajout de fibres de polypropylène au sable stabilisé au ciment pour améliorer les propriétés mécaniques du mélange. Des spécimens de sable-ciment ont été préparés avec différentes teneurs en ciment (Cc=2,5 % ; 5 % ; 10 %) et teneurs en fibres (Fc=0,1 % ; 0,2 % ; 0,3 %). Des tests de cisaillement direct ont été effectués à une teneur en eau de 10 %, une densité relative de 80 % et une contrainte normale (50 ; 100 ; et 200 kPa). Les spécimens ont séjourné pendant 7 jours à température ambiante. Les principales conclusions ont montré une augmentation de la résistance au cisaillement, de la cohésion et de l'angle de frottement interne avec l'augmentation de la teneur en ciment et en fibres. La résistance au cisaillement maximale du mélange sable-ciment-fibres a été atteinte à une teneur en fibres de 0,2 %, puis a commencé à diminuer avec l'augmentation de la teneur en fibres. De plus, l'inclusion de fibres entraîne une diminution de l'indice de fragilité et du comportement dilatant du sable cimenté renforcé de fibres.

Mots-clés : Stabilisation; Renforcement; Amélioration de sol ; Resistance au cisaillement ; Sable

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1-Introduction

With the increase in population and urban sites, grounds with favourable geotechnical properties became occupied, while on the other hand, the demand for suitable construction sites has increased. Nowadays, geotechnical engineers are challenged to provide proper grounds for construction projects.[13,15,16]

Ground improvement is a technique that aims to improve soil`s mechanical characteristics to match the desired performances for a project, it can be classified into three major categories physical, mechanical, and chemical improvement (treatment). hence, soil improvement can be achieved through both laboratory or in-situ tests such as vibro-compaction, fibers, and geosynthetics inclusion [5-8], soil stabilization with hydraulic binders [7,9], and bio-cementation using biopolymers [2,3]. In geotechnical engineering, chemical stabilization using cement is the most traditional method. Several researchers reported that the addition of cement to soils leads to an increase in resistance, a reduction of permeability as well as settlement reduction, and an improvement of bearing capacity [1,4,10,11,12,14,17,18].

However, the addition of cement to improve the mechanical properties of sand also increases the brittle behavior of the sand-cement mixture. Numerous studies investigated reinforcement techniques using different additives such as fibers to enhance the shear strength, reduce the brittleness of the sand-cement mix and improve its ductility in order to limit loss of post-peak strength. This paper investigates the influence of cement and polypropylene fibers on the mechanical properties of Chlef sand through direct shear tests [19-23].

2- Materials and Methods

2.1- Materials

2.1.1- Sand

The soil used in this study is sand collected from the Chlef river banks north of Chlef (Algeria). Once collected and transported to the laboratory, the sand was dried at 105° for 24 hours and then sieved to remove particles larger than 2mm. The particle size distribution curve of the sand used is illustrated in Figure 1 and its physical properties are presented in Table 1. It is classified as well-graded sand according to USCS.

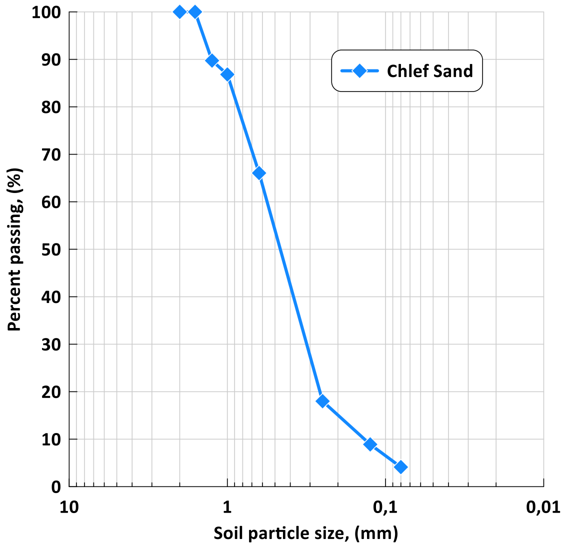

Figure 1: Particle size distribution of Chlef sand.

Figure 1 : Analyse granulométrique de sable de Chlef

Table 1: Physical properties of Chlef sand.

Tableau 1 : Propriétés physiques de sable de Chlef

Properties	Value
Uniformity coefficient, Cu (.)	4,1
Coefficient of curvature, Cc (.)	1,3
Medium size, D_{50} (mm)	0,46
Maximum diameter, D_{max} (mm)	2.00
Specific density, GS (.)	2.69
Maximum void ratio, e_{max} (.)	1.05
Minimum void ratio, e_{min} (.)	0.64

2.1.2- Cement

The cement used in this study is Portland cement with limestone (CEM-II/B-L 32,5 N), manufactured by LAFARGE company following the Algerian standard (NA442-2013) and the European standard (EN 197-1). The physical properties of this cement are given in Table 2.

Table 2: Physical properties of cement

Tableau 2: Propriétés physiques de ciment

Properties	Value
Specific density, GS (.)	3,1
Average diameter (Microns)	1.258
Median diameter (Microns)	0,122
Specific surface (cm2/cm3)	4.9733E+5
D10 (Microns)	0.0787
D60 (Microns)	0.133

2.1.3- Polypropylene fiber

The fiber used in this study was a white monofilament polypropylene fiber with an average length of 12 mm and a diameter of 32 µm . Different fiber contents : Fc= 0%, 0.1%, 0.2% and 0.3% were used.

2.2- Sample preparation and test procedure

To achieve the main objective of this study, a series of tests were carried out, on Chlef sand mixed with different contents of cement (2.5%; 5%; and 10%) and different fiber contents (0.1%; 0.2%; 0.3%), using a square shear box having plan dimensions of 60 mm on 60 mm. The initial height of the samples was 20 mm. The three sand-cement-fiber mixtures were prepared at a relative density of 80% and a moisture content of 10%.

The production of cement-treated sand with fiber samples was done first by mixing, sand, cement, Fiber, and water in specific amounts determined in advance. The cement, sand,Fiber, and water mixture were stirred until the materials were completely merged to form a uniform paste, then the mix was poured into a mold and left to be cured for 7 days at room temperature of 35°±3. The mixture was then removed and placed directly into the direct shear testing apparatus.

The sample was then subjected to a vertical load using slotted steel weights. Each mixture was tested under three different normal stresses 50 kPa, 100 kPa, and 200 kPa.

The sample was left under the effect of normal load for a few moments until the vertical displacement stabilized, after which the sample was sheared at a constant rate of 1 mm/min until a horizontal displacement of about 8 mm was obtained. The shear rate was kept constant for all tests.

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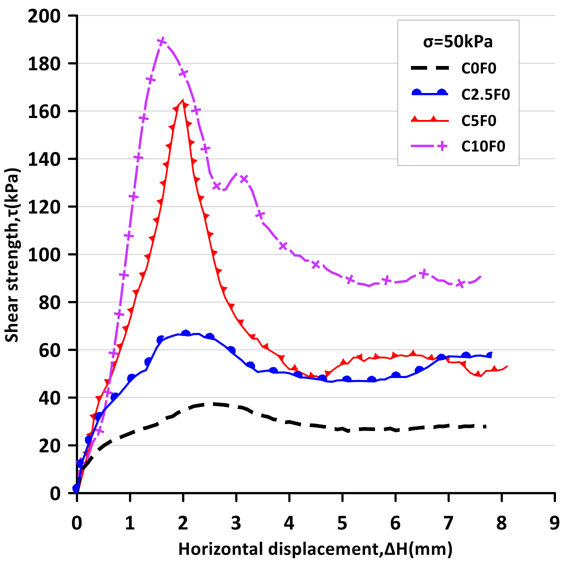
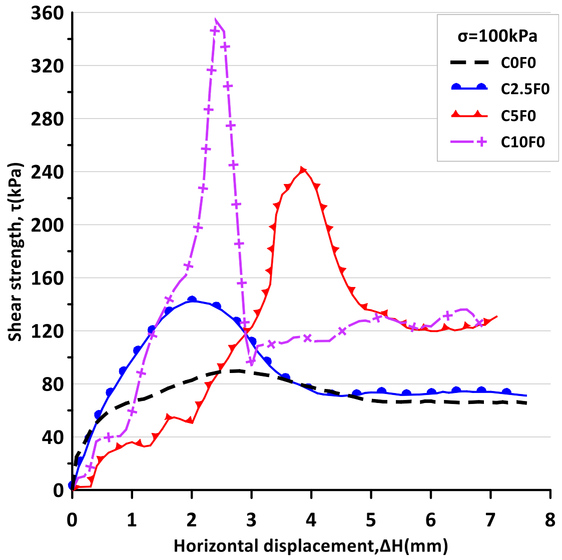
3-Results and discussion

3.1-Influence of cement content on the shear strength of Chlef sand

Figure2 represents the evolution of shear strength τ (kPa) as a function of the horizontal displacement δH (mm) of untreated and treated sand specimens with various cement content under three different normal stresses (σN = 50, 100, and 200 kPa) at dense state (Dr = 80%), a moisture content of 10% and were cured for 7 days. It can be noticed that the shear stress (τ) of untreated sand increases until reaching its highest value, located between 1.5 and 5.5 mm of horizontal displacement (Δh), after which the variation in τ values becomes less significant with the evolution of Δh. The treated samples compared to sand show a sharp increase in shear stress at the beginning of the test and after reaching a maximum value is reached a remarkable decrease in stress values is noticed. It can also be seen that the maximum shear strength values obtained for treated samples with cement are much higher than those obtained for untreated samples. These values are accentuated with an increase in cement percentage and normal stress. This higher strengthening effect is a result of resulting in an improvement in inter-particle cohesion.





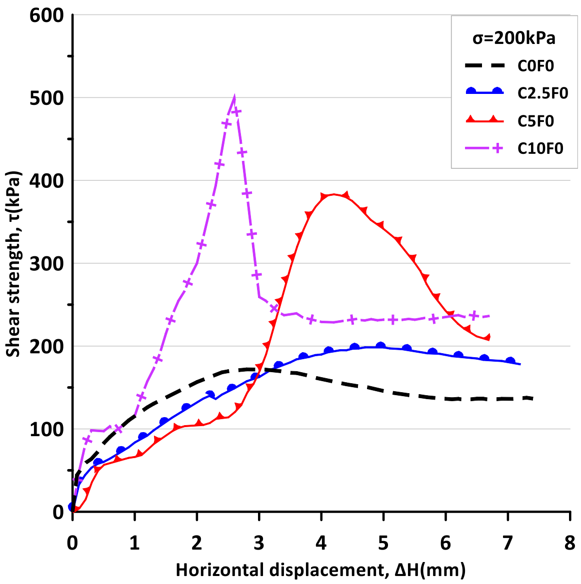


Figure2: Shear strength in terms of horizontal displacement

Figure2 : Resistance au cisaillement en fonction de déplacements horizontal

3.2- Influence of fiber content on the shear strength of cemented Chlef sand

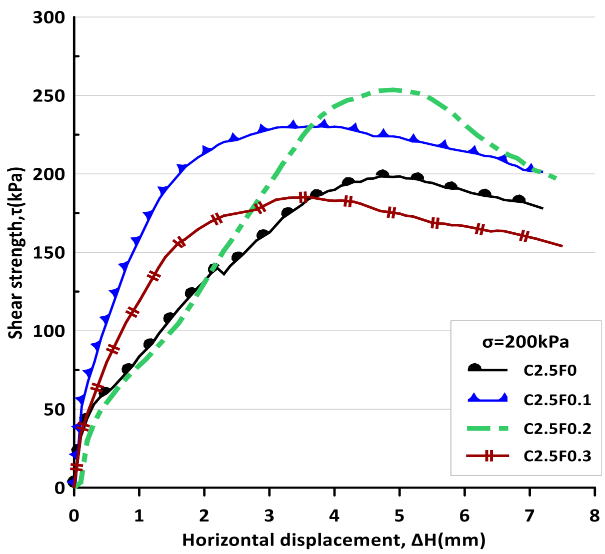


Figure3: Shear strength in terms of horizontal displacement

Figure3 : Resistance au cisaillement en fonction de déplacement horizontal

This figure exhibits the evolution of the shear strength as a function of the horizontal displacement of polypropylene fiber-reinforced cemented sand, it`s clear to see from the graphics that the shear strength enhances with the increase of fiber content to reach its optimum value at fiber content of 0.2% then starts decreasing noticeably as the fiber content increases from 0.2% to 0.3% , this indicates that higher fiber contents have a negative impact on the mechanical properties of fiber-reinforced cemented sand. Fiber-reinforced cemented sand exhibits a ductile behavior compared to cemented sand before the inclusion of fiber which exhibits a brittle behaviour.

3.3 Influence of fiber and cement content on the cohesion and internal friction angle

Table3: Influence of cement content on the cohesion and internal friction angle

Tableau3 : L`influence de teneur and ciment sur la cohésion et l`angle de frottement interne

Cc(%)	C(kPa)	Φ(°)
2.5%	22,431	45
5%	93,667	44,99
10%	116,49	43,53

Table 3 presents the evolution of the cohesion and the internal friction angle as a function of cement content, it`s clear to see that with the increase of cement content, the cohesion increases significantly compared to the uncemented sand samples. This increase in cohesion could be associated with the hydration process of cement in which it fills the space between the sand particles and binds them together. It also appears from the table that with the increase of cement content, the internal friction angle slightly decreases.

Table4: influence of fiber content on the cohesion and the internal friction angle

Tableau4 : L`influence de teneur en fibre sur la cohésion et l`angle de frottement interne

Fc(%)	C(kPa)	Φ(°)
0.1%	21,71	45,53
0.2%	53,219	44,25
0.3%	61,93	43,34

The evolvement of the shear parameters of cemented sand in terms of fiber content are displayed in table 4, it`s clear to see from the results that the inclusion of polypropylene fibers enhanced the cohesion of the cemented sand, and was estimated at 21.17kPa; 53.219kPa; and 61.93kPa respectively for fiber content of 0.1%; 0.2%; and 0.3%. in addition to the previous findings, the internal friction angle decreased with the increase of the fiber content.

4-Conclusion

This paper investigated the influence of various proportions of cement and fiber on the mechanical properties of Chlef sand. The following conclusions can be drawn:

1. The maximum shear strength of Chlef natural sand treated with cement increases significantly with increasing cement content and normal stress. However, all cemented samples exhibited post-peak strength loss due to the increasing brittleness of the samples.

2. The addition of cement increased cohesion and decreased the internal friction angle, the inclusion of fiber also increased the cohesion and reduced the internal friction angle

3. the augmentation of cement content increased the brittleness of the cemented sand. However, with the addition of polypropylene fibers, the fiber-reinforced cemented sand exhibits a ductile behavior

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OPTIMIZING EARTHQUAKE-RESISTANT BUILDING DESIGN: THE INTERPLAY OF SHEAR WALL PLACEMENT AND BRACING SYSTEMS

OPTIMISATION DE LA CONCEPTION DES BÂTIMENTS RÉSISTANTS AUX SÉISMES : INTERACTION ENTRE LA DISPOSITION DES VOILES ET LES SYSTÈMES DE CONTREVENTEMENT

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Abstract - In civil engineering, the design and construction of earthquake-resistant structures remain a top priority, particularly in regions prone to seismic activity. This study examines the dynamic relationship between the positioning and dimensions of shear walls and their influence on the selection of appropriate bracing systems, aiming to optimize structural performance and cost-effectiveness. The central issue addressed in this study is the complex decision-making process faced by civil engineers and architects when designing earthquake-resistant buildings. While the seismic role of shear wall positioning is well recognized, the interaction between their dimensions and the choice of bracing systems has been less comprehensively explored. This study aims to tackle the complex challenge of shear wall positioning and stiffness in relation to bracing system selection, ultimately promoting improved seismic design practices in civil engineering. The aim of this work is to establish optimization models for the quantity of shear walls in each individual seismic direction. This prediction is carried out using the machine learning method, with estimation performed by the artificial neural network (ANN) algorithm. Additionally, a parametric study is conducted to determine the quantity of shear walls while selecting the bracing system based on the vertical and horizontal loads supported by the shear walls. The study revealed that for optimal layout, shear walls should be placed along the perimeter of the architectural plan, allowing for better distribution of seismic forces and reduced torsional effects. Moreover, it is crucial to combine frames with shear walls positioned in the opposite seismic direction. This configuration ensures that the bracing system remains in category (4b), thereby maximizing seismic resistance efficiency.

Keywords: Shear walls, Position, Stiffness, Seismic Resistance, Bracing System.

Résumé - En génie civil, la conception et la construction de structures résistantes aux séismes restent une priorité, en particulier dans les régions sujettes à une forte activité sismique. Cette étude examine la relation dynamique entre la position et les dimensions des voiles et leur influence sur le choix des systèmes de contreventement appropriés dans le but d'optimiser les performances structurelles et la rentabilité. La problématique centrale abordée dans cette recherche est le processus décisionnel complexe auquel sont confrontés les ingénieurs civils et les architectes lors de la conception de bâtiments résistants aux séismes. Bien que le rôle sismique de la position des murs de cisaillement soit largement reconnu, l'interaction entre leurs dimensions et le choix des systèmes de contreventement a été moins explorée en profondeur. Cette étude vise à relever le défi complexe de la disposition et de la rigidité des murs de cisaillement en lien avec la sélection des systèmes de contreventement, dans l'objectif d'améliorer les pratiques de conception sismique en génie civil. Le but de ce travail est de développer des modèles d'optimisation pour la quantité de voiles dans chaque direction sismique spécifique. Cette prévision est réalisée en utilisant la méthode d'apprentissage automatique, avec une estimation effectuée par l'algorithme du réseau de neurones artificiels (ANN). En outre, une étude paramétrique est menée pour déterminer la quantité des voiles tout en choisissant le système de contreventement en fonction des charges verticales et horizontales supportées par les murs de cisaillement. L'étude a révélé que, pour une disposition optimale, les murs de cisaillement devraient être placés le long du périmètre du plan architectural, permettant ainsi une meilleure répartition des forces sismiques et une réduction des effets de torsion. De plus, il est crucial de combiner des cadres avec des voiles placés dans la direction sismique opposée. Cette configuration garantit que le système de contreventement reste dans la catégorie (4b), maximisant ainsi l'efficacité de la résistance sismique.

Mots - clés : voiles, Position, Rigidité, Résistance sismique, Système de contreventement.

1-Introduction

The optimization of earthquake-resistant building design is a critical concern in civil engineering, particularly in regions prone to seismic activity [1]. Structural bracing often employs reinforced concrete walls due to their strong resistance to lateral forces. While the importance of shear wall positioning in enhancing the seismic performance of structures is well-established [2-3], the complex interplay between the dimensions of these walls and the choice of bracing systems remains less thoroughly examined. The capacity of a building to withstand seismic loads is not only dependent on the presence of shear walls but also on how their dimensions and arrangement interact with other structural elements, such as bracing systems. In the international technical literature, it is possible to find numerous references involving seismic studies [4-13]. Tarigan et al. (2018) examined the impact of shear wall placement on the seismic resistance of RC buildings. The study found that placing shear walls symmetrically at the core significantly reduced lateral displacement and story drift, offering the best performance compared to other configurations [14]. Research by Chen et al. (2020) highlights that appropriately sized shear walls significantly improve energy dissipation and overall stiffness, which are key to better performance during seismic events [15]. Similarly, Mangalathu et al. (2020) emphasize the importance of carefully considering wall dimensions to prevent catastrophic failures [16]. Bracing systems also play a vital role in stabilizing structures against lateral forces, with their selection often guided by building characteristics and specific seismic demands. Chen et al. further demonstrate that combining shear walls with energy dissipators enhances the ability to absorb seismic energy, while Mangalathu et al.'s use of machine learning to identify optimal bracing configurations that complement shear wall dimensions underscores the importance of these elements working in synergy [15-16]. In a study conducted by Sayed (2021), the seismic performance of symmetrical multistory reinforced-concrete (RC) buildings was evaluated with a focus on the effects of various in-plane shear wall configurations. The analysis revealed that central core configurations increase seismic demands, while perimeter configurations better reduce forces. The study highlights the importance of strategic shear wall placement for improved seismic resilience and cost efficiency [17]. The study by Khelaifia et al. (2024) highlights the importance of both the position and quantity of shear walls in optimizing a structure's ability to withstand seismic activity. Their research shows that strategically placed and appropriately distributed shear walls significantly improve a building's resistance to seismic forces. However, adding too many shear walls can lead to diminishing returns, suggesting an optimal balance is necessary [18].

Current research has primarily focused on the benefits of placing shear walls symmetrically to balance seismic forces and minimize torsional effects, contributing to overall structural stability. However, the critical role of wall stiffness and how it integrates with the selected bracing system to influence the building's seismic response has been underexplored. An overly stiff shear wall can lead to stress concentrations and potential failure at specific points, particularly at the base, whereas an insufficiently stiff wall may not adequately control lateral displacements, risking structural collapse. This research aims to fill the gap by examining the interaction between the dimensions of shear walls and the selection of bracing systems to optimize the seismic resistance of buildings. Understanding this interplay is essential for developing design strategies that not only ensure safety and stability but also adhere to practical design and cost constraints.

2- Reference structure description

The structure studied in this paper is a six-story reinforced concrete building, designed to be braced with shear walls, as shown in Fig. 1, with a storey height of 3,06m. It is located in a seismic zone III, following the standards of the Algerian seismic code RPA99/V2003 [19]. The numerical modeling of this structure was conducted using the ETABS V9 software [20], allowing for an analysis of its dynamic behavior. The characteristics of the materials initially considered are, 25 MPa for the compressive strength of the concrete and 400 MPa for the yield strength of the reinforcement. The floors are composed of beams and hollow blocks (16+4) cm, which are considered as infinitely rigid diaphragms, contributing to the overall stability of the building. The structural elements, such as columns and beams, were dimensioned in accordance with the applicable regulations [21], with particular attention given to seismic resistance. The geometric configurations and the quantities of reinforcement obtained for the load-bearing elements of the building are presented in Fig. 2. The structure exhibits irregularities in its plan, necessitating complex and precise modeling to accurately assess the natural frequencies of vibration and the forces induced by seismic activity.

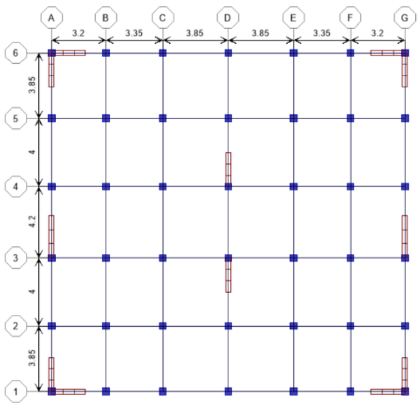
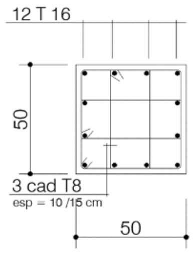
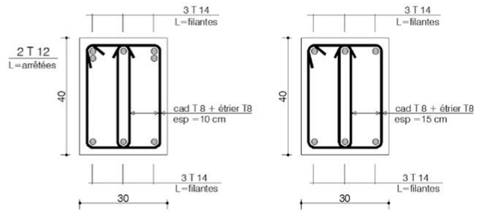


Figure 1: Plan view of the studied structure

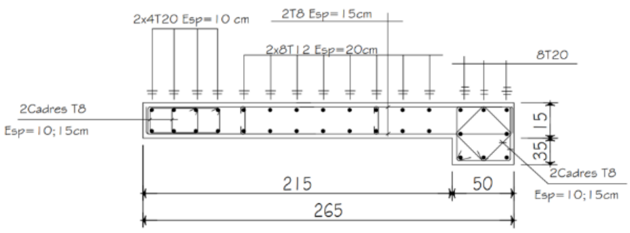
Figure 1 : Vue en plan de la structure étudiée



(a) Columns (Poteaux)



(b) Beams (Poutres)



(c) Shear Walls (Voiles)

Figure 2: Reinforcement Details

Figure 2 : Détails des armatures

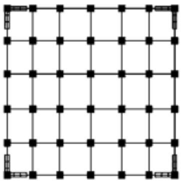
3- Justification of the bracing system

The RPA 99 - 2003 Version [19] stipulates that for bracing system 2, the shear walls carry more than 20% of the stresses caused by vertical loads. In contrast, for systems 4a and 4b, the shear walls carry at most 20% of the stresses caused by vertical loads. In fact, in the event of a strong earthquake, when the structure undergoes nonlinear deformations, significant vertical loads (more than 20% according to the RPA) on the shear walls can cause instabilities that may lead to a reduction in ductility and deformation capacity. These instabilities can manifest as buckling of the compressed ends of the shear walls or as buckling of the longitudinal reinforcements at the ends. As a result, bracing system 2 is considered the least ductile (R=3.5) compared to systems 4.a (R=5) and 4.b (R=4).

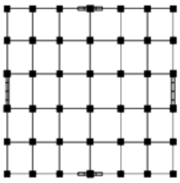
Therefore, according to the RPA, the first classification criterion is to verify the load-bearing capacity of the shear walls concerning vertical loads to determine if it exceeds 20% of the building's total vertical loads. On the other hand, the fundamental difference between bracing systems 4a and 4b is that system 4b is limited to buildings with a height of less than 10 stories or a maximum of 33 meters. Thus, according to the RPA, for frame-wall structures taller than 10 stories (or 33 meters), the effect of frame-wall interaction must be considered (R=5) [19]. However, for buildings with shear walls and frames that are less than 10 stories or a total height of less than 33 meters, the RPA does not provide an explicit selection criterion. It would be prudent to consider system 4b for buildings less than 10 stories high (or 33 meters) where the shear walls carry less than 20% of the vertical loads [19].

4- Influence of Shear Wall Position and Rigidity on Bracing System Selection

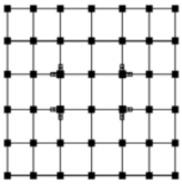
To optimize the selection of a bracing system, a detailed analysis of different building variants is crucial. These variants, despite having identical architectural plans, differ in the arrangement and thickness of shear walls (Fig. 3), which are key to ensuring structural stability. By varying wall thicknesses and configurations, the study evaluates their impact on overall structural performance.



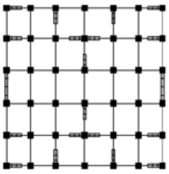
Corner
Coin



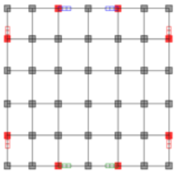
Periphery
Périphérie



Centered
Centré



Mixed
Mixé



Different thicknesses
Épaisseurs différentes

Figure 3: configurations of different shear wall location

Figure 3 : Configurations de différentes positions des voiles

A total of 310 variants were designed and analyzed to identify the most suitable bracing system, ensuring a robust construction that meets specific project requirements. The study includes walls with thicknesses of 15 cm, 20 cm, 25 cm, and 30 cm to enable precise performance comparisons.

4.1- Vertical load taken by the walls

In the first phase of our study, we modeled the 310 variants using a category (4b) bracing system according to the Algerian seismic code. The key condition for these variants is that the vertical load carried by the bracing walls must not exceed 20% of the total vertical load [19]. Variants that did not meet this condition were reclassified to category (2), corresponding to load-bearing walls. The study revealed that 120 variants failed to meet the required condition, designated by the letters NV, while 190 variants complied, designated by the letter V. Optimal variants, with load transfer under 20%, ensure the study's effectiveness, while suboptimal variants exceed 20% for superior structural performance.

The pie chart in Fig. 4 shows the percentage of vertical load carried by different bracing wall variants, with higher percentages indicating better seismic resistance. Variants exceeding 20% are reclassified from category (4b) to category (2).

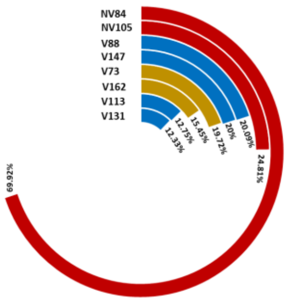
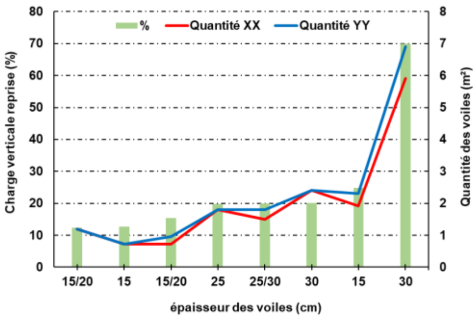


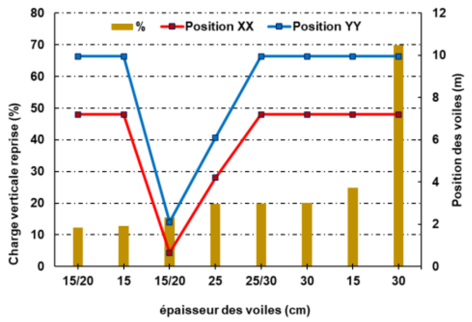
Figure 4: Percentage of the vertical load taken by the walls of the optimal and sub-optimal variants

Figure 4 : Pourcentage de la charge verticale supportée par les voiles des variantes optimales et sous-optimales

Fig. 5a indicates that increasing the number of walls improves vertical load distribution. Fig. 5b demonstrates that while increasing wall thickness generally improves vertical load support, the increase in horizontal load capacity is not always linear, with only slight differences observed between 15/20 cm and 25 cm thicknesses.



(a) according to quantity (selon la quantité)



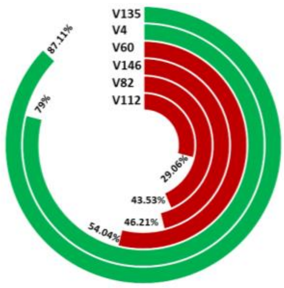
(b) according to position (selon la position)

Figure 5: Comparison of the vertical load taken by the walls

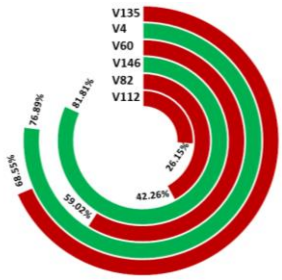
Figure 5 : Comparaison de la charge verticale supportée par les voiles

4.2- Horizontal load taken by the walls

In the second phase of our study, we examined a new regulatory condition for the 190 variants that passed the first phase. These variants were designed using a category (4b) bracing system under the Algerian seismic code. We specifically verified that the entire horizontal load is supported exclusively by the bracing walls. If a variant failed this requirement, it was reclassified to category (2), where the walls act as load-bearing elements. Figs. 6-7-8 illustrate the effectiveness of bracing walls in supporting horizontal seismic loads. Higher percentages in pie charts indicate better efficiency, with variants below 75% reclassified to a different category. Thicker bracing walls generally improve load support but also increase material usage. The position of the walls within the structure affects their ability to carry horizontal loads, with the XX direction showing higher load support than the YY direction. Wall thickness and position are crucial factors in designing earthquake-resistant structures.



(a) XX



(b) YY

Figure 6: Percentage of the vertical load taken by the walls of the optimal and sub-optimal variants

Figure 6 : Pourcentage de la charge verticale supportée par les voiles dans les variantes optimales et sous-optimales

The study found that out of 190 variants, 154 did not meet the second seismic regulation condition, which requires bracing walls to support all horizontal loads. Variants V3 and V4 fully complied, while V134, V135, and V161 only met the condition in the XX direction, and 31 other variants only in the YY direction (see Appendix A). The 36 compliant variants had walls placed exclusively at the ends of the architectural plan, optimizing seismic resistance and stability while minimizing the impact on interior space flexibility.

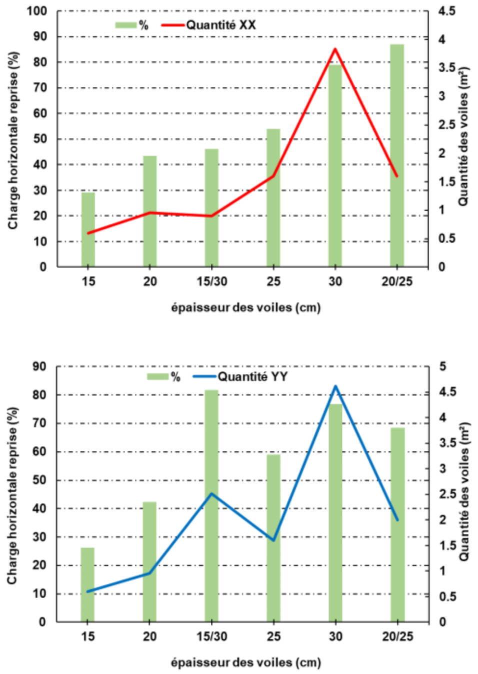


Figure 7: Comparison of the vertical load taken by the walls according to quantity

Figure 7 : Comparaison de la charge verticale supportée par les voiles en fonction de la quantité

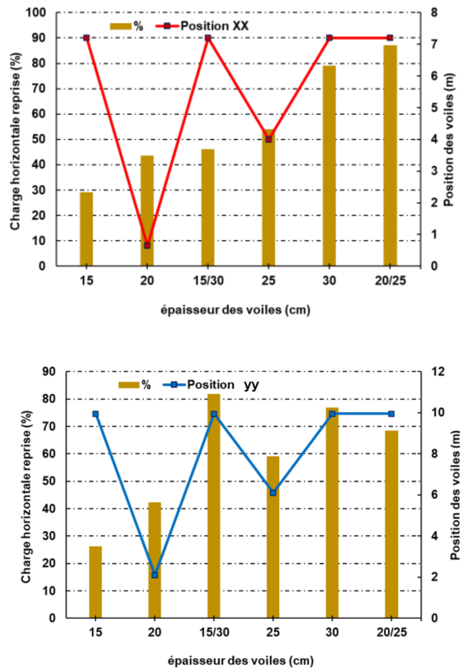


Figure 8: Comparison of the vertical load taken by the walls according to position

Figure 8 : Comparaison de la charge verticale supportée par les voiles en fonction de leur position

4.3- Checking gantries for reduced seismicity

In the third phase of the study, the focus is on verifying the third regulatory condition for 36 category (4b) bracing system variants that have already met the first two conditions under the Algerian seismic code. This phase aims to assess the frames' ability to withstand horizontal loads representing 25% of the total horizontal effort [19]. For each seismic direction meeting the initial conditions of seismic regulations, we follow a modeling procedure that involves: first, removing shear walls to isolate the effect of frames in that direction; second, applying a reduction factor of 0.25 to the initial seismic load, which only affects the frames and ensures that any remaining shear walls support at least 75% of the load; and finally, verifying the stability and shear resistance at the base of the frames to ensure the structure can withstand seismic forces effectively. The results indicate that among the 36 variants tested, frames braced by load-bearing shear walls met the seismic regulations effectively. For frames to withstand 25% of the total seismic load, they must be paired with shear walls in the opposite seismic direction. This strategic configuration ensures optimal force distribution and enhances the structure's stability and resistance by utilizing the combined strengths of the shear walls and frames.

5- Predictive ANN models

The performance of artificial neural network (ANN) models is influenced by network topology and learning parameters [22-28]. Topology includes the number of inputs, outputs, hidden layers, and neurons per hidden layer, while learning parameters involve the algorithm, performance function, transfer functions, maximum error, and learning cycles [29-31]. There are no fixed rules for setting these parameters, so trial and error is often used. The backpropagation network, trained with the Levenberg-Marquardt algorithm, was used for developing models [32]. ANNs, inspired by the human brain, consist of interconnected nodes organized in layers [33-35]. Optimal performance for predicting bracing shear wall quantities is achieved with an architecture of two hidden layers, each with

10 neurons (Fig. 9). Input parameters are the ratios of vertical and horizontal loads, with shear wall quantity as the output.

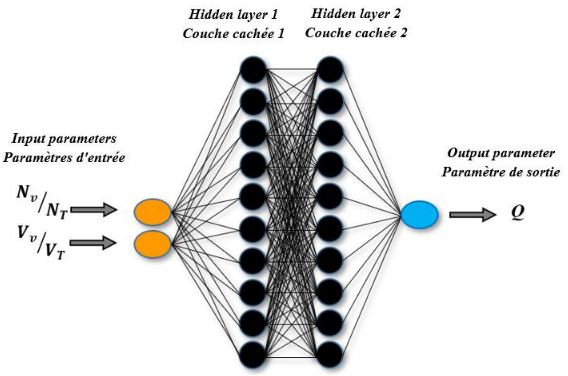
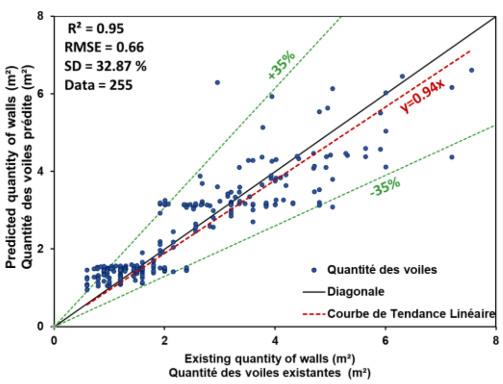


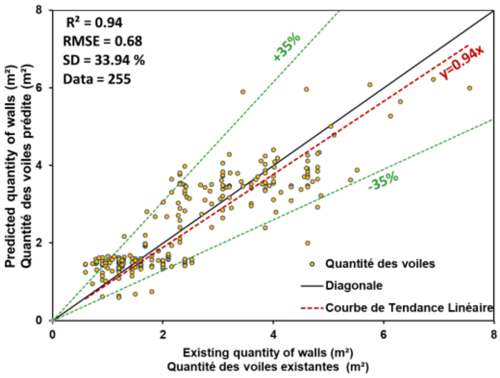
Figure 9: Architecture used in the ANN model

Figure 9 : Architecture utilisée dans le modèle ANN

Fig. 10 effectively illustrates this performance for each seismic direction XX and YY, respectively. From these figures, it is clear that the good distribution of data points is along the diagonal (X=Y) of the best-fit line, where an ideal agreement between prediction points and experimental results is achieved. This is confirmed by the slope of the linear trend line being equal to 0.94. This distribution falls within an error margin not exceeding 35% relative to the best-fit line. The results also show that these predictions provide a better coefficient of determination R^2 = 0.95 and 0.94, as well as a better error in terms of root mean square error (RMSE) = 0.66 and 0.68, and a standard deviation (SD) = 32.87% and 33.94% for the X and Y directions, respectively.



(a) XX



(b) YY

Figure 10: Performance of the ANN models for predicting shear wall quantities

Figure 10 : Performance des modèles (ANN) pour prédire les quantités des voiles

4- Parametric study

In this section, we conduct a parametric analysis of the input variables to explore their correlations with the quantity of bracing shear wall, regardless of the bracing system. Using an artificial neural network (ANN) to predict models for each seismic direction, we precisely examine the impact of parameters such as the vertical load ratio and the horizontal load supported by the bracing shear walls on the quantity of shear walls, in order to facilitate the selection of the bracing system.

Figs. 11 and 12 show how the horizontal load ratio affects the quantity of bracing shear walls for two bracing system categories (4b and 2) across two seismic directions (XX and YY). For the analysis, vertical load values are kept constant at three levels for each system type. Results indicate that increasing both the vertical and horizontal load ratios increases the quantity of bracing shear walls. Specifically, for system (4b), the number of shear walls remains constant for horizontal loads below 85%, while for system (2), it remains unchanged for horizontal loads above 95% and 90%, regardless of vertical load.

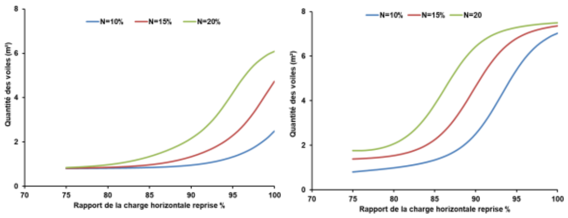


Figure 11: Effect of the vertical load ratio for a bracing system (4a)

Figure 11 : Effet du rapport de charge verticale pour un système de contreventement (4a)

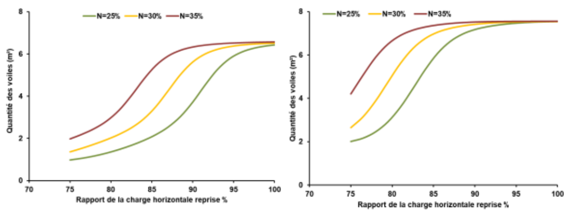


Figure 12: Effect of the vertical load ratio for a bracing system (2)

Figure 12 : Effet du rapport de charge verticale pour un système de contreventement (2)

Figs 13 and 14 show how the vertical load ratio affects the quantity of bracing shear walls for two bracing system categories (4b and 2) in seismic directions XX and YY. Increasing both vertical and horizontal load ratios leads to a proportional increase in the quantity of bracing shear walls. For system (4b), the number of shear walls varies by up to 12% with a maximum increase of 1.8 m². For system (2), the quantity remains constant for horizontal loads in direction XX but can increase significantly (up to 5 m²) by 39% in direction YY.

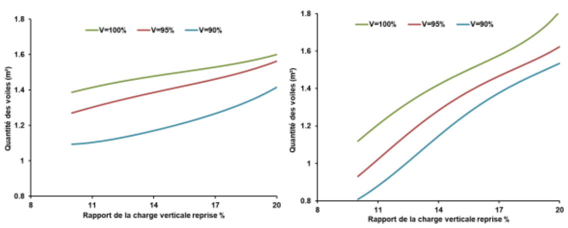


Figure 13: Effect of the horizontal load ratio for a bracing system (4a)

Figure 13 : Effet du rapport de charge horizontale pour un système de contreventement (4a)

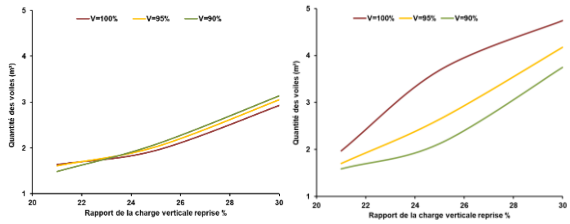


Figure 14: Effect of the horizontal load ratio for a bracing system (2)

Figure 14 : Effet du rapport de charge horizontale pour un système de contreventement (2)

4- Conclusion

This research has focused on optimizing the design of earthquake-resistant buildings by examining the interplay between shear wall placement, wall dimensions, and bracing systems. The study involved a comprehensive analysis of 310 building variants, taking into consideration the effects of both vertical and horizontal loads on the seismic performance of structures. Through the use of artificial neural networks (ANNs) and a detailed parametric study, we have provided insights into how these variables influence the overall stability and resistance of buildings in seismic zones. The principal findings of this study are summarized as follows:

- The study confirmed that placing shear walls along the perimeter of the architectural plan significantly enhances the distribution of seismic forces and reduces torsional effects. Specifically, variants with shear walls at the ends of the plan demonstrated superior seismic resistance.

- The research indicated that increasing the thickness of shear walls generally improves their ability to support vertical loads. For instance, variants with wall thicknesses of 25 cm and 30 cm showed better performance in both vertical and horizontal load support, with a reduction in the reclassification from category 4b to category 2.

- The analysis revealed that bracing systems categorized under 4b are more effective in supporting seismic loads when the shear walls carry less than 20% of the total vertical load. Approximately 190 of the 310 variants met this condition, ensuring optimal structural performance.

- The study found that increasing the number of shear walls improved the distribution of vertical loads, with optimal variants carrying less than 20% of the vertical load. The horizontal load capacity also showed improvement, particularly in the XX seismic direction, where a wall thickness increase from 15 cm to 30 cm resulted in a more stable load distribution.

- The use of artificial neural networks demonstrated high accuracy in predicting the quantity of shear walls required for optimal seismic resistance. The ANN model achieved a coefficient of determination R2R^2R2 of 0.95 and 0.94 in the XX and YY directions, respectively, with a root mean square error (RMSE) of 0.66 and 0.68, indicating a strong correlation between predicted and actual results.n this section, we conduct a parametric analysis of the input variables to explore their correlations with the quantity of bracing shear wall, regardless of the bracing system. Using an artificial neural network (ANN) to predict models for each seismic direction, we precisely examine the impact of parameters such as the vertical load ratio and the horizontal load supported by the bracing shear walls on the quantity of shear walls, in order to facilitate the selection of the bracing system.

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Appendix A. Description of the final 36 variants

Fig. A1 shows the 36 variants with wall arrangements exclusively at the ends of the architectural plan that satisfy the second regulatory condition. This specific configuration is chosen to optimize the structure's resistance and stability against seismic loads.

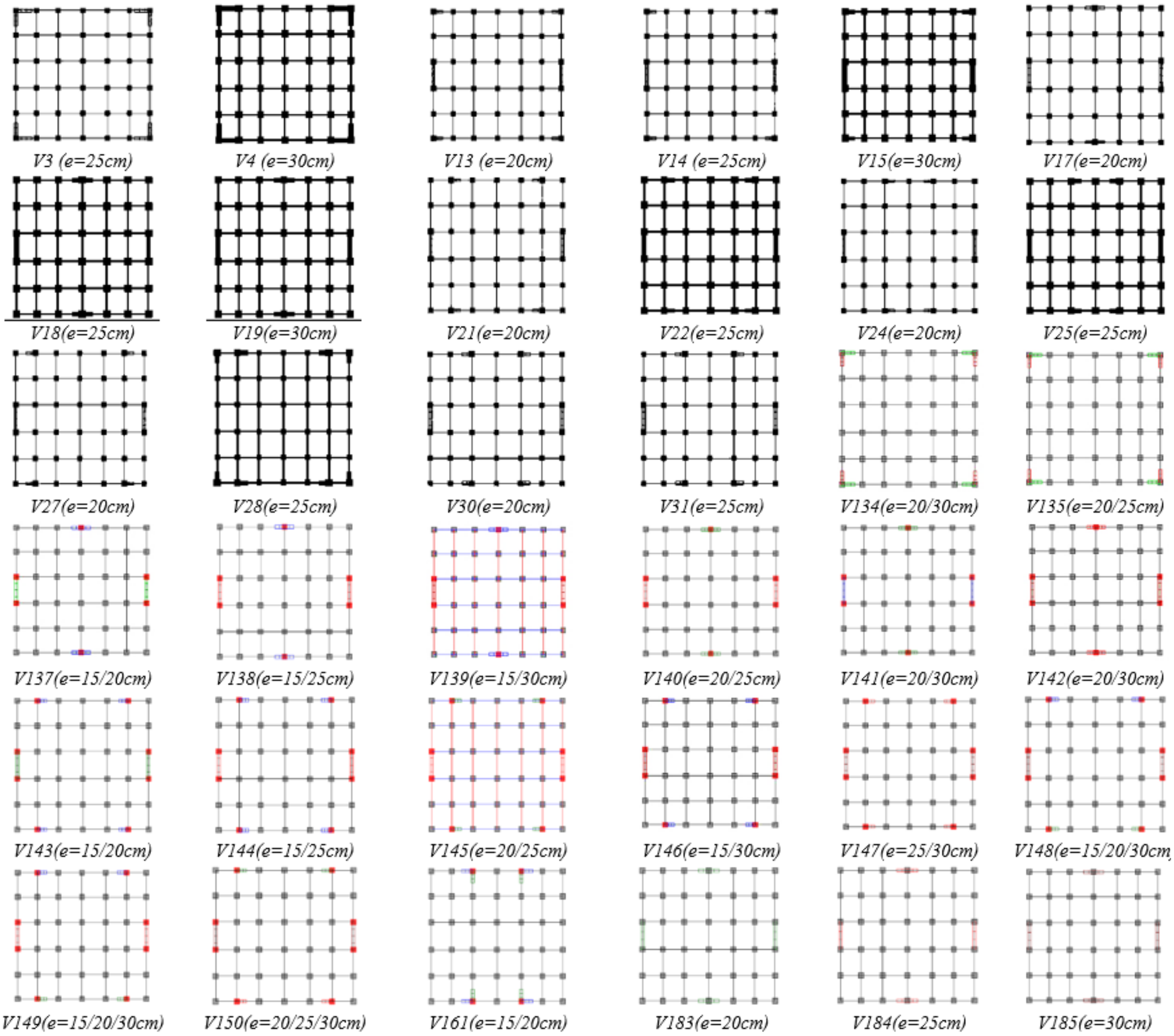

Figure A1: Variants satisfying the first two regulatory conditions of the bracing system (4b)

Figure A1 : Variantes satisfaisant les deux premières conditions réglementaires du système de contreventement (4b)

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AMÉLIORATION DES PERFORMANCE DES ENROBÉS BITUMINEUX PAR LA MODIFICATION A BASE DE POLYMÈRE DE DÉCHETS PLASTIQUES

IMPROVING THE PERFORMANCE OF BITUMINOUS COATINGS BY POLYMER-BASED MODIFICATION OF PLASTIC WASTE

Réception : 19/11/2024 Acceptation : 29/11/2024 Publication : 10/01/2025

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Résumé - Il est essentiel d'avoir une chaussée plus performante face à la croissance du trafic et aux conditions climatiques agressives. Il y a de nombreux additifs disponibles pour améliorer les caractéristiques des bitumes. Les polymères sont parmi les additifs les plus couramment employés pour modifier les bitumes, mais la majorité d'entre eux sont des polymères vierges. L'objectif est de trouver des additifs performants simples à incorporer dans des matrices bitumineuses et financièrement abordables. Les déchets de polymères non biodégradables peuvent en effet jouer un rôle dans la mise en place d'une stratégie durable pour la construction de routes. Ceci nous permet non seulement de récupérer le matériau brut modificateur à moindre coût, mais aussi de répondre à la problématique écologique posée par l'augmentation constante des déchets plastiques. L'objectif de cette étude est d'analyser l'impact des déchets plastiques sur les propriétés physiques des bitumes modifiés et sur les propriétés mécaniques induites sur les bétons bitumineux. Selon l'étude, l'ajout de déchets plastiques (DP) dans le liant améliore ses caractéristiques physiques telles que la pénétrabilité, le point de ramollissement et la résistance thermique. L'amélioration de la stabilité Marshall a un impact positif sur l'enrobé modifié par la modification par DP.

Mots - clés : bitume, DP, enrobé bitumineux, Marshall.

Abstract- It will be essential to have a better performing pavement in the face of traffic growth and aggressive climatic conditions. There are many additives available to improve the characteristics of bitumens. Polymers are among the most commonly used additives to modify bitumens, but the majority of them are virgin polymers. The objective is to find high-performance additives that are easy to incorporate into bituminous matrices and affordable. Non-biodegradable polymer waste can indeed play a role in implementing a sustainable strategy for road construction. This not only allows us to recover the modifying raw material at a lower cost, but also to address the ecological problem posed by the increase in the use of waste. The objective of this study is to analyze the impact of plastic waste on the physical properties of modified bitumens and on the mechanical properties of updating asphalt concrete. According to the study, the addition of waste plastic (WP) in the binder improves its physical characteristics such as penetration, softening point and thermal resistance. The improvement of Marshall stability has a positive impact on the asphalt modified by WP modification..

Keywords : bitumen, DP, bituminous coating, Marshall.

1-Introduction

Le bitume dans sa forme classique ne garantit plus un bon fonctionnement des routes [1]. Le bitume est fragile à basse température (fissuration de la chaussée), visqueux à haute température (problèmes d'orniérage). En outre, le bitume présente une sensibilité au vieillissement et ses caractéristiques se détériorent au cours du temps. [1-2].

Différents additifs peuvent être employés afin d'améliorer les caractéristiques des bitumes. Les polymères sont les additifs les plus couramment employés pour modifier les bitumes, parmi lesquels les plastomères et les élastomères, mais la plupart d'entre eux sont des polymères vierges [3]. Il est compliqué de trouver des polymères vierges et ils sont peu économiques lorsqu'ils sont employés comme modificateurs. Nous sommes à la recherche d'additifs performants, simples à incorporer dans des matrices bitumineuses et abordables du point de vue financier. L'incorporation de déchets dans enrobés routiers améliore non seulement les performances des chaussées et réduit la pollution de l'environnement, mais réduit également la nécessité d'utiliser des polymères vierges dans les chaussées, permettant ainsi de réaliser des économies de coûts à long terme**.**

Au cours des dernières années, la quantité de déchets a augmenté considérablement, par exemple, la production annuelle de 4 à 5 billions de sacs en plastique polyéthylène à travers le monde. [4]. Avec 6 milliards de sacs par an, l'Algérie occupe la cinquième place mondiale en termes de consommation [5]**.** Les déchets de polymères non biodégradables peuvent en effet jouer un rôle dans la mise en place d'une stratégie durable pour la construction des routes. Cela nous offre non seulement la possibilité de récupérer le matériau brut modificateur à un prix abordable, mais aussi une réponse à la menace écologique causée par l'augmentation de l'utilisation de déchets (non biodégradables).

L'objectif de cette étude est d'améliorer les caractéristiques des bitumes modifiés et des enrobés bitumineux modifiés par l'ajout de déchets plastiques.

2- Matériaux utilises

2.1- Identification du bitume

Le bitume pur, utilisé dans cette étude, est de grade 35/50. Il provient de l'entreprise des travaux publics EVSM de Réghaia (Alger).

2.2- Le déchet plastique alimentaire (DP)

Figure 1: Déchets plastique

Les matériaux plastiques employés dans cette étude proviennent de sacs d'emballage alimentaire. Pour préparer le déchet plastique, il est nécessaire de découper les sacs en petits morceaux de 2 à 5 mm de longueur. L'essentiel des déchets plastiques rougeâtres utilisés est composé de polypropylène. Le plastique utilisé a une formule chimique de $(C3\ H6)_n$ et une densité de 0,9 g/cm^3 [9-10]

2.3- Les granulats

Les granulats utilisés dans cette étude sont les plus fréquemment employés par les entreprises dans la construction des chaussées. Les granulats de classe 0/3, 3/8 et 8/15 utilisés dans notre recherche proviennent de la carrière de Haoud El-Hamra, wilaya de Ouargla.

4- La modification

La modification a été réalisée au laboratoire de routes de la faculté de génie civil de l'USTHB (Algérie). Nous avons pour cela utilisé, un appareillage se composant :

- d'un agitateur électrique ;
- d'un thermomètre allant de – 40 °C à 250 °C ;
- d'un récipient.

Nous avons adopté les paramètres suivants :

- Une température du mélange de 180±7°C ;
- Une vitesse de malaxage : 600 tr/min ± 7 tr/min ;
- Une durée de malaxage de 2 heures.

4- Résultats et discussion

4.1- Pénétrabilité à 25 °C

La figure ci-dessous présente les résultats de la pénétrabilité des bitumes en fonction de la teneur en DP.

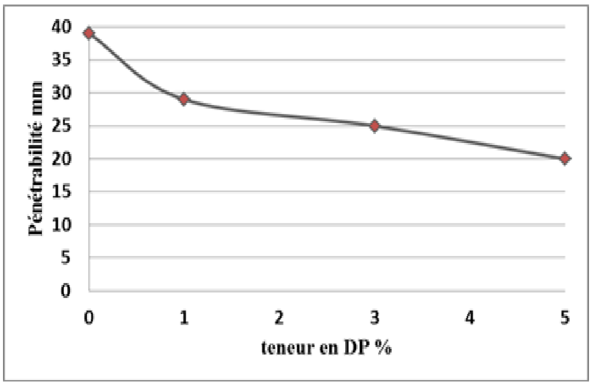

Figure 02 : Pénétrabilité des bitumes modifiés

Il est observé que la pénétrabilité diminue en fonction de la quantité de polymères présents. En comparaison avec le bitume pur, les bitumes modifiés présentent une consistance accrue, ce qui démontre que les bitumes créés à partir de déchets peuvent avoir un comportement plus performant à haute température. Dans l'ensemble, l'ajout de déchets DP peut augmenter la rigidité du bitume et améliorer sa résistance aux déformations à haute température. **[6]**.

4.2- Température de ramollissement

La figure ci-dessous illustre les résultats de la température de ramollissement en fonction de la quantité de DP.

Selon les résultats de la figure 3, il est observé que la TBA augmente lorsque la teneur en DP augmente. Effectivement, l'ajout de 5% DP entraîne une augmentation d'environ 12% de la TBA par rapport au bitume de base. Les conclusions de la TBA montrent clairement que l'utilisation d'additifs (DP) améliore les propriétés du bitume à des températures élevées. Il y a une corrélation proportionnelle entre la TBA et la résistance à l'orniérage, selon certains articles.[6-8]. Effectivement, lorsque la TBA augmente, la résistance à l'orniérage augmente également. Cela démontre que les bitumes transformés à partir de déchets plastiques améliorent la résistance à l'orniérage des chaussées bitumineuses conçues à partir de ces déchets.

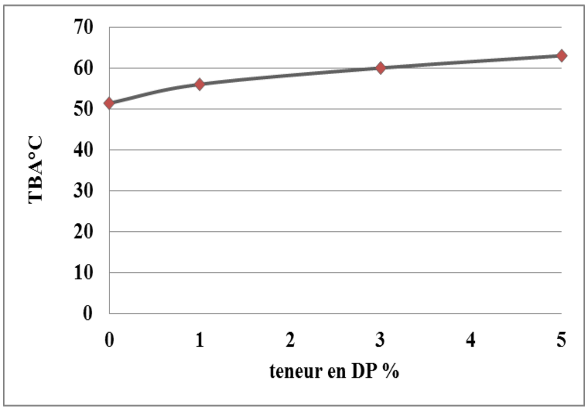

Figure.03 : TBA des bitumes modifiés

4.3. Stabilité Marshall (SM)

La figure 4 représente la variation de la stabilité Marshall en fonction de la teneur en déchet plastique.

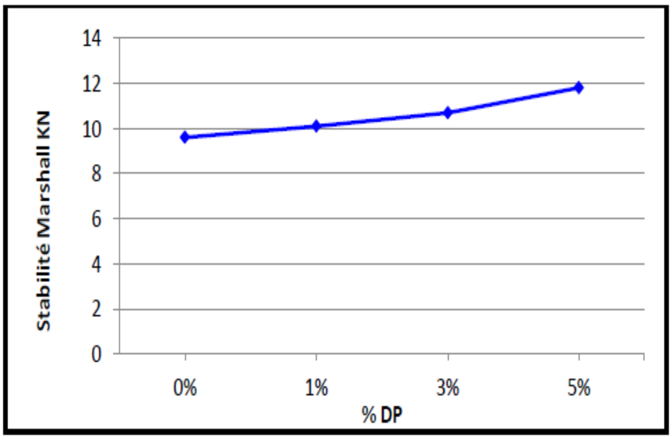

Figure 6.3 Stabilité Marshall.

On remarque que la SM augmente avec l'augmentation de la teneur en polymère et qu'elle est toujours plus petite que celle du bitume de base. L'incorporation du déchet plastique dans le bitume influe positivement sur la stabilité Marshall pour les différentes teneurs étudiées. Cette stabilité est maximale pour 5% de déchet plastique.

5. Conclusion

Les résultats des analyses traditionnelles ont démontré que l'incorporation de déchet plastique dans le bitume modifie les caractéristiques des bitumes. La dureté du bitume modifié est supérieure à celle du bitume pur. Effectivement, la pénétrabilité des bitumes diminue tandis que le point de ramollissement augmente avec l'ajout de polymères.

Selon les résultats des tests réalisés, il est observé que les bétons bitumineux modifiés présentent une meilleure performance mécanique par rapport aux autres bétons bitumineux. Les résultats sur les enrobés bitumineux démontrent également que les bétons bitumineux modifiés présentent une meilleure performance mécanique par rapport aux autres bétons bitumineux.

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INFLUENCE DU MÉLANGE DE SABLE DE DUNES ET DE SABLE CONCASSÉ SUR LES PROPRIÉTÉS DU SABLE RÉSULTANT

INFLUENCE OF THE MIXTURE OF DUNE SAND AND CRUSHED SAND ON THE PROPERTIES OF THE RESULTING SAND

Réception : 12/11/2024 Acceptation : 05/12/2024 Publication : 10/01/2025

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Résumé - Le sable de dunes fait partie des matériaux de construction utilisés dans la fabrication du béton et du mortier, surtout dans les zones arides, en raison de sa disponibilité en grandes quantités et à grande échelle. Le sable des dunes (SD) se caractérise par ses petits grains (D<1,25 mm) et son faible module de finesse (MF<1,80) ; ce qui affecte négativement les propriétés du béton à l'état frais et durci.
Pour cette raison, l'objectif de notre travail était de corriger la distribution granulaire et le module de finesse du sable des dunes en le combinant avec du sable concassé (SC) d'un diamètre de (0/4) mm dans des proportions calculées sur la base de la relation d'Abrams afin d'obtenir un sable préférentiel avec un module de finesse compris entre 2,2 et 2,8.
Dans les résultats des expériences menées sur le sable corrigé obtenu, nous avons constaté une amélioration de la distribution granulaire et une augmentation du module de finesse avec des valeurs acceptables qui répondent aux exigences des normes où nous pouvons combiner le sable concassé jusqu'à 70% avec le sable des dunes pour obtenir une bonne résistance à la compression et à la traction après 28 jours pour le mortier.

Mots - clés : Sable de dunes, Sable concassé, Sable corrigé, Module de finesse, Zone aride.

Abstract-Dune sand is among the building materials used in the manufacture of concrete and mortar, especially in arid zone, due to its availability in large quantities and on a large scale. Dune sand (DS) is characterized by its small grains (D<1.25mm) and low fineness modulus (FM<1.80), which negatively affect the properties of concrete in its fresh and hardened state.
For this reason, the objective of our work was to correct the granular distribution and fineness modulus of the dune sand by combining it with crushed sand (CS) with a diameter of (0/4) mm in proportions calculated based on the Abrams relation to obtain preferential sand with a fineness modulus between 2.2 and 2.8.
In the results of the experiments carried out on the corrected sand obtained, we have noticed an improvement in the granular distribution and an increase in the fineness modulus with acceptable values that meet the requirements of the standards, where we can combine crushed sand down to 70% with dune sand to obtain good compressive and tensile strength after 28 days for the mortar.

Keywords: Dune sand, Crushed sand, Corrected sand, Fineness modulus, Arid zone.

1-Introduction

Dune sand and crushed sand are frequently used materials in the construction and concrete in manufacturing sector. Dune sand, when finely ground, offering physical characteristics comparable to other additives [1]. On the other hand, crushed sand, can significantly improve the mechanical properties of concrete, especially when used as a coarse aggregate with a high proportion of fine particles (<80 µm), thanks to its angular shape that favors adhesion to cement [2]. In addition, research has shown that the combination of crushed sand and dune sand can affect the fresh, hardened properties of concrete. Dune sand is distinguished by its low fineness (MF<1.8) and higher cleanliness (ES> 80) compared to other types of crushed sand [3]. Stabilizing the sand from the dunes with crushed sand improved the cohesion and overall quality of the building materials [4].

The use of dune sand corrected with crushed sand is a common practice in concrete production to improve the properties and performance of the final product. Adding crushed sand to dune sand can significantly improve the mechanical properties of concrete, especially in terms of compressive strength [5].

Studies have shown that the compressive strength of concrete made with dune sand can be improved by adding crushed sand. For example, a study published in the Journal of Building Materials and Structures found that the compressive strength of concrete increased by up to 104.43% when dune sand was used as a partial substitute for river sand, with the addition of crushed sand further enhancing this improvement [6].

The workability of concrete made with dune sand and crushed sand is also an important factor. Studies have shown that adding crushed sand can improve the workability of concrete by reducing viscosity and increasing the fluidity of the mix. For example, a study published in the Journal of Construction and Building Materials found that adding crushed sand to dune sand improved the workability of concrete by increasing slump and reducing viscosity [7].

In recent years, some research has been devoted to the study of alternatives for river and quarry aggregates in concrete. The sand from the dunes, mainly as a partial replacement for the fine aggregates part of the structural concrete, has attracted interest due to its wide availability [8]. A.S. Al-Harthy et al. [9] in their work on these ordinary structural concretes, where fine sands were subjected to partial replacement (from 10%) to total replacement by dune sand, observed that the workability of these concretes was improved when the sand content of the dunes increased to a certain point as a function of the m/c ratio and the initial subsidence of the control sample. The results of compressive strengths indicated a decrease in performance of up to 24% as the sand content of the dunes increases. The reason, they explained, is the increase in the surface area of the particles, which requires more cementing materials to achieve a suitable coating.

On sand concretes, with consistent proportions of cement, lime powder, water/binder ratio and superplasticizer, T. Bouziani et al. [10] also noted that the addition of sand from round siliceous dunes in proportions of 0.1, 0.2 and 0.3 of the total weight of the sand changed the compressive strength of the mixture. The replacement rate of 0.1 induced a slight improvement in compactness and strength at 28 days, while the rates of 0.2 and 0.3 resulted in a steady and sharp decrease in strength on both parameters. Abu Seif [11] on a large sample of 15 dune sands in the Saudi Arabian desert, evaluated the replacement of crushed sand by dune sand in concrete. Their results showed a strongly correlated smooth decline (R2 = 0.9917) in compressive strength as the proportion of dune sand increases in the mixture. Later, Abu Seif et al. [11] showed that their observations on concretes were also extendable to mortars, since they noted a similar decrease in strength related to the sand of the dunes.

The influence of dune sand on rheological properties, settlement density and porosity has also been demonstrated over the years [12], [13]. And, as far as compactness is concerned, there is a consensus on the enhancing character of dune sand particles in concretes, to a certain extent, which can be explained by the very fine size, smooth surface texture and round shape of these particles. As a result, it is easier for particles to move through the matrix [14], [15]. The same conclusions were drawn on self-consolidating concrete by A. Rmili et al. [16], [17] after studying the gradual replacement of crushed sand by dune sand. Handling parameters, they noted, have been improved with the addition of dune sand by up to 30 percent. Beyond that, the sand from the dunes improved the viscosity of the concrete but decreased both strength and fluidity. Reports from Abu Seif [11] also showed an improvement in concrete slump values of up to 60% dune sand replacement rate. Higher rates led to an abrupt loss of manoeuvrability, with the largest drop being observed between 60% and 80% with slump dropping from 100 mm to 50 mm. One of the reasons given is the low gradation of these sands, where generally, 25% by weight of the grains are less than 150 µm, while this proportion is generally less than 6% in ordinary sands [18].

2- Experimental program

2.1- Materials

In our study, we used two types of dune sand in addition to crushed sand, the sands used are local materials from the Adrar region. Dune sand from the dunes of the Aoulef region (DSA) and dune sand from the dunes of the Tsabit region (DST) as well as crushed sand from the Koussane quarry (CSK).

Tab.1 shows the different physical properties of the sands studied, in addition to Figure 1 showing the granular analysis curves.

Table 1: Physical properties of the sands.

Tableau 1 : Propriétés physiques des sables.

Type of sand	DSA	DST	CSK
Fineness modulus (FM)	1,69	1,02	3,19
Coeff. of curvature (Cc)	1,22	0,98	1,25
Coeff. of uniformity (Cu)	3,27	2,73	2,81
Water Absorption (WA) (%)	0,23	0,23	2,73
Sand Equivalent (SE)	95,9	79,87	58,23
Apparent Volumetric Mass (g/cm^3)	1,68	1,59	1,65
Absolute Volumetric Mass (g/cm^3)	2,61	2,59	2,57

The results shown in Tab.1 and Fig.1, meaning that:

- The Modulus of Fineness (FM) for the two sands of the dunes (DSA and DST) is less than 1.7 according to the standards, these two sands are classified as fine sand.
- Crushed sand (CSK) is classified as coarse sand when the Fineness Modulus (FM) is approximately 3.20.
- The sand (DSA) is very clean (ES>80), but the sand (CSK) is clayey when their (ES<60).

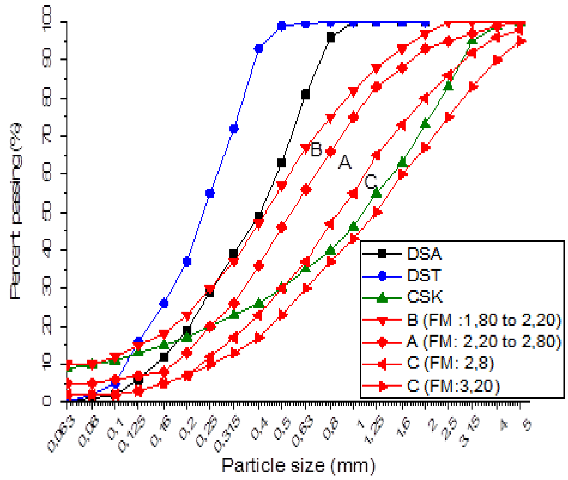

Figure 1: Particle size curves of the sands studied.

Figure 1 : Courbes granulométriques des sables étudiés.

From Fig.1, we can see that:

- The particle size curves of the two sands (DSA and DST) are out of the spindle zones.
- The crushed sand (CSK) particle size curve is in the coarse sand interval.

3- Determination of the proportions of sand (dune sand and crushed sand)

3.1- Fineness modulus

The experimental fineness modulus is defined as the sum of the cumulative percentages, by mass, of the refuse on thefollowing series of sieves, 0.125 - 0.25 - 0.5 - 1 - 2 - 4 (mm), given as a percentage.

Depending on the requirements of the standards (EN12620) [19], the FM is between:

- 1.8 and 2.2: Sand is mostly fine-grained.
- 2.2 and 2.8: Preferential sand.
- 2.8 and 3.3: Sand is a bit coarse.

To obtain a preferential sand with a fineness modulus between 2.2 and 2.8, we use

Abrams' rule [20], to determine the proportions of the two sands (dune sand and crushed sand) :

- Crushed sand= $((FM-FM_2)/(FM_1-FM_2))$ (1)

Formula (1) is used to calculate the proportion of crushed sand combined with dune sand.

- Dune sand= $((FM_1-FM)/(FM_1-FM_2))$ (2)

Formula (2) is used to calculate the proportion of dune sand combined with crushed sand.

- FM: Target fineness modulus.
- FM_1: Fineness modulus of crushed sand.
- FM_2: Fineness modulus of dune sand.

In our case study, three fineness modulus were chosen to obtain a preferential sand:
FM=2.2
FM=2.5
FM=2.8

3.2- Corrected Sand (DSA+CSK)

The tab.2 above shows the deferent proportions for a mixture between the two sands (DSA+CSK).

Table 2: Dune sand (DSA) proportions and crushed sand (CSK)

Tableau 2 : Proportions de sable des dunes (SDA) et de sable concassé (SCK)

	CSK (%)	DSA (%)
FM=2.2	34	66
FM=2.5	54	46
FM=2.8	74	26

The tab.2, shows the proportions of dune sand (DSA) with the incorporation of crushed sand (CSK) we notice that:

- The rate of crushed sand varies between 34% and 74%, this rate decreases with the rate of sand in the dunes which is varied between 66% and 26%.
- When the fineness modulus is increased, the rate of crushed sand is also increased.

3.3- Corrected Sand (DST+SCK)

The substitutions of dune sand (DST) and crushed sand (CSK) for the targeted fineness modulus are presented in the tab.3 above.

Table 3: Dune sand (DST) proportions and crushed sand (CSK)

Tableau 3 : Proportions de sable des dunes (SDT) et de sable concassé (SCK)

	CSK (%)	DST (%)
FM=2.2	54	46
FM=2.5	68	32
FM=2.8	82	18

Based on these results (tab.3), it can be seen that:

- The minimum dune sand content (DST) for a fineness modulus of 2.2 is 46% because of the fineness modulus of (DST) which is equal to 1.03.
- The proportions of (CSK) are varied in the interval [54%; 82%], meaning that the sand correction (DST) requires a rate of (CSK) greater than 55%.

4- Identification of the physical characteristics of the sands obtained

Once the two types of sanddune sand and crushed sandare mixed, we attempt to identify their distinct physical properties.

4.1- Particle size analysis of corrected sands

After the kneading of the two sands: (DS+CS). We test the particle size analysis to obtain a homogeneous sand.

4.1.1- Corrected sand: Dune sand (DSA) and crushed sand (CSK)

The particle size curves of the corrected sands are illustrated in the following figure (fig.2).

In fig.2, we notice that:

- The two curves of corrected sand with a fineness modulus of 2.2 and 2.5 are in the preferred sand interval.
- The corrected sand particle size curve with a fineness modulus equal 2.8 is outside the preferred sand interval for grains with a diameter varied between 0.5 and 2.0 mm.

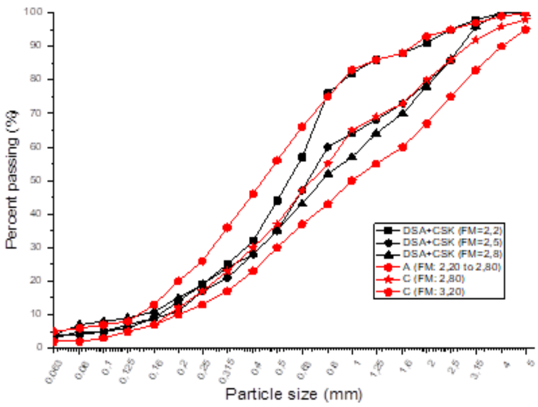

Figure 2: Particle size curves of corrected sands (SDT+SCK)

Figure 2 : Courbes granulométriques des sables corrigés (SDT+SCK)

Tab.4 shows the physical properties of dune sand (DST) after it has been corrected with crushed sand (CSK).

Table 4: Physical properties of the corrected sands.

Tableau 4 : Propriétés physiques des sables corrigés.

Type of corrected sand	DSA+CSK		
Theoretical fineness modulus	2,20	2,50	2,80
Experimental fineness modulus	2,30	2,57	3,01
Coeff. of curvature (Cc)	1,12	0,32	0,09
Coeff. of uniformity (Cu)	3,95	2.00	2,11
Water Absorption (WA) (%)	0,81	1,74	2,11
Sand Equivalent (SE)	80	79	75
Apparent Volumetric Mass (g/cm^3)	1,71	1,69	1,60
Absolute Volumetric Mass (g/cm^3)	2,64	2,65	2,63

Based on the results presented in Tab.4 and, it was concluded that:

- The experimental fineness modulus of the three corrected sands is similar to the theoretical fineness modulus targeted.
- It will be noted that the three corrected sands obtained are clean when the (SE) is greater than 60.
- The rate of (WA) is increased with the increase of (FM).

4.1.2- Corrected sand: Dune sand (DST) and crushed sand (CSK)

The figure (Fig. 3) illustrates the results of particle size distribution curves for the corrected sands (SDT+SCK).

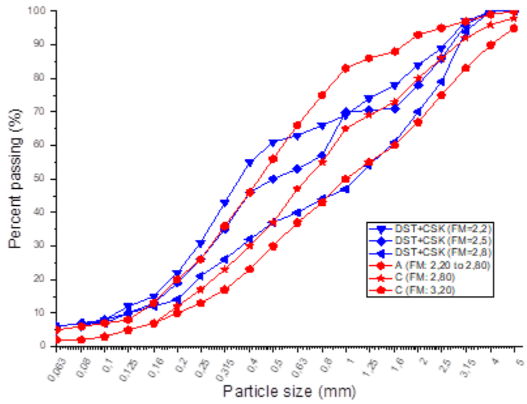

Figure 3: Particle size curves of corrected sands (SDT+SCK)

Figure 3 : Courbes granulométriques des sables corrigés (SDT+SCK)

Fig. 3, shows that:

- The corrected sand particle size curve FM=2.2 contains elements with a diameter of less than 0.5mm more than the preferred sand.
- The sand corrected with a fineness modulus FM=2.5 is well located in the preferred sand interval.
- Corrected sand with a modulus of fineness equal to 2.8 contains aggregates with a diameter 0.5 mm greater than a preferred sand.

The results obtained from the study of the physical properties of dune sand (DST) corrected with crushed sand (CSK) are summarized in Tab.5.

Table 5: Physical properties of the corrected sands.

Tableau 5 : Propriétés physiques des sables corrigés.

Type of corrected sand	DST+CSK		
Theoretical fineness modulus	2,20	2,50	2,80
Experimental fineness modulus	2,44	2,77	3,14
Coeff. of curvature (Cc)	0,05	0,04	0,04
Coeff. of uniformity (Cu)	3,33	2,67	3,75
Water Absorption (WA) (%)	1,13	1,27	1,74
Sand Equivalent (SE)	78	75	73
Apparent Volumetric Mass (g/cm^3)	1,67	1,68	1,61
Absolute Volumetric Mass (g/cm^3)	2,66	2,65	2,61

Based on the results presented in Tab.4, it was found that:

- The theoretical and experimental fineness modulus values show almost similar results, a difference of (0.20).
- In accordance with the requirements of the standard and according to the fineness modulus obtained from the corrected sands, most sands are classified as preferential sand.
- The three corrected sands obtained are clean sands when the (FM>60).

5- Conclusion

After identifying the physical characteristics of the corrected sands obtained, it was concluded that:

- An improvement on the granular distribution of corrected sands, a well-graded granularity and the sand obtained is preferred.
- The experimental fineness modulus of corrected sands is varied between 2.2 and 2.8 which meets the requirements of the standards.
- The corrected sands obtained are clean with a sand equivalent greater than 70.
- The water absorption coefficient is negligible when it is less than 1.74%.

We can say that the correction of dune sands with crushed sand is essential to obtain a sand with physical characteristics that meets the requirements of the standards.

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A REVIEW OF THE DIFFERENT TYPES OF SOIL STABILIZATION TECHNIQUES - TREATMENT WITH AGRICULTURAL WASTE
UNE REVUE DES DIFFÉRENTES TECHNIQUES DE STABILISATION DES SOLS - TRAITEMENT AVEC DES DÉCHETS AGRICOLES

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Résumé - La stabilisation des sols est un processus vital pour améliorer les paramètres de résistance au cisaillement des sols et augmenter leur capacité portante, en particulier lorsque le sol existant est insuffisant pour supporter des charges structurelles. Cela implique souvent de corriger les propriétés d'ingénierie indésirables des sols par des modifications visant à améliorer leurs propriétés physiques. En augmentant la résistance au cisaillement et en gérant les caractéristiques de retrait et de gonflement, la stabilisation vise à renforcer la capacité portante des sols pour soutenir les pavés et les fondations. Cela implique un examen de l'effet de la stabilisation sur les sols, y compris les mécanismes d'interaction avec les additifs, l'impact sur la résistance et l'amélioration de la teneur en humidité et de l'entretien. La stabilisation mécanique se concentre sur l'amélioration des propriétés du sol en modifiant leur gradation, tandis que la stabilisation chimique consiste à modifier les conditions physiques et chimiques entourant les particules d'argile pour réduire l'absorption d'eau et le mouvement au sein de la matrice du sol. Ces méthodes sont cruciales pour diminuer la perméabilité et la compressibilité dans les structures souterraines tout en améliorant la résistance au cisaillement. L'utilisation de déchets agricoles pour améliorer les propriétés des sols est significative. L'industrie agricole produit de grandes quantités de déchets, ce qui contribue à des problèmes environnementaux tels que la pollution de l'eau et de l'air. Des exemples notables incluent les cendres de coque de riz et les cendres de canne à sucre produites par les moulins. Les cendres de coque de riz, riches en silice amorphe, servent de stabilisateur efficace, tandis que les cendres de canne à sucre sont riches en silice et en oxydes d'aluminium. Cet article examine la stabilisation des sols expansés à l'aide de résidus agricoles dans des proportions variées (5 %, 10 %, 15 %, 20 %) et détermine la Masse Sèche Maximale (MSM) par le biais du test de Proctor standard. Divers tests, y compris le test de Résistance Compressive Non Confinée (RCNC) à des intervalles de durcissement de 7, 14 et 28 jours, ainsi que le test du Rapport de Portance de Californie (RPC), ont été effectués. Les résultats révèlent une augmentation de la résistance au cisaillement et une diminution de la compressibilité des sols. Dans l'ensemble, comprendre les différents aspects des techniques de stabilisation des sols est essentiel pour assurer le succès des projets de construction en abordant efficacement les propriétés des sols qui impactent la stabilité et la capacité portante

Mots - clés : Stabilisation des sols, Sols expansifs, Déchets agricoles, CBR, Résistance à la compression non confinée.

Abstract-Soil stabilization is a vital process for enhancing the shear strength parameters of soils and increasing their bearing capacity, particularly when the existing soil is inadequate for supporting structural loads. This often entails correcting undesirable engineering properties of soils through modifications aimed at improving their physical properties. By increasing shear strength and managing shrinkage and swelling characteristics, stabilization seeks to boost the bearing capacity of soils for supporting pavements and foundations. It involves an examination of how stabilization affects soils, including the mechanisms of interaction with additives, the impact on strength, and the enhancement of moisture content and maintenance. Mechanical stabilization concentrates on improving soil properties by altering their gradation, while chemical stabilization entails modifying the physical and chemical conditions surrounding clay particles to reduce water absorption and movement within the soil matrix. These methods are crucial in decreasing permeability and compressibility in ground structures while enhancing shear strength. The use of agricultural waste to improve soil properties is significant. The agricultural industry produces large quantities of waste, which contributes to environmental issues such as water and air pollution. Notable examples include rice husk ash and sugarcane ash generated by mills. Rice husk ash, rich in amorphous silica, serves as an effective stabilizer, while sugarcane ash is high in silica and aluminum oxides. This paper reviews the stabilization of expanded soil using agricultural residues in varying proportions (5%, 10%, 15%, 20%) and determines the Maximum Dry Density (MDD) through the standard Proctor test. Various tests, including the Unconfined Compressive Strength (UCS) test at curing intervals of 7, 14, and 28 days, as well as the California Bearing Ratio (CBR) test, were conducted. The findings reveal an increase in shear strength and a decrease in soil compressibility. Overall, understanding the different aspects of soil stabilization techniques is essential for ensuring the success of construction projects by effectively addressing soil properties that impact stability and load-bearing capacity.

Keywords: Soil stabilization, Expansive soil, Agricultural wastes, CBR, unconfined compressive strength,

1-Introduction

Expanded soil exhibits swelling properties. Agricultural waste presents a significant challenge in developing countries, but these wastes can serve as effective stabilizing agents. Clay soil poses construction difficulties for infrastructure, such as pavements and foundations. During the rainy season, expanded soil absorbs water, swells, and becomes soft, while in dry conditions, it shrinks and solidifies as moisture evaporates. To enhance clay soil characteristics, agricultural waste materials are utilized. Research shows that Sugarcane Residue Ash (SCBA) offers a cost-effective stabilization solution, while Rice Husk Ash (RHA) effectively binds soil particles, reducing water absorption and increasing soil durability and strength Agricultural wastes are mainly of four types as shown in Figure 1. They consist of crop, food, industrial processing and livestock wastes. They are generated after the extraction of the useful part of the crop or during livestock rearing. Like any other waste, agricultural wastes need to be managed properly for a healthy environment through various waste management strategies. These strategies include utilizing agricultural wastes to produce new products as value addition to the agricultural economy. These agricultural wastes are incinerated to produce agricultural waste ash. Some of the new products that can be produced from agricultural waste ash are SNPs. SNPs are produced either through bottom-up or top-down methods using non-renewable minerals such as silica sand. There is a need to reduce the use of non-renewable resources to produce SNPs. This has led to research on the use of AWAs to produce SNPs that are considered green. This leads to the management of AWs while enhancing value addition in agriculture. These SNPs can be used as pozzolanic additives in civil engineering projects to strengthen concrete, and produce plastic and rubber materials. This leads to sustainable construction. In this review, recent advances in soil stabilization, bitumen and asphalt in the road construction sector are studied.

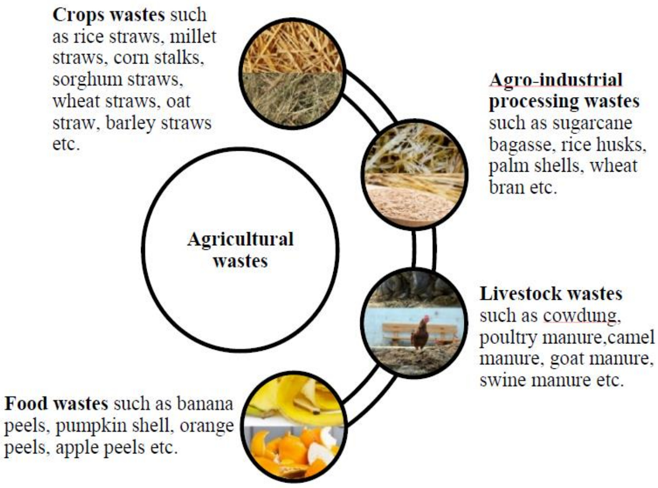

Figure 1: Types of agricultural wastes.

Table 1: Agricultural wastes ashes containing silica as characterised by x-ray fluorescence spectroscopy (XRF) from different studies

Biomass ash	Silica (SiO_2) (%)	Reference
Rice husk ash	72.2–99.50	[1]–[6]
Areca sheath ash	78.00	[7]
Sugar cane bagasse ash	40.46–98.40	[8]–[16]
Palm leaf ash	53.11–82.15	[17], [18]
Corn cob ash	64.80	[19]
Barley straw ash	55.00–61.75	[20], [21]
Bamboo leaf ash	72.81	[22]
Millet husk ash	69.40	[23]
Wheat straw ash	67.83	[23]
Wood ash	7.75–68.51	[24]–[27]
Sorghum huskash	70.48	[28]
Paddy waste ash	84.78	[29]
Ficus leaf ash	81.45	[30]
Palm oil fuel ash	61.68	[31]
Sunflower ash	50.36	[32]
Anacardium ash	65.02	[33]
Cowdung ash	57.33–61.00	[34], [35]

2- Soil Stabilization Methods

2.1- Husk Ash as a Soil Stabilizer in Road Construction

The use of coconut husk ash (CHA) as a low-cost alternative to traditional soil stabilizers, such as cement and lime, in road construction projects is particularly significant in developing countries where local soils lack the required engineering properties. Laboratory experiments were conducted on mixtures of clay soil and coconut husk ash in proportions ranging from 0% to 20% to determine its effect on the physical and mechanical properties of the soil.

2.1.1- Chemical Composition: Coconut husk ash consists of oxides such as SiO_2, K_2O, and CaO, making it a suitable pozzolanic material.

2.1.2- Mix Properties: The results showed that the optimal CHA content for improving soil strength was at 8%, where California Bearing Ratio (CBR) values and Unconfined Compressive Strength (UCS) increased with the ash content up to this percentage, after which the values began to decline with higher ratios.

2.1.3- Applications: Despite the improvements achieved with the mixtures, the use of coconut husk ash alone is insufficient for stabilizing soil in major foundations. It is recommended to combine it with traditional stabilizers to enhance performance in base layers and sub-layers.

2.2- The Effect of a Mixture of Sorghum Straw Ash and Lime on Clayey Soil:

The impact of a mixture of sorghum straw ash (GCHA) and lime on improving the properties of clayey soil used in the construction of highways is significant, especially since this type of soil often faces stability issues due to environmental factors and excessive loading.

2.2.1- Improvement Tests: The results indicated that the addition of GCHA and lime in proportions of 2%, 3%, and 4% for GCHA and 4%, 6%, and 8% for lime significantly enhanced the soil properties:
Maximum Dry Density (MDD): Increased from 1.71 mg/cm³ to 1.86 mg/cm³.
California Bearing Ratio (CBR): Rose from 3% to 12% at 3% GCHA and 6% lime.
Unconfined Compressive Strength (UCS): Increased from 157.35 kN/m² to 357.14 kN/m² at the same proportions.

2.3- Rice Husk Ash and Coconut Husk Ash:

The use of agricultural wastes such as Rice Husk Ash (RHA) and Coconut Husk Ash (CS) to enhance the properties of clayey soil utilized in the subbase layer of roads is gaining attention. Untreated clayey soil is typically weak in strength, necessitating improvement through the incorporation of additional materials.

2.3.1- Results: Geotechnical Properties: The findings indicated an increase in optimal moisture content (OMC) and a slight decrease in maximum dry density (MDD) with the addition of RHA and CS
Unsoaked Condition: CBR values significantly increased with the addition of CS and RHA, reaching 36.75% at the top layer and 40.81% at the bottom layer when using 8% CS and 20% RHA.
Soaked Condition: The results demonstrated an increase in CBR values compared to untreated soil, indicating a substantial improvement in strength.

2.4- Evaluation of Cassava Peels Ash (CPA) and Cement Performance:

The effect of adding Cassava Peels Ash (CPA) on the engineering properties of soil aims to enhance the properties of the soil by utilizing CPA and cement, contributing to agricultural waste management and reducing reliance on traditional cement. CPA was added in proportions of 0%, 2%, 4%, 6%, 8%, and 10%, with the addition of 5% cement in some samples.

2.4.1- Results:

Atterberg Limits: There was an increase in the liquid limit with an increase in CPA content, while the plastic limit decreased. Maximum Dry Density (MDD) This decreased with an increase in CPA.
California Bearing Ratio (CBR): Increased from 15% for natural soil to 22% at 8% CPA, and rose further with the addition of cement.
Unconfined Compressive Strength (UCS): Increased from 21.09 kN/m² to 32.80 kN/m² at 10% CPA
These results underscore the potential of utilizing rice husk ash and coconut husk ash as effective materials for enhancing the geotechnical properties of clayey soils, thereby contributing to improved performance in road construction.

2.5- The effect of mango straw ash (MSA) :

The effect of mango straw ash (MSA) on black cotton soil, which is considered expansive and unsuitable for construction purposes. The objective of the study is to assess the suitability of MSA for improving soil properties for use in road construction.

2.5.1- Results:

Improvement of geotechnical properties:
California Bearing Ratio (CBR): Increased by 85.7% with the addition of 15% MSA. Unconfined Compressive Strength (UCS): Improved by 60.24% with the optimal value at 15% MSA.
Maximum Dry Density (MDD): Increased by 60%.
Optimum Moisture Content: Decreased by 54%.Free Swell Index: Decreased by 33.33%.Specific Gravity: Increased by 62.5%.Plastic Limit: Decreased by 62.6%.Plasticity Index: Decreased by 61.34%.

2.6- Assessment of the Impact of Using Palm Fiber Ash :

Using natural components such as palm fiber ash is considered a sustainable option for improving the performance of materials used in infrastructure projects, especially in countries where these materials are abundant.

2.6.1- Dry Density and Mechanical Properties:

It was found that the increase in the content of palm fiber ash leads to a slight decrease in maximum dry density, while the optimum moisture content improved. A significant improvement in the California Bearing Ratio (CBR) was observed, with the highest value reaching 190.09% after soaking when using a mix containing 80% laterite soil, 14% palm fiber ash, and 6% cement.

2.6.2- Improvement of Engineering Performance:

Experiments showed that the soil treated with palm fiber ash and cement exhibited better unconfined compressive strength, making it more resistant to loads and repeated stresses, thus enhancing the stability of roads when used in high traffic environments..

2.7- Effect of Using Ground Palm Kernel Shells (PPKS)

Tests were conducted to determine the engineering properties of this soil after adding varying percentages of PPKS ranging from 5% to 12.5%.

2.7.1- Physical Properties:

The laterite soil exhibited a liquid limit of 36% and a plastic limit of 26.18%, indicating a reduced susceptibility of the soil to shrinkage or cracking.

The maximum dry density (MDD) increased from 1.76 to 1.94 kg/m³ with the increasing content of PPKS.
Optimum Moisture Content (OMC): The optimum moisture content decreased from 14.69% to 12.65% with the increase in PPKS percentage, indicating an improvement in the engineering properties of the soil.
California Bearing Ratio (CBR):The wet CBR value increased from 24% to 53% with the addition of 12.5% PPKS, indicating a significant improvement in the strength of the soil as a construction material for roads.
Unconfined Compressive Strength (UCS):The unconfined compressive strength increased from 46.69 to 127.08 kg/m² with the increase in PPKS content, reflecting a substantial improvement in soil strength

2.8- Effect of Adding Egg Shell Ash (ESA) on Improving Soil Properties

2.8.1- Chemical Analysis of Egg Shell Ash

Eggshell ash contains a high percentage of calcium oxide (CaO) reaching 68.20%, while the silica (SiO_2) content is low at 11.29%.

California Bearing Ratio (CBR) Test:The results showed an increase in CBR values (both saturated and unsaturated) with the increasing content of ESA, with peak values achieved at 8% ESA. For example, in Ekiti State, the saturated CBR value rose from 31.85% (0% ESA) to 36.44% (8% ESA).

Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) Tests:MDD increased with the rise in ESA content, while OMC decreased. The highest MDD was achieved at 8% ESA.

Unconfined Compressive Strength (UCS) Test:The UCS results showed a significant increase in strength with the increasing ESA content, with values ranging from 464.10 to 1032.20 kN/m², achieving peak values at 8% ESA.

Direct Shear Test:The results of the direct shear test indicated an increase in cohesion (C) and internal friction angle (φ) values with the rise in ESA content, with peak values reached at 8% ESA.

2.9- Soil Stabilization Using Groundnut Straw Ash (GSA)

Using groundnut straw ash (GSA) as a stabilizing agent for expansive clay soil comes at a time of rising costs for traditional stabilizing agents and the need to utilize agricultural and industrial waste economically.

2.9.1- Stabilization Results:

The highest unconfined compressive strength (UCS) of 455 kN/m² was achieved with the addition of 4% GSA using the standard Proctor compaction method, and 526 kN/m² was achieved with 6% GSA using the West African compaction method.

The results did not meet the recommended requirements for base materials, as they were below 1710 kN/m².

The California Bearing Ratio (CBR) test results indicated that the values did not reach the minimum required threshold for base or sub-base materials.

2.10- Using Bagasse Ash for Stabilizing Expansive Soil

This study addresses the use of bagasse ash as a stabilizing material for expansive soils, which pose challenges in civil engineering due to their properties of swelling and shrinkage when exposed to water. The aim of the study is to improve the characteristics of this soil using bagasse ash as an economical and sustainable alternative.

2.10.1- Study Results

Improvement of Properties: The results showed that the addition of 6% bagasse ash led to a significant improvement in the soil's engineering properties, with an increase in maximum dry density by 5.8%, an increase in California Bearing Ratio (CBR) by 41.52%, and an increase in unconfined compressive strength by 43.58%.

Effect of Ratios: The best results were observed when 6% of the soil was replaced with bagasse ash, while the properties decreased with higher ratios of 9% and 12%.

2.10.2- Chemical Properties of Bagasse Ash: Bagasse ash contains a high silica content, which imparts pozzolanic properties that help improve the cohesion of the soil.

3-Recommendations

Future research needs to focus on:

Evaluating the operational characteristics of these components over time.

Conducting field studies to analyze the actual performance of the treated roads.

Considering the economic and environmental quality of generalizing this method in infrastructure projects.

These findings underscore the importance of using sustainable techniques in road construction, positively impacting sustainable development and environmental conservation.

Further research is recommended to explore other properties and their effects on different soil types, which could contribute to improving the sustainability of construction projects and reducing agricultural waste.

This research highlights the significance of using sustainable agricultural materials to enhance soil properties, contributing to the development of more sustainable infrastructure.

3- Conclusion

The study represents an important step towards exploring sustainable and environmentally friendly alternatives to traditional soil stabilizers, enhancing the potential for using local resources in infrastructure projects.

The use of CS (Calcium Sulfate) and RHA (Rice Husk Ash) significantly improves the engineering properties of clay soils, making them more suitable for use in road base layers.

This research is a significant step towards utilizing natural materials as sustainable alternatives in construction projects, which reduces costs and lessens environmental impact.

The study demonstrated that using CPA (Calcium Phosphate Ash) as a stabilizing agent can improve the engineering properties of soils, making them suitable for road construction.

The soil's classification changed from A-7-5 to A-2-7 with the addition of 10% CPA, indicating a notable improvement in quality.

The results indicate that mango straw ash (MSA) has the potential to enhance the engineering properties of black cotton soil, making it suitable as a paving material for roads.

The study confirms that introducing palm fiber ash as a sustainable method for soil improvement can enhance its applications in construction, as it is an environmentally friendly and cost-effective option, while also reducing waste from palm processing.

Further research is recommended to explore the behavior of these materials under varying conditions, such as dynamic loads and changing climates, to gain a deeper understanding of their performance in practical applications..

Sugarcane straw ash can be used as an effective alternative to improve the properties of black cotton soil up to a ratio of 6% without the need for additional chemical or cementitious materials.

The results indicate that the use of sugarcane straw ash could be an economical and environmentally friendly solution to soil stabilization issues, contributing to the reduction of agricultural waste.

Effective stabilization of black cotton soil could not be achieved using peanut straw ash as a stabilizing agent.

Nevertheless, the ash showed the ability to improve strength over time, suggesting its potential for use in other applications or in combination with additional materials to enhance its effectiveness.

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