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SAND STABILIZATION BY USING UREA-FORMALDEHYDE RESIN

تثبيت الرمل باستخدام راتنج اليوريا فورمالدهايد

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ABSTRACT

This paper presents the results of detailed laboratory tests to improve the natural subgrade soils using polymer resins. The improvement may be through increasing compressive strength, flexural strength and California bearing ratio. The urea-formaldehyde resin was used in this study, as a soil stabilizing agent, to improve the characteristics of desert and beach sands. Comparison was done of properties of soil with no modified urea-formaldehyde resin with the properties of soil with modified urea-formaldehyde resin. The results are encouraging since the addition of the urea-formaldehyde resin increase the compressive strength which enables the sands to carry the heavy traffic. In addition, California bearing ratio, dry density, abrasion resistance and water absorption have been improved to use in the construction of highways.

الملخص العربي

يحتوي هذا البحث علي دراسة معملية لتحسين خواص وتثبيت طبقة التأسيس لنظام الرصف باستخدام المواد الراتنجية لتحسين الخواص المختلفة للتربة الطبيعية ومنها مقاومة الضغط والانحناء ومقاومة التحمل. وقد استخدمت مادة اليوريا فورمالدهايد في هذه الدراسة لتثبيت وتحسين خواص عينات من الرمل مأخوذة من الصحراء ومن شاطىء البحر. وتم عمل مقارنة بين نتائج التربة الغير المثبتة والمثبتة بمادة اليوريا فورمالدهايد. وقد كانت نتائج التجارب مرضية حيث أنه تم الحصول علي مقاومة للضغط تسمح باستخدام هذا الرمل المثبت لتحمل حركة النقل الثقيل. بالإضافة إلي تحسن ملحوظ لخواص أخري للتربة مثل مقاومة التحمل والكثافة الجافة ومقاومة البري وامتصاص الماء مما يسمح باستخدام هذه التربة في أعمال الطرق.

KEYWORDS: Stabilization, Polymerization, Urea-Formaldehyde Resin and curing time.

1. INTRODUCTION

Highway engineers are interested in the basic engineering properties of soils because soils are used extensively in highway construction. Soil properties are of significant importance when a highway is to carry high traffic volumes with a large percentage of trucks [1]. They are also of importance when high embankments are to be constructed and when the soil to be strengthened and used as intermediate support for the highway pavement [2]. In a flexible pavement, the bituminous concrete and it's under courses distribute loads downwards to the subgrade soil. Additional strength in the subgrade soil can lead to a prolonged pavement lifetime. Recently many investigations are done to study the possibility of using polymers to modify the properties of some types of soil. Polymeric materials possess outstanding tensile strength, chemical inertness, good adhesion to other materials and other valuable properties which draw considerable attention for their use in soil stabilization.

The urea-formaldehyde resin was used to stabilization of brown shale gravel. The results indicated that, addition of 2% of urea-formaldehyde resin was sufficient to raise the indirect tensile strength in dry case to 340 KPa but the strength in wet case was still poor [3]. Stabilization of fine sand is the longest-established and most widely used grouting technique. It involves the filling of the pore space of soils. The objective is to fill a void space without displacement of the formation or any change in the void configuration or volume [4]. Fine alluvial sand stabilized with multi-molecular organic solutions. Comparison was done of properties of conventional multi-molecular organic solutions on basis of urea-formaldehyde resins with properties of modified with active component solutions. Compressed strength of sands stabilized with multi-molecular organic solutions is time dependent and increased from 2.2 MPa after 7 days to 2.9 MPa after 3 months. 12 to 19 times less formaldehyde is liberated into the air from soil stabilized with the modified solutions than from the soil stabilized with the conventional solutions [5].

Permeable soils strengthened were studied with modified polymer resins in laboratory and field over a period of one year. Comparison was done of properties of no modified urea formaldehyde resins with properties of modified urea-formaldehyde resins. Results of field tests confirmed the results of The goal of this study is centered on the possibility of using the available local urea-formaldehyde resins to stabilize different types of sands: desert sand, uncleaned beach sand and washed beach sand. The investigation includes the effect of use of the urea-formaldehyde resins on sand properties such as compressive strength, flexural strength, California bearing ratio, dry density water absorption and abrasion resistance. Also, the investigation includes the effect of the time of air curing on the above properties.

2. THE MECHANISM OF POLYMERIZATION

Polymer are macro molecules built up by the linking together of large numbers of much smaller molecules. The small molecules which combine with each other to form polymer molecules are termed "monomers". The reaction by which they combine is termed "polymerization". Polymers are classified as linear, branched or cross linked polymers depending on the structure shape of the polymer molecules. Urea-formaldehyde resin has an excessive rigidity due to extensive cross-linking which leads to an inability to crystallize. Urea-formaldehyde resin shows the characteristics of highly viscous liquids. The polymerization of urea-formaldehyde resin under mildly basic conditions yields methyl derivatives such as mono- methlolurea ($HOCH_2$-NH-CO-NH_2) and di-methlolurea ($HOCH_2$-NH-CO-NH-CH_2OH) which are then polymerized to network structures under neutral or slightly acid conditions [10]. The laboratory tests. Addition of active components to urea-formaldehyde resins increase density and pH of solution of urea-formaldehyde resin, decrease viscosity. Uniaxial strength of sands stabilized with polymer resins is highly time dependent [1]. The use of urea-formaldehyde resin is used in stabilized of some types of soils. The properties of soil samples with of urea-formaldehyde resin were determined. Several samples of soil and resin mixed in different ratios were prepared. The results show that the addition of the of urea-formaldehyde resin increase the compressibility module, the load strength and the bearing capacity of the stabilized soil. Also, the structures erected on the soils stabilized by of urea-formaldehyde resin may be expected to settle less [6]. Sand of Maadi-desert near Cairo has been stabilized using polmeric materials which resulted in improvement of its absorption and strength properties [7]. A number of polymeric materials were used in the Soviet Union as "structure forming agents" suitable for creating highly water resistant and mechanically strong soil structures to control erosion by wind and water on farm lands under cultivation [8]. Japanese used polymeric materials in road construction and bridge deck overlays for the negligible permeability and high strength of the mixture [9].

nature of the cross linking reaction is out of scope of this paper.

3. USED MATERIALS AND TESTING PROGRAM

The chemical composition of sand determines the type of polymer to be used. The urea-formaldehyde resin is the beat type of resins to be used for sand stabilization due to sand contains a high percent of Silicon Oxide Sio_2.

3.1 Sand Samples

Three different types of sand samples were used. They are:

Sand I: Obtained from a depth of one meter below the ground surface from Cairo-Alexandria desert road around the El-Aameria city.

Sand II: Obtained from Balteem beach to represent beach sand with salts and chlorides.

Sand III: Obtained from Balteem beach to after washing with tap water.

The chemical analysis of the three types of sand is given in Table (1) and (2).

3.2 Urea-Formaldehyde Resin

Urea-formaldehyde resin is classified as a thermo set material. The high degree of cross linking is used to import high rigidity and dimensional stability under conditions of heat and stress. Most mechanical properties depend on and vary considerably with molecular weight. The urea-formaldehyde polymer is generally characterized by; the high rigidity and high resistance to deformation, the modulus of elasticity ranges from 6.895 x 10^5 to 3.448 x 10^6 kN/m^2 and the tensile strength is 34475 to 82740 KN/m^2. Also, it has a very small elongation (0.5 to 3.0 %).

The amorphous polymer with high chain rigidity is achieved by extensive cross linking. It can bond and link sand mineral particles and becomes insoluble after the reaction is completed and it resists the biochemical decomposition. The sample of the urea-formaldehyde resin used in this work is produced by "Mansoura for Resins and Chemical Industries Company" at El-Mansoura [11]. The specifications of the used urea-formaldehyde resin are given in Table (3).

3.3 Testing Program

The selected three types of sand mixed with urea-formaldehyde resin percentage of 4%, 5%, 6%, 7% and 8% by weight. The time of air curing of mixtures was divided into 7, 14, 21 and 28 days after preparation. Soaking of specimens in water where samples were allowed to soak in water for one day before performing tests. In addition ammonium chloride was used to accelerate polymerization process. For each specimen, the following properties were determined; compressive strength, flexural strength, California bearing ratio, the maximum dry density, abrasion resistance and water absorption.

4. ANALYSIS AND DISCUSSION OF RESULTS

4.1 The Compressive Strength

Figure (1) Relationship between compressive strength at 28-days and the percentage of urea-formaldehyde (by weight) for all types of sands. From this Figure, it could be seen that, the value of compressive strength of desert sand was increased with the percentage of the added urea-formaldehyde resin increases with a peaking value showing an optimum at 5.8% then it starts to decrease. For beach sand either before or after washing, the compressive strength increases steadily to the maximum percentage of added urea-formaldehyde resin 8%. Also, it could be found that, the compressive strength increase with increasing air curing time. From Figure (1), it could be concluded that, the maximum obtained values of compressive strength after 28 days for desert sans, beach sand and washed beach sand were 90, 143 and 159 kg/cm^2, respectively. These values are quite suitable for many structural and highways construction uses. Soaking the urea-formaldehyde treated specimens in water for 24-hours after 28-days air curing time reduces the compressive strength to about 40% of the original value before soaking. This may be due to the long curing time required to complete the polymerization process before soaking.

4.2 Flexural Strength

Summary of test results are given in Figure (2). It could be seen that, increasing the percentage of added urea-formaldehyde resin resulted in an increase in flexural strength. This increase peaked at 5.8% for desert sand, while it was steady for beach sand before or after washing with water. The maximum achieved values of the modulus of rupture for the desert sand, beach sand and washed sand were 47, 50 and 54 kg/cm^2, respectively. Soaking the urea-formaldehyde treated specimens in water for 24-hours after 28-days air curing time reduces the flexural strength to about 40-50% due to the incompleteness of the polymerization process.

4.3 Abrasion Resistance

Summary of test results are given in Figure (3). From this Figure, it could be found that, the percentage of losses in weight by abrasion decreases with increasing air curing and by adding urea-formaldehyde resin up to 6.7% for desert sand. 6% for beach sand and 8% for washed sand. After these percentages, the losses reach approximately a steady state giving percentages of wear between 4 to 5.5 % by weight for all specimens. The maximum values of abrasion losses for treated samples ranged from 4 to 5% by weight after 28-days air curing time.

4.4 Water Absorption

Figure (4) shows the relationship between water absorption at 28 days and the percentage of urea-formaldehyde resin for all types of Sands. From this Figure, it could be found that, the percentage of water absorption decreases with increasing the percentage of urea-formaldehyde resin up to 6.5% for desert and beach sands, while it reaches 8% for washed beach sand. Also, it could be seen that, the percentage of water absorption decreases with increasing the air curing time. The minimum value of the percentage of water absorbed of all types of sands is about 6.5% of urea-formaldehyde resin. This value was obtained after 28-days air curing time.

4.5 California Bearing Ratio (CBR)

Figure (5) shows the relationship between Califorina bearing ratio (CBR %) at 28-days and the percentage of urea-formaldehyde resin (by weight) for all types of sands. From this Figure, it could be seen that, the value of Califorina bearing ratio CBR of desert and beach sands were increased with the percentage of the added urea-formaldehyde resin increases with a peaking value showing an optimum at 6.1% then it starts to decrease. Also, it could be found that, the Califorina bearing ratio CBR increases with increasing air curing time. From Figure (5), it could be concluded that, the maximum obtained values of Califorina bearing ratio CBR after 28-days for desert sand, beach sand and washed beach sand were 11, 11.2 and 11.3%, respectively.

4.6 Maximum Dry Density

Figure (6) shows the relationship between maximum dry density at 28-days and the percentage of urea-formaldehyde resin (by weight) for all types of sands. From this Figure, it could be seen that, the value of the maximum dry density of desert and beach sands were increased with the percentage of the added urea-formaldehyde resin increases with a peaking value showing an optimum at 5.4% then it starts to decrease. Also, it could be found that, the maximum dry density increases with increasing air curing time. From Figure (6), it could be concluded that, the maximum obtained values of maximum dry density after 28-days for desert sand, beach sand and washed beach sand were 1.99, 2.01 and 1.97 gm/cm^3, respectively.

5. CONCLUSIONS

Based on the test result and above analysis, the following conclusions of this study are summarized below.

1. Adding 5.8% of urea-formaldehyde resin to medium size desert sand gives about 90 Kg/cm^2 compressive strength after 28 days curing time. The same amount enables the beach fine sand to withstand 130 Kg/cm^2 compressive strength curing time. This means that urea-formaldehyde resin treated sands will satisfy the AASHTO requirements with higher factor of safety for all types of tested fine and medium sands.
2. The compressive strength of sands treated with urea-formaldehyde resin increases with the increase of curing time in air.
3. Washing the beach sand with tap water increases the P^H value. This gives the higher compressive and flexural strengths values.
4. Abrasion losses reach a minimum value (3%) by adding (5.8-6%) urea-formaldehyde resin to sand by weight for all types of sands. The abrasion losses may be decreased also by increasing air curing time. The same percent of urea-formaldehyde resin may decrease the ability of specimens for water absorption to its minimum value (6%).
5. The value of Califorina bearing ratio CBR of desert and beach sands were increased with the percentage of the added urea-formaldehyde resin increases with a peaking value showing an optimum at 6.1% then it starts to decrease. Also, it could be found that, the Califorina bearing ratio CBR increases with increasing air curing time.
6. The maximum dry density of desert and beach sands were increased with the percentage of the added urea-formaldehyde resin increases with a peaking value showing an optimum at 5.4% then it starts to decrease. Also, it could be found that, the maximum dry density increases with increasing air curing time

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***Table (1)**: Chemical Analysis of the Three Types of Sands (Soluble Salte Content)*

Salt	Sand I	Sand II	Sand III
Chloride $^{-}$ Cl^{-}	0.16	0.30	0.15
Sulphate $^{---}$ So_3^{--}	0.10	0,20	0.10
Sodium^{+} Na^{+}	0.00	0.05	0.00
Potasium^{+} K^{+}	0.00	0.02	0.00
P^{H}	7.2	7.80	8.00

***Table (2):** Chemical Analysis of the Three Types of Sands (Oxide Content)*

Oxide	Sand I	Sand II	Sand III
Silicon Oxide Sio_2	91.7	84.28	87.80
Aluminium Oxide Al_2o_3	1.52	5.62	4.20
Ferric Oxide Fe_2o_3	1.63	1.97	1.82
Titanium Oxide Tio_2	0.33	0.42	0.22
Calcium Oxide Cao	1.43	2.48	1.76
Magnesium Mgo	0.28	0.67	0.48
Sodium Oxide Na_2o	0.37	1.62	0.56
Potassium Oxide E_2o	0.62	1.16	1.10
Sulpher Trioxide So_3	0.57	0.58	0.56
L.O.I	1.25	1.14	1.12

Table (3): *Characteristics of Urea-Formaldehyde Resin [11]*

Character	Specifications
Appearance	Milky Liquid free from foreign matter
P^H	7.8-8.8
Solid Content(3 h/120°C)	(60 ± 2)%
Viscosity @ 20 °C	(350-450) cps
Gel Time @ 100 °C	(65-90) sec
Specific Gravity @ 20 °C	(1.25 ± 0.02)
Shelf Life @ 25 °C	One Month
Chemical Stability in Water	Stable
Storage	In Plastic Containers
Handling	It is very sensitive to P^H and high temperature

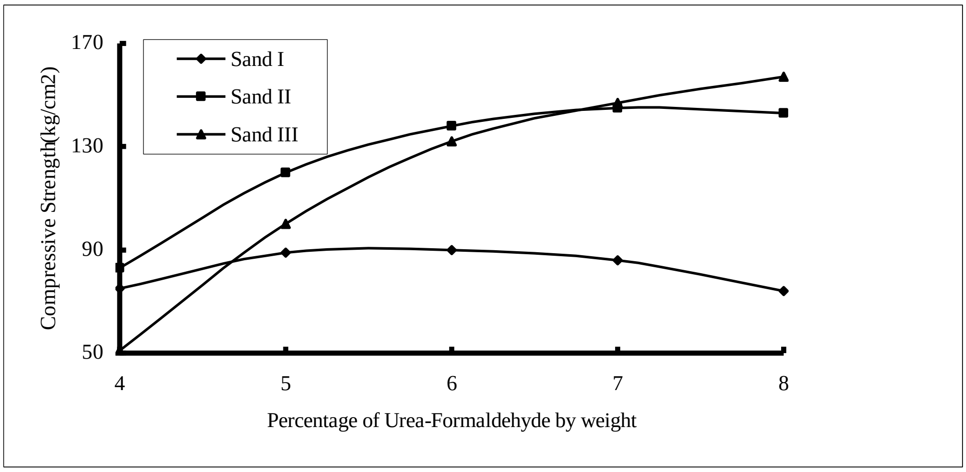

Figure 1*: Relationship between Compressive Strength (kg/cm^2) at 28 days and the Percentage of Urea-Formaldehyde (by weight) for all types of Sands.*

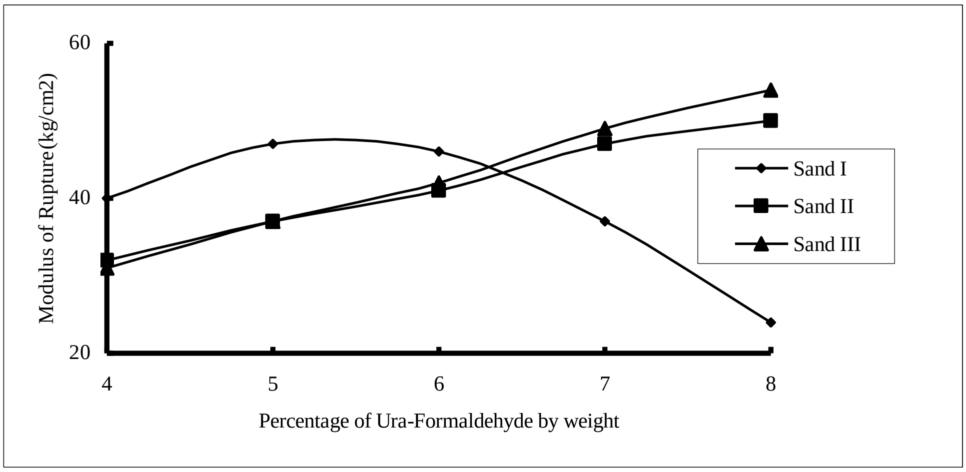

***Figure 2**: Relationship between Modulus of Rupture (kg/cm^2) at 28 days and the Percentage of Urea-Formaldehyde (by weight) for all types of Sands.*

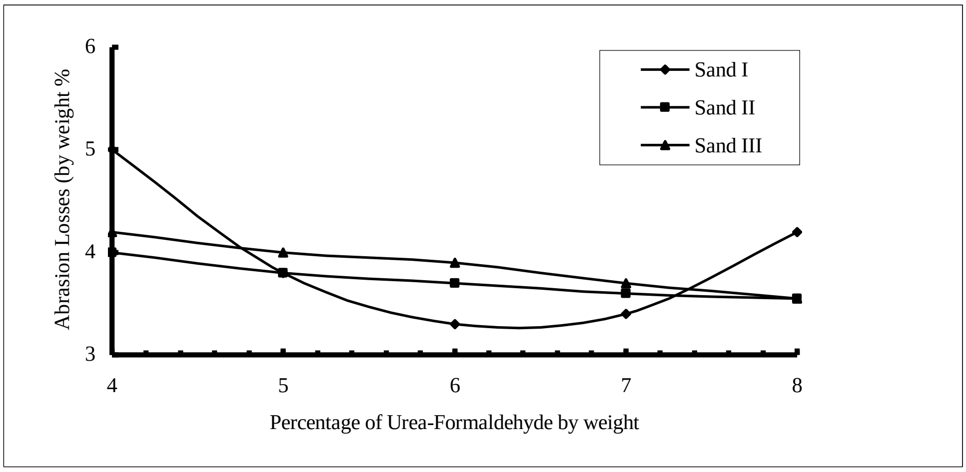

***Figure 3**: Relationship between Abrasion Losses (by weight %) at 28 days and the Percentage of Urea-Formaldehyde (by weight) for all types of Sands.*

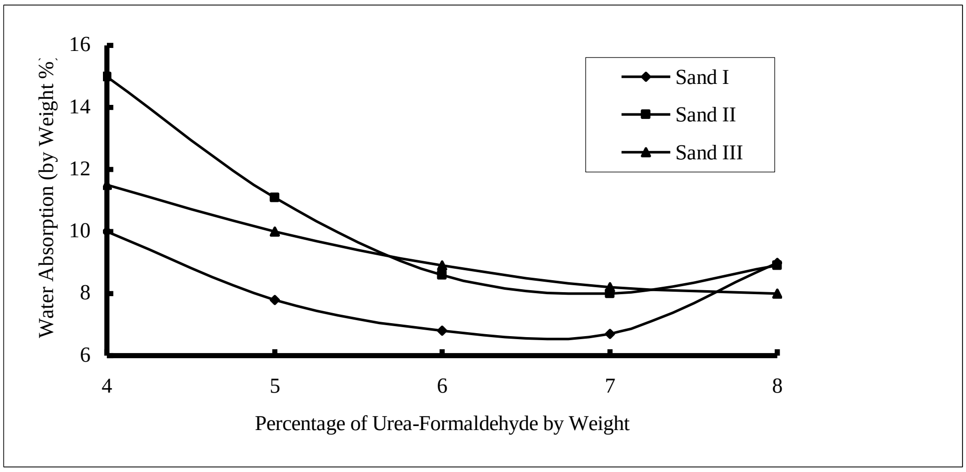

***Figure 4**: Relationship between Water Absorption (by weight %) at 28 days and the Percentage of Urea-Formaldehyde (by weight) for all types of Sands.*

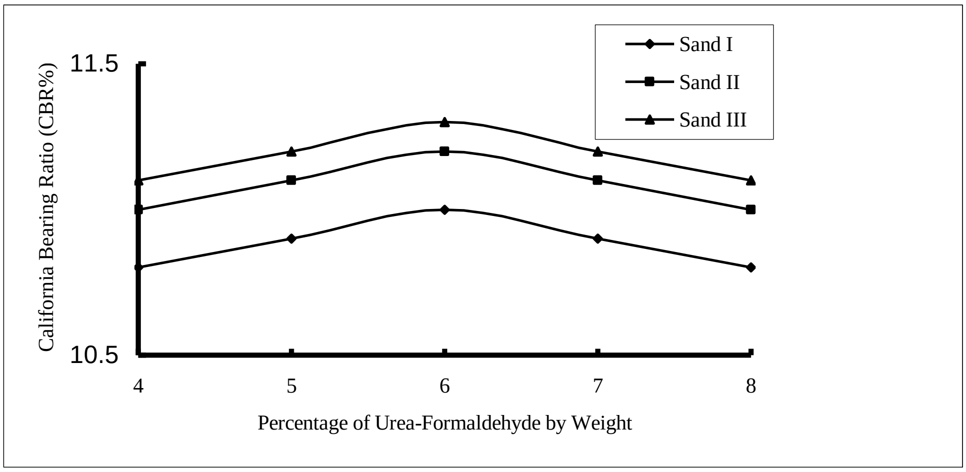

***Figure 5**: Relationship between Califorina Bearing Ratio (CBR %) at 28 days and the Percentage of Urea-Formaldehyde (by weight) for all types of Sands.*

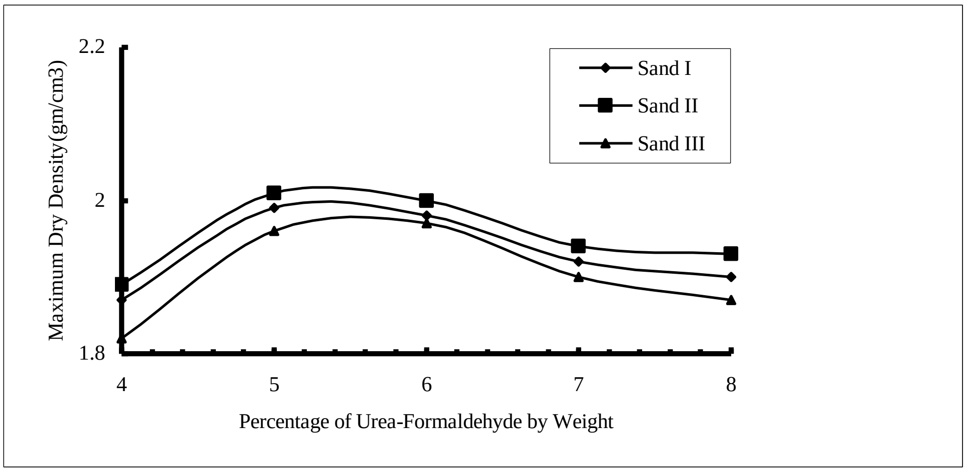

***Figure 6:** Relationship between Maximum Dry Density at 28 days (gm/cm^3) and the Percentage of Urea-Formaldehyde (by weight) for all types of Sands.*