Australian Journal of Basic and Applied Sciences, 6(5): 45-53, 2012
ISSN 1991-8178

# Modified Polyester Resin as a Constructional Material

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**Abstract:** The currently used methods of design of concrete structures depends mainly on the hypothesis that concrete can resist compression load while steel reinforcing bars should exist to resist tensile forces. This may be due to the difficulties of analyzing such composite material. The concept of relative rigidity contradicts the basic assumption mentioned above as the reinforced concrete should be treated as "concrete system" of certain geometry and materials of different moduli of elasticity. Therefore, the vital improvement from the material aspect will not be fruitful unless the design procedure expresses the actual behavior of the structural concrete elements. Assumptions based on the concept of relative rigidity should be considered. In this study we focused on a modified Polyester resin subjected to different temperatures for different durations. This study also includes a finite element analysis and a cost analysis comparison between RC slab and modified Polyester resin slab.

**Key words:** Concrete system, Geometry, Polymer, Polyester, Filler, Compressive Strength, Tensile Strength, Flexural Strength, Glass Fiber GF, Steel Fiber SF, Maturity Concept.

## INTRODUCTION

Normal concrete mix NC is distinguished by its high compressive strength and low tensile strength, which leads to the use of reinforcing materials such as steel bars, steel plates, and fiber reinforced polymer bars. Another concept was based on improving the tensile strength of the concrete mix by adding GF and SF. However, the increase in the tensile strength was still limited and the use of the reinforcing materials was still dominant. It is believed that existence of new building materials that have both high compressive and tensile strengths instantaneously is important from the design and construction points of view. Worldwide, the concept of relative rigidity has been established since 1985 to solve the defects in the assumptions of the most common used methods of design such as the ultimate strength design method USDM. Several research studies focused on using polyester to deal with this problem (Das, 1981) (Dorfman, 1977) (Davallo, 2010) (Hussein, 2005) (Grayson, 1982) and (Smith, 1960). Others focused on using glass fibers (Kliger, 1984) and (Mallick, 1979). In this study we used a modified Polyester resin mixed with sand and powder to develop a new matrix that has good compressive as well as good tensile characteristics. It should be noted that the economical considerations are also important and should be considered aside the mechanical characteristics.

### *Objectives and Scopes:*

The presented work aims at investigating the followings: Providing a construction building material that has high mechanical properties with respect to normal concrete mixes. Investigating the influence of exposing the presented mix, to different temperatures and times of exposure on the physical and mechanical characteristics. Establishing the fundamental physical and mechanical characteristics,of the presented mix. The scope of work comprises the following variables: Exposing the specimens to 20ºC, 40ºC, 60ºC, and 80ºC. Exposing the specimens to temperatures for periods 2hrs, 4hrs, 6hrs, and 8hrs. Computing the density. Carrying out the compression test, direct tension test, splitting test, and the flexural test.

### *Experimental Program:*

Charts [1] and [2] summarize the experimental program implemented in this paper. Table [1] presents the type, dimensions, and number of the specimens and Table [2] presented the contents of the mix. The tested specimens were prepared using steel molds and released from the molds after 6 hours where classified into two groups. The first group was kept at the room temperature (20ºC) for an hour and taken as reference. The second group was exposed to different time and temperature as shown in Chart [2]. Photo [1] showed the final shape of the specimens.

### *Results and Analysis:*

#### *Influence of Time of Exposure on Compressive Strength:*

Table [3] and Fig. [1] present the results of the compressive strength versus the time of exposure of cube specimens exposed to 40ºC, 60ºC, and 80ºC respectively. Increasing the time of exposure from 2 hrs to 4hrs led

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to the increase of the compressive strength from 52.81 N/mm² to 52.98 N/mm². After 2 hrs, the compressive strength decreased to reach the minimum value after 8hrs. At 60ºC, increasing the time of exposure from 2hrs to 6hrs led to the increase in the compressive strength from 53.33 N/mm² to 58.23 N/mm². After 8hrs of exposure, the compressive strength decreased to 57.87 N/mm².The results of cube specimens exposed to 80ºC showed different trend where the compressive strength decreased with the increase of the time of exposure. After 2 hrs, the compressive strength was 54.33 N/mm² after 8 hrs of exposure it decreased to 52.12 N/mm².

**Table 1:** Type and Number of specimens.

| Test | Compressive strength | Tension tests | | | Density |
|---|---|---|---|---|---|
| | | Direct | Splitting | Flexure | |
| Dimension (mm) | 50*50*50 | 150*40*10 | 50*50*50<br>150*50*50 | 500*100*25 | 50*50*50 |
| No. of Specimens | 26 | 8 | 4 | 16 | 26 |

**Table 2:** Mix design.

| Material | Polyester resin | Hardener | Accelerator | Filler | |
|---|---|---|---|---|---|
| | A | B (broxide) | Spyrene | Sand | Powder |
| Percentage (%) | 15.024 | 0.375 | 0.385 | 74.216 | 10.000 |
| Weight (Kg) | 2.28 | 0.057 | 0.058 | 11.550 | 1.520 |

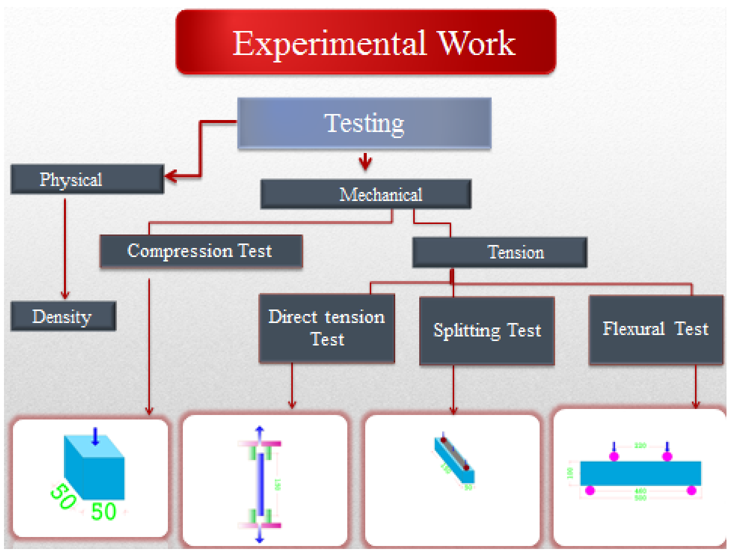


**Chart 1:** Implemented tests and specimens.

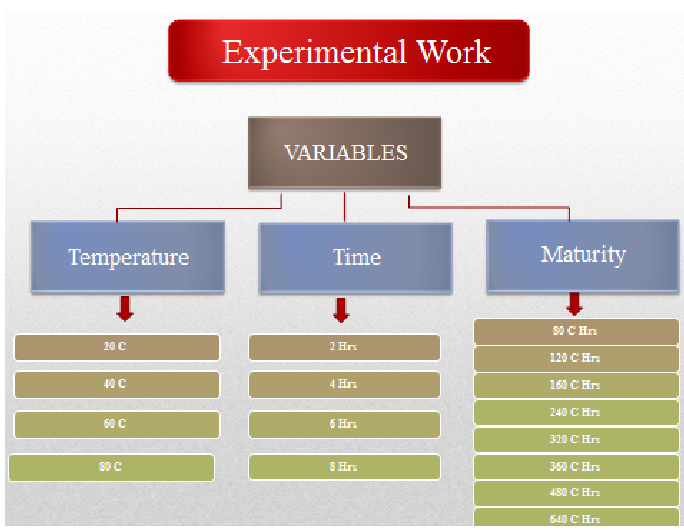


**Chart 2:** Studied variable.

**Photo 1:** The prepared specimens.

**Table 3:** Influence of time and temperature on compressive strength and density of tested specimens.

| Temperature˚C | Time of exposure | Average density (Kg.m3) | Average Comp. Strength (N/mm2) |
|---|---|---|---|
| 40 | 2 | 2012 | 52.81 |
| 40 | 4 | 1964 | 52.98 |
| 40 | 6 | 1936 | 52.78 |
| 40 | 8 | 1920 | 52.61 |
| 60 | 2 | 1960 | 53.33 |
| 60 | 4 | 1982 | 55.11 |
| 60 | 6 | 2004 | 58.23 |
| 60 | 8 | 2001 | 57.87 |
| 80 | 2 | 2001 | 54.33 |
| 80 | 4 | 1976 | 52.75 |
| 80 | 6 | 1952 | 52.23 |
| 80 | 8 | 1948 | 52.123 |

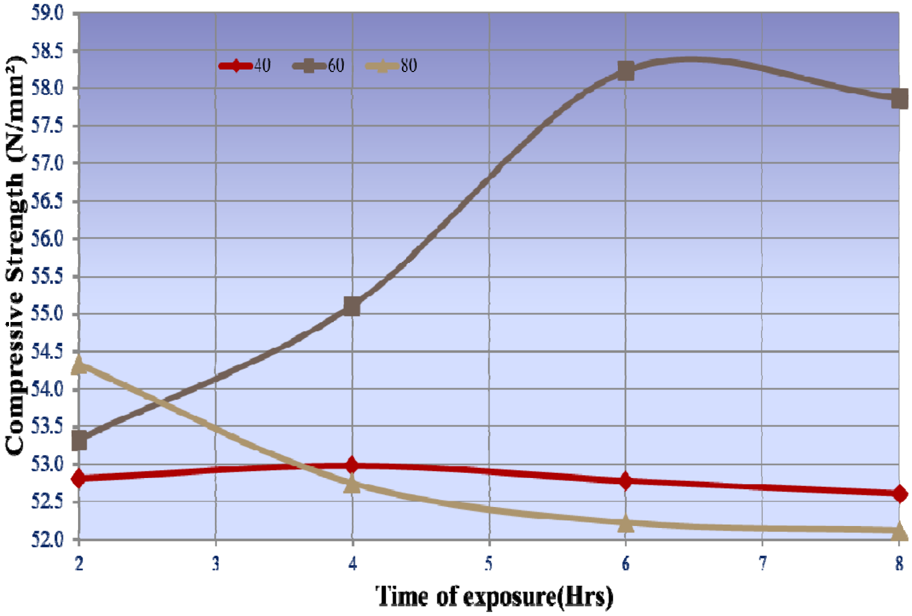


**Fig. 1:** Influence of time of exposure on compressive strength of cube specimens.

***Influence of Exposure Temperature on Compressive Strength:***

Table [3] and Fig. [2] show the influence of the exposure temperature on the compressive strength. At a time of exposure of 2hrs, 4hrs, 6hrs, and 8hrs, the compressive strength increased with the increase in the time of exposure from 40ºC to 60ºC. Increasing the temperature from 60ºC to 80ºC led to the decrease in the compressive strength. It was noted that the maximum compressive strength was obtained at 60ºC when the cube specimens were exposed to that temperature for 6 hrs to reach 53.33N/mm². Taking the compressive strength at 60C after 6 hrs as a reference, the compressive strength after 2hrs, 4hrs, and 8hrs represented 91.59%, 94.53%, and 99.38%. At 40ºC, the compressive strength ranged from 52.61N/mm² to 52.98 N/mm². At 60ºC, the compressive strength ranged from 53.33N/mm² to 58.23N/mm². At 80ºC, the compressive strength ranged from 52.12N/mm² to 54.33N/mm². It should be noted that the results indicate the optimum limits for temperature and duration for the production of the newly modified polyester resin mixed with sand and powder.

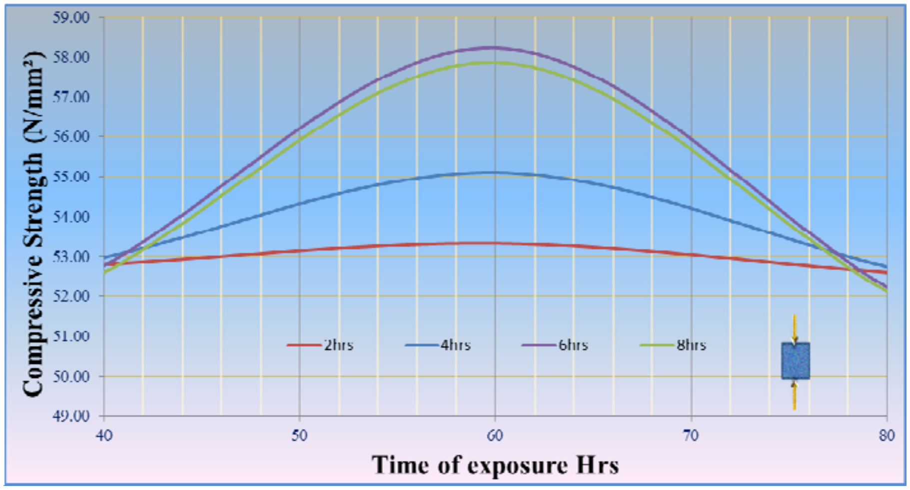


**Fig. 2:** Influence of temperature of exposure on the compressive strength of cube specimens.

***Influence of Time of Exposure on the Density:***

Table [3] shows the influence of the time and temperature of exposure on the density of the specimens. At temperatures of exposure to 40ºC and 80ºC, increasing the time of exposure led to the decrease of the density at the different times of exposure. At 40ºC, the density decreased from 2012 kg/m³ after 2hrs of exposure to 1920 kg/m³ after 8hrs of exposure period leading to a reduction in the density by4.57%. At 80ºC, the density decreased from 2001 kg/m³ to 1948 kg/m³ due to the increase of the exposure time from 2hrs to 8hrs leading to a reduction in the density by 2.65%As given in Table [3], exposing the specimens 60ºC showed a different trend. The density increased with the increase of the time of exposure from 2hrs up to 6hrs. At that interval, the density increased from 1960kg/m³ after 2hrs of curing period to 2004kg/m³ after 6hrs of curing time indicating a percentage of increase of 2.25%. The density is then slightly decreased to 2001kg/m³ after 8hrs of exposure. the percentage of decrease in the density, it was 0.15%.Relating the results of the compressive strength to the density indicated that good agreement in the general trends is existed for the cases of curing the specimens at 60ºC and 80ºC. For the case of exposing the specimens to 40ºC, good agreement of the general trend is existed after 4hrs of exposure.

***Influence of Dual Action "Maturity Concept":***

The maturity concept may be defined as the function of the product of exposure time (t) and curing temperature (T) which is based on the assumption that mixes having the same maturity will have the same strength regardless of the time and temperature leading to the maturity. The following factors should be considered the applying of this concept:

1- The function is not useful at low maturities unless the time is calculated from the point at which the mix begins to gain strength.

2- The function is applied only for thin sections to avoid the effect of heat loss as massive sections exhibited much less rate of heat loss if they are compared to normal sections.

3- The concept of maturity should be applied for the cases of small temperature variations during the curing period.

4- The method and rate of cooling after curing.

The maturity concept may be useful when trying to establish the strength of the structure at some previous time. Also, it can be used to estimate the appropriate time of form removal.

The strength gain can be related to the time-temperature product as given in Table [4] and Fig. [3].

**Table 4:** Dual action of time and temperature.

| Time.temp. (hrs.ºC) | 80 | 120 | 160 | 240 | 320 | 360 | 480 | 640 |
|---|---|---|---|---|---|---|---|---|
| Comp. strength (N/mm2) | 52.810 | 53.330 | 53.655 | 53.945 | 52.680 | 58.230 | 55.050 | 52.120 |

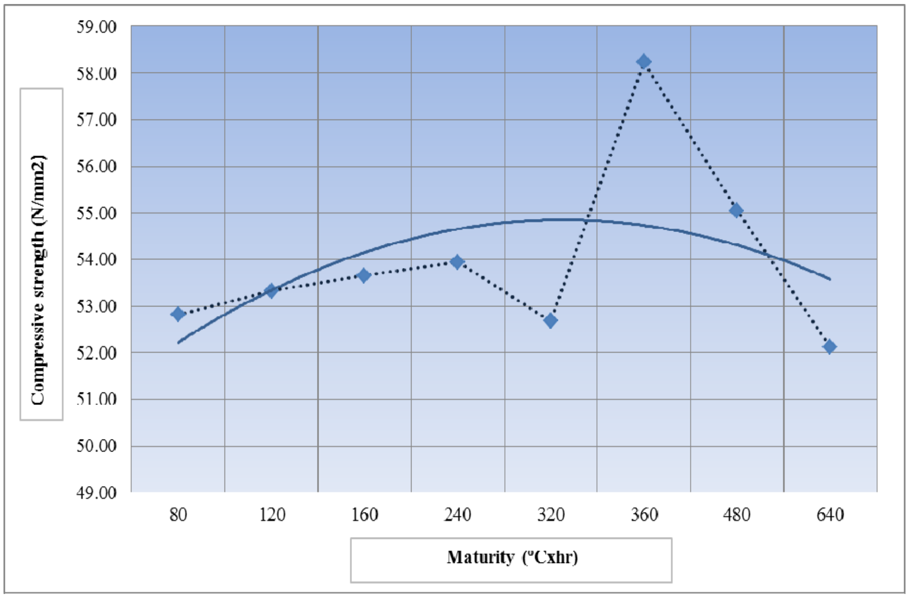


**Fig. 3:** The dual action of time and temperature T.ºC.

***Influence of Exposure Temperature on the Tensile Strength:***

The tensile strength was computed from the results of the direct tension test and the splitting test, and the flexural test using the following equations:

$$ftd = \frac{P}{a^2} forthecaseofdirecttensiontest$$

$$ftsp = \frac{2P}{\pi a^2} forthecaseofsplittingtest$$

$$ftr = 3\frac{PL}{2bh^2} forthecaseofflexuraltest$$

Where:

$ftd$: The tensile strength from the direct tension test in (N/mm²)

$ftsp$: The tensile strength from the splitting test in (N/mm²)

$ftr$: The modulus of rupture in (N/mm²)

P : The total crushing load of the two beams in (KN)

L : The distance between the support point and the loading point in (mm)

$a$: The length of the cube specimen in (mm)

$b$: The breadth of the beam in (mm)

$h$: The depth of the beam in (mm)

Table [5] and Fig. [4] show the results of the tensile strength obtained from the direct tension test. The specimens were exposed for 2hrs to 20ºC, 40ºC, 60ºC, 80ºC. Increasing the temperature from 20ºC to 60ºC led to the increase in the tensile strength from 46.20 N/mm2 to 48.36 N/mm2. At 80ºC, the tensile strength decreased to 46.09N/mm2. Results of the compressive strength and the tensile strength indicate agreement and compatibility in the general trend. The tensile strength results obtained from the splitting test method ranged from 44.60 N/mm² to 60 N/mm². The average tensile strength obtained from the splitting test represent a factor of 1.12 of that obtained from the direct tension test. The flexural test resulted in a modulus of rupture ranging between 93.80 N/mm² to 104.22 N/mm² with an average value 99 N/mm2. The modulus of rupture represents 2.0 of the direct tensile strength and 1.79 of the indirect tensile strength.

**Table 5:** Tensile strength of the tested specimens.

| Test | Stress N/mm$^2$ |
|---|---|
| Direct Tension | 46.82 |
| Splitting | 52.31 |
| Flexure | 93.79 |

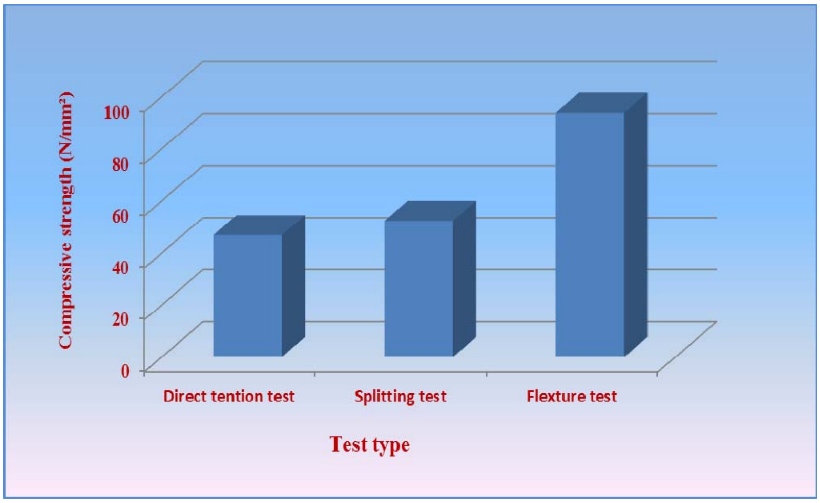


**Fig. 4:** Tensile strength of the different tension tests.

***Modes of Failure of Tested Specimens:***

Cube specimens subjected to compression load exhibited apparent shear failure. Due to loading conditions induced shear stresses decreased gradually at the mid-section of the specimen where tensile stresses were induced. In the splitting test, it was clear that the vertical section passing through the vertical load line, was subjected to lateral tensile stresses over the middle two thirds of the specimen causing the cracking of the specimen in the direction of the applied compression load. In the flexural test, the cracking occurred in the middle third of the beam where the sections were subjected to almost pure bending moment and zero shear force. The cracks initiated at bottom where tensile stresses were induced and propagated upward in the compression zone till failure took place. Photo [2] explains the different modes of failure of the tested specimens.

**Photo 2:** Modes of failure of tested specimens.

***Comparison Between RC Slab and Modified Polyester Resin Slab:***

The cost of the modified polyester resin slab was compared with RC slab covered the same area. Figs. [6] and [7] show the covered area and the proposed structural systems. The criteria of comparison were the induced bending moments and deflections under the same the design loads. Also, the cost of the materials and the construction was taken with great care. The field of application and the time required to form removal were considered because of their impact on the economical consideration. The RC slab exhibited maximum bending moment 9.0KN.m while the modified polyester resin slab exhibited maximum negative and positive bending moments of 0.35KN.m and 0.40KN.m as shown in Fig.[8]. The bending moment of the RC slab represents 22.5 times the modified polyester resin slab. The maximum deflection of the RC slab was 1.35mm while it was 3.41mm for the modified polyester resin slab. It should be noted that both values are less than the allowable limit of deflection stated in the Egyptian Code of Design and Practices of RC Structures.

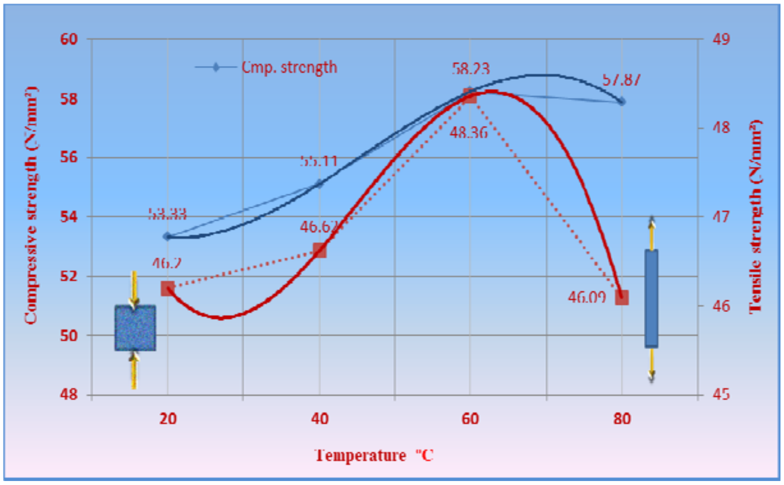


**Fig. 5:** Relating the direct tensile strength to the compressive strength.

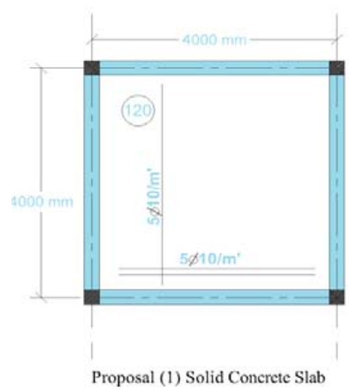


**Fig. 6:** RC concrete slab.

**Table 6:** Comparison between RC slab and modified polyester resin slab.

| NO. | Item | Structural System | |
|---|---|---|---|
| | | Reinforced Concrete Slab | Modified Polyester Resin Slab |
| 1 | Max. Deflection due to live load | 1.35 mm[Gravity] | 3.41 mm[Gravity] |
| 2 | Resultant Bending Moment-M11 | Max. Value[+ve] = 9.00 $_{KN.mm}$ | Max. Value[+ve] = 400 x$10^{-3}$ $_{KN.mm}$<br>Max. Value[-ve] = 350 x$10^{-3}$ $_{KN.mm}$ |
| 3 | Resultant Bending Moment-M22 | Max. Value[+ve] = 9.00 $_{KN.mm}$ | Max. Value[+ve] = 400 x$10^{-3}$ $_{KN.mm}$<br>Max. Value[-ve] = 350 x$10^{-3}$ $_{KN.mm}$ |
| 4 | Form removal | At least after 7 days | After 6 hors |
| 5 | Time of curing | 7 days at least | No Need |
| 6 | Total weight ( kg) | 4.8ton | 0.50t |
| 7 | Total Cost | 2448 LE | 2120 LE |

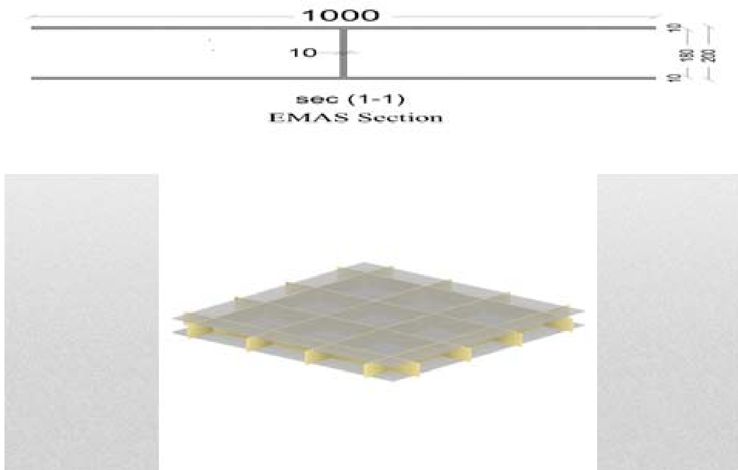


**Fig. 7:** Proposed EMAS Concrete Model.

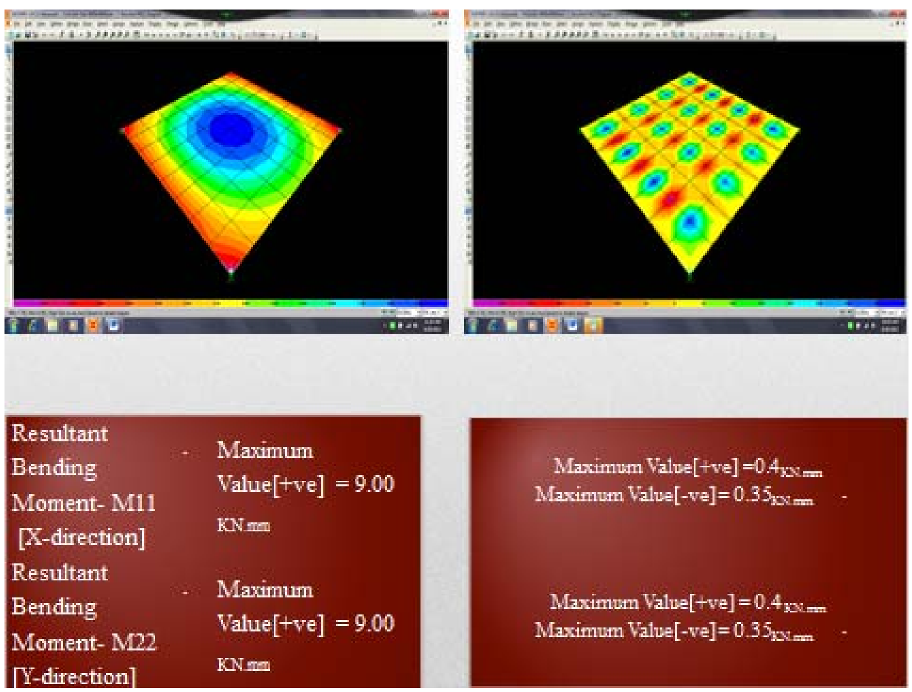


**Fig. 8:** Comparison of load carrying capacity (BM).

***Cost Analysis:***

The cost of the materials and construction for the Reinforced Concrete slab was 2448 LE . Meanwhile the cost of the materials and construction for the modified polyester resin slab was 2120LE. The weights of the RC slab and the modified polyester resin slab were 4.8 ton and 0.5 ton. The weight of the modified polyester resin slab represents10.4% of the RC slab which reflects the impact of using the modified polyester resin in the field of adding more floors on existing structures and solving the problem of soils of low net bearing capacity.

***Conclusions:***

The research work presented here led to the following remarks:

1- The modified polyester resin represents an approach to the materials that have significantly high tensile strength if it is compared to the normal concrete mixes.

2- The tensile strength of the direct tension test ranges from 46.2 N/mm2 to 48.36 N/mm2.

3- The tensile strength of the flexural test ranges from 93.80 N/mm2 to 104.22 N/mm2.

4- The ultimate compressive and tensile strengths are gained within 6 hours from casting.

5- The maximum compressive and tensile strengths are obtained when the modified polyester resin specimens cured at 60ºC for 4 hours.
6- The dual action of time and temperature can be used to obtain better mechanical characteristics.
7- The cube specimens exhibited shear failure when subjected to compression load and the beams exhibited tension failure when subjected to flexural load. Both the modes of failure are similar to that obtained for the case of normal concrete mixes.

***Recommendations:***

The aim of this study was to investigate the fundamental mechanical properties, (compressive strength, the tensile strength, and the flexural strength) . The dual action of time and temperature was considered. However, the research program should be extended to include the following:
1-Evaluation the shear strength, modulus of elasticity, Poisson's ratio, and the shear modulus.
2- Evaluation of the creep and fatigue of the modified polyester resin.
3- Implement a testing program on large scale models to examine actual structural behavior of the members.

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