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ANALYTICAL AND EXPERIMENTAL STUDY ON SURFACE TREATMENT FOR REINFORCED NORMAL CONCRETE

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Abstract: Applying some material such as Flunkout or sodium silicate on concrete surface has a great effect in enhancing the strength of concrete and eliminate the damage resulted from exposure to aggressive environments. Besides, it's extended the service life of concrete. This research present a study on the effect of (Flunkout and sodium silicate) on the flexural behavior of 24 reinforced concrete beams with dimensions (100*100*900mm). Several variables were studied such as the type of surface treatment (Flunkout and sodium silicate), the method of curing (air and water curing) and the age of testing (30, 90, 180, and270days). In addition, the test result was compared with the normal specimens (without surface treatment). The test results showed that, by using surface treatment there is a noticeable enhancement in the concrete strength, also surface treatment affect mode of failure. In the second part of this study, an analytical study was done by using ANSYS (R.15). It was concluded that the results obtained from ANSYS models were underestimate the result of the study beams, however the maximum discrepancy in central deflection is found to be approximately (15.9%).

Keywords: *Surface Treatment, Sodium silicate, Flunkout, Flexural strength, normal reinforced concrete beams, finite element analysis*

دراسة تحليلية و تجريبية للمعالجات السطحية للخرسانية الاعتيادية المسلحة

الخلاصة: تطبيق بعض المواد مثل الفلانكوت او سليكات الصوديوم له تاثير كبير في تعزيز مقاومة الخرسانة و الحد من الضرر الناجم من التعرض لبيئات قاسية. الى جانب ذلك تحسين العمر الخدمي للخرسانة. يقدم هذا البحث دراسة عن تاثير المعالجات السطحية(الفلانكوت و سليكات الصوديوم) على سلوك القص لاربعة وعشرون عتبة خرسانية مسلحة بابعاد (100*100*900ملم). تمت دراسة العديد من المتغيرات مثل نوع المعالجة السطحية (الفلانكوت و سليكات الصوديوم) و طريقة المعالجة (المعالجة بالهواء و الماء) و عمر الفحص (30، 90، 180و270 يوما). الى جانب ذلك، تمت مقارنة النتائج مع عينات مرجعية(بدون معالجة سطح). اظهرت نتائج الاختبارات ان استخدام المعالجة السطحية يظهر تحسن ملحوظ في قوة الخرسانة، كما ان المعالجة السطحية تؤثر على نمط الفشل. في الجزء الثاني من هذه الدراسة، اجريت دراسة تحليلية باستخدام ANSYS(R.15) من خلال تحليل النماذج باستخدام برنامج ANSYS وجد ان الحمل الاقصى للنماذج اقل من الحمل الاقصى للعتبات المفحوصة عمليا، الى جانب ذلك ان مقدار التغير الاقصى في الهطول تقريبا (15,9%)

1. Introduction

Concrete structures may be affected by different chemical or physical processes of deterioration[1]. For this purpose, large resources are usually used for the rehabilitation

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of degraded structure. In this case the cost of repair is sometimes higher than the original investment. Therefore, it is recommended preventive measures [2] to avert unseasonable deterioration of new concrete structures . Several ways can be used to offer surface treatments for concrete elements [3] such as physical form (penetrating sealer, barrier coatings that form a thin surface film, or membrane), chemical composition (silane, siloxane , epoxy, or cementitious), mechanism (hydrophobic pore lining, or barrier coating) and function (aesthetic, or barrier to gas penetration).

The performance of surface treatment have been discussed by different researchers . Ghoddousi. et al[4] evaluated the performance of surface treatment on concrete quality . Four different coating types were used (polyurethane, epoxy, epoxy/coal tar and silane/siloxane) as surface treatment to four different concrete mixtures with (w/c) ratio of (0.4 and 0.1) with and without silica fume.The main aspects studied were corrosion potential, sulfate resistance, corrosion damage, and heat-cool cycles. The results showed that, the effectiveness of surface treatment materials improve the concrete quality. Franzoni, et al[5] studied the effectiveness of using ethyl silicate, as a surface treatment for concrete and compared with other inorganic products such as sodium silicate in terms of water absorption rate, microstructure and morphology. The results showed that ethyl silicate is the most efficient protection treatment for reinforced concrete structures among the products investigated. Pigino. et al[6] used ethyl silicate as a surface treatment for concrete structures. The results indicated that, using ethyl silicate, on the surface of concrete made with w/c (0.45 and 0.65), was able to penetrate up to a depth of about 3–5 mm in concrete and that result in a significant reduction in sorptivity of water, despite the low quantity of absorbed product , as well as reductions of carbonation depth and chloride migration depth on the same samples.

liu et al [7] assesses the behavior of concrete coated with a silicone-based material. Studies were conducted to evaluate the rate of carbonation, resistance to chloride penetration, and water permeability of concrete when treated with silicone coatings. The results indicate that the water absorption, chloride ion, and carbonation resistance of concrete with a silane coating were greatly improved when compared to concrete coated with the acrylic coating used in this study and uncoated concrete.

2. Research Significant

The aim of this article is to study the effect of surface coatings on the properties of concrete and the behavior of coated beams under the influence of external loads. On the other hand, this research presents a parametric study on variables which are not incorporated in the experimental work by using ANSYS program.

3. Materials

The concrete mixtures were proportioned on a weight basis. The following parameters were kept constant in all the mixtures:

1. Cement content: 300 kg/m^3. The cement was tested and checked according to ASTM C 150[8]

2. Coarse aggregate =1088 kg/m^3. The maximum size of the coarse aggregates was 19mm. The material was tested and checked according to ASTM C 33[9].
3. fine aggregate =783. kg/m^3. The material was tested and checked according to ASTM C 33[9].
4. Effective water to cement materials ratio was 0.47.
5. The main reinforcement consisted of (1Ø12) used as minimum steel reinforcement with cover of 19mm. To prevent shear failure, transverse reinforcement (stirrups) of Ø 4mm was provided. Both longitudinal and transverse steel reinforcement were designed according to ACI 318-M95 [10]. As shown in Fig. (1)

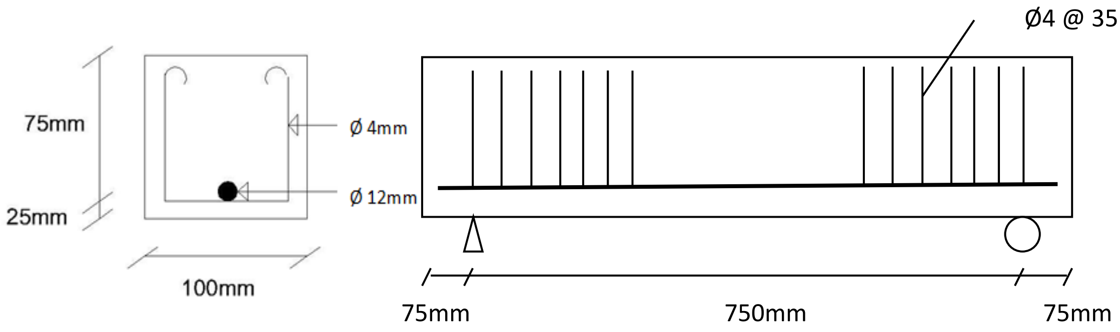


Figure 1. Reinforcement Details

3. Surface Coating

Surface coating forms a continuous film which acts as a physical barrier to prevent substances penetrating into cementitious substrate. Sodium silicate or flunkout surface treatment help to eliminate the porosity in most masonry products like concrete, plasters and stucco. The excess $Ca(OH)_2$ (Portlandite) which is presented in concrete is permanently binds the silicates with the surface and this make concrete more durable and water repellent. Generally, this treatment was applied after demolding the specimens. In the present work, a dense film with total thickness of about 1 mm was applied on the concrete surface.

4. Test Variables and Specimens Categories

The specimens were demolded after 24 hours of casting. The specimens were divided into three groups. Each group consists of eight beams, cured in water or air till the time of testing (after 30, 90, 180 and 270 days). The first group consists of normal beams without coating treatment while the second and third groups consist of the specimens that were coated with (sodium silicate or flunkout), respectively. Table (1) shows the characteristics of the studied beams. From Table (1), it can be concluded that the compressive strength of concrete increased with increasing the age of the specimen. Also, the use of surface treatment has a significant effect in enhancing the compressive strength of concrete. On the other hand, the compressive strength of the specimens which cured in water was higher than that specimens cured at air. All beams were tested under two point loads, the dial gage was placed at the mid span of the bottom surface. The beam was considered to reach failure when it showed a drop in loading with increasing in the value of deformation. Fig.(2) shows details of testing setup.

Table 1. The Characteristics of the Studied Specimens

Labeling	N-W-30	N-W-90	N-W-180	N-W-270	N-A-30	N-A-90	N-A-180	N-A-270	S-W-30	S-W-90	S-W-180	S-W-270	S-A-30	S-A-90	S-A-180	S-A-270	F-W-30	F-W-90	F-W-180	F-W-270	F-A-30	F-A-90	F-A-180	F-A-270
Type of loading	-	-	-	-	-	-	-	-	S	S	S	S	S	S	S	S	F	F	F	F	F	F	F	F
Type of curing	W	W	W	W	A	A	A	A	W	W	W	W	A	A	A	A	W	W	W	W	A	A	A	A
Age at test days	30	90	180	270	30	90	180	270	30	90	180	270	30	90	180	270	30	90	180	270	30	90	180	270
Compressive strength MPa	25.5	27	28.5	28	23.2	24	24.5	25	32	33	34	34.5	30	32.2	33	33	30.5	31	32	32	28	29	29.5	29

Where : F : Flunkout , A : Air curing and W: Water curing

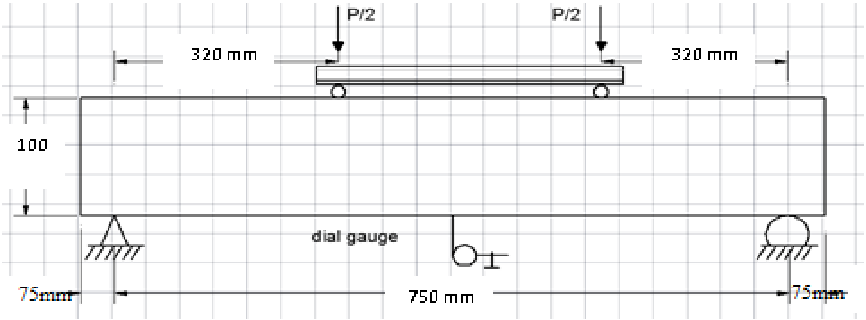


Figure 2. Details of Testing Setup

5. Custom Title Results and Discussion

5.1. Effect of Type of Curing on Ultimate Load

Fig. (3) shows the strength gain or loss of concrete beams with age for different types of curing. It was noticed that there was an increase in ultimate load for specimens cured in water at all ages with different level compared with specimens cured in air. In the case of air curing, due to the decreases in the internal relative humidity of the paste, this will cause self-desiccation (dry out) of the cement paste if no external water is provided. The paste can be self-desiccated to a level where hydration stops. This may affect the desired properties of concrete, especially the strength of the concrete. Also, it was noticed that there is a noticeable increase in ultimate load in specimens coated with sodium silicate or flunkout compared with specimens without coating.

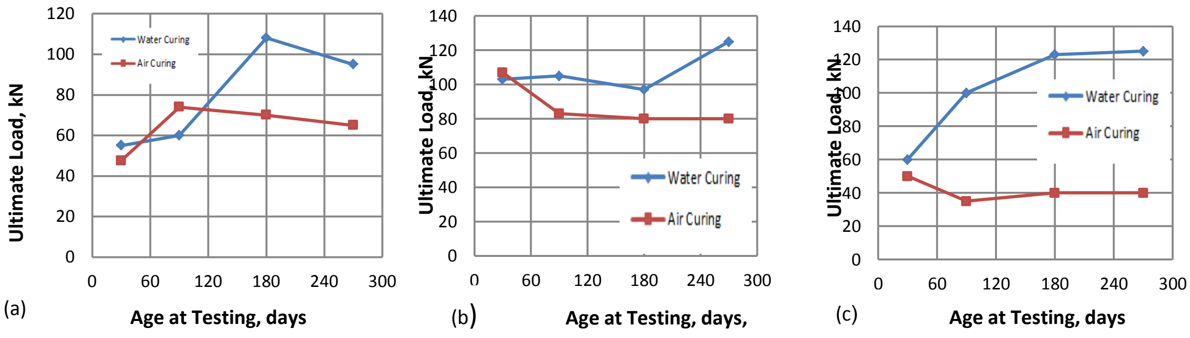


Figure 3. Ultimate Load for Different Type of Curing for (a) Beams without Surface Treatment, (b) Beams Coated with Sodium Silicate and (c) Beams Coated with Flunkout

5.2. Effect of Type of Curing on Ultimate Deflection

As shown in Fig. (4), for air curing a significant increase in ultimate deflection after 270 days of curing was noticed in specimens without surface treatment, this may be due to the effect of self-desiccation of the cement paste which may cause more cracks and voids while a significant reduction in ultimate deflection was noticed in specimens coated by sodium silicate or flunkout. This indicates that the use of surface treatment has an important role in enhancing the performance of concrete. On the other hand, in the case of water curing it was noticed that the use of sodium silicate enhanced the performance of beams compared with specimens without coating and specimens coated with flunkout.

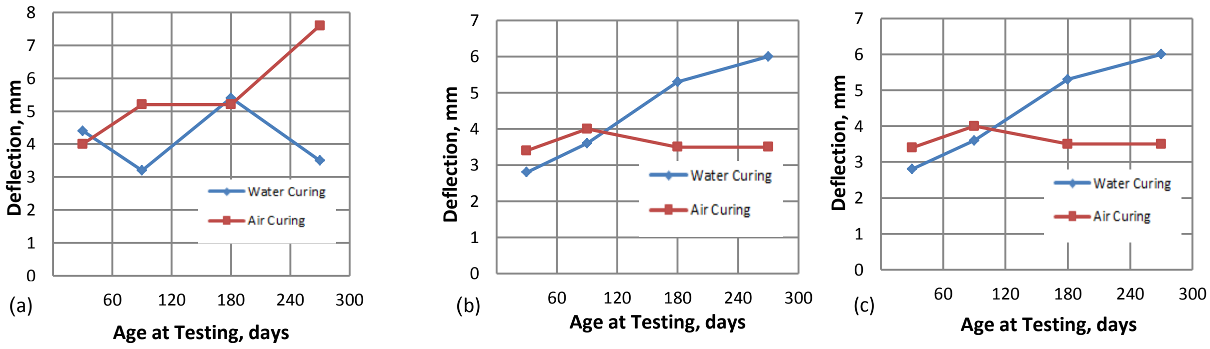


Figure 4. Ultimate Deflection for Different Type of Curing for (a) Beams without Surface Treatment, (b) Beams Coated with Sodium Silicate and (c) Beams Coated with Flunkout.

5.3. Effect of Surface Treatment on Ultimate Load

As shown in Fig. (5), the use of sodium silicate as a surface treatment enhance the strength of the beams because its delay the evaporation of water from the paste and this process will cause a continues hydration of cement paste. On the other hand, after 90 days of curing, a significant reduction in strength for flunkout treatment is noticed compared with normal beams without coating

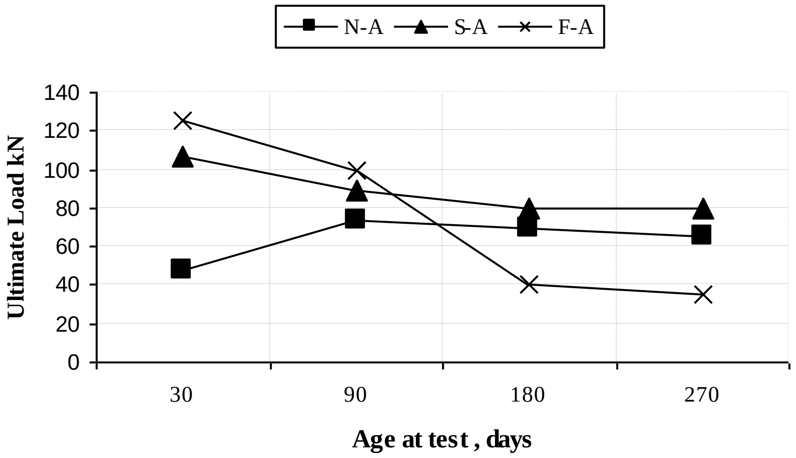


Figure 5. Ultimate Load for Different Type of Surface Treatment

5.4. Load-Deflection Relationships

Vertical deflection was measured at one point on the tension face of the beam by using (0.01 mm) dial gauge, the readings from this gage were recorded for each load increment of (5 kN). The last reading of deflection was always taken before the last load increment which causes the failure. The load-deflection response of the beams is shown in Fig. (6). The slope of the curve at the beginning are almost identical for all beams as it depends on the stiffness of the beam, arrangement of supports and type of load. Also, for all beams, the first crack appears approximately at the same load level. After the formation of first crack, the deflection increases until failure associated with an increase in the number of cracks. Also, it was noticed that the deflection in specimens cured at air is higher than that cured in water at the same load level. This may be due to the loss of beam stiffness which results from the early initiation of cracks in between pores of concrete, the increase in porosity results from self-desiccation of the cement paste. On the other hand, the deflection in normal specimens (without surface treatment) is higher than that in specimens treated by sodium silicate or flunkout at the same load level. This mean that using surface treatment has a significant role in enhancing the behavior of concrete beams.

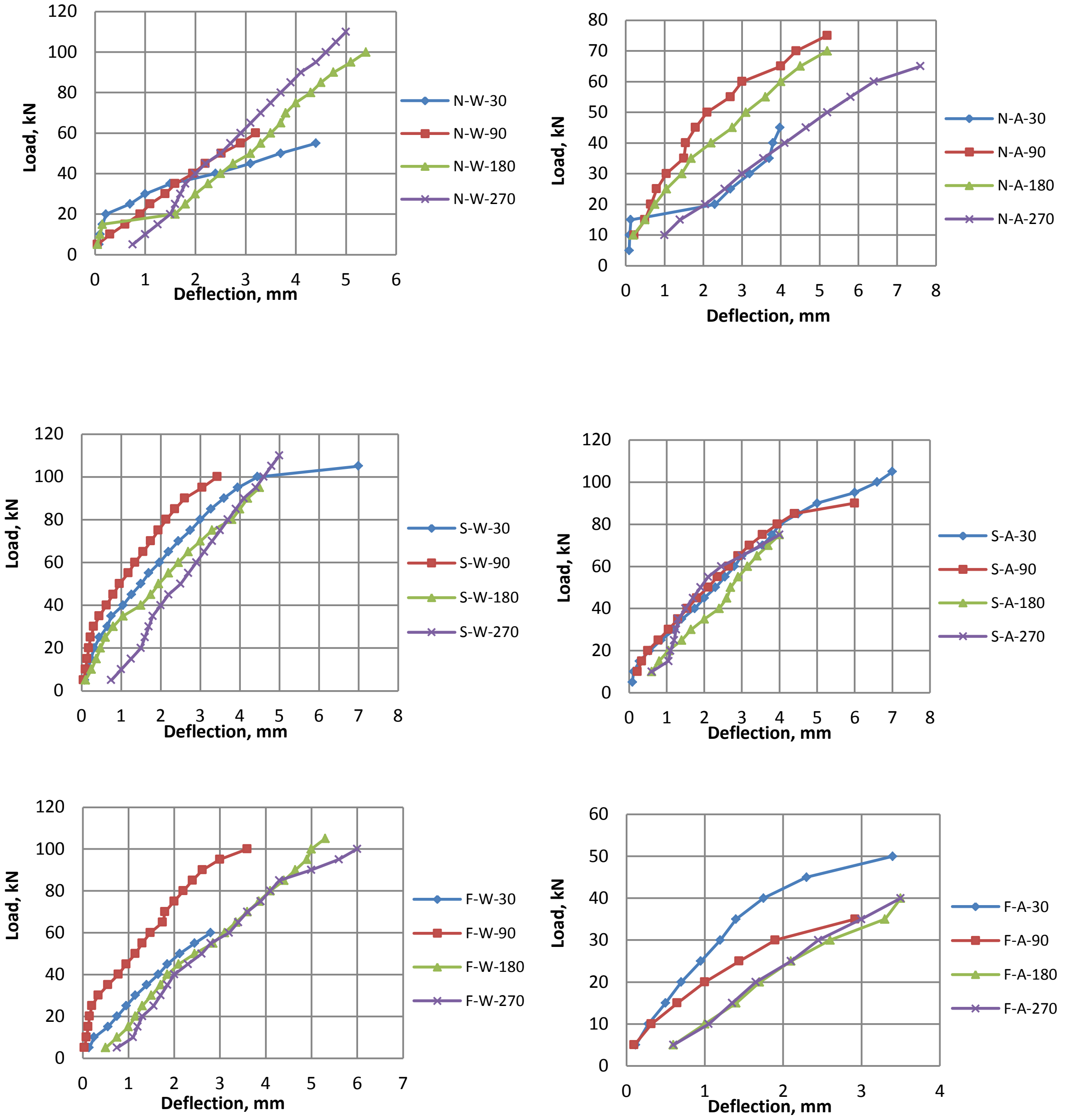
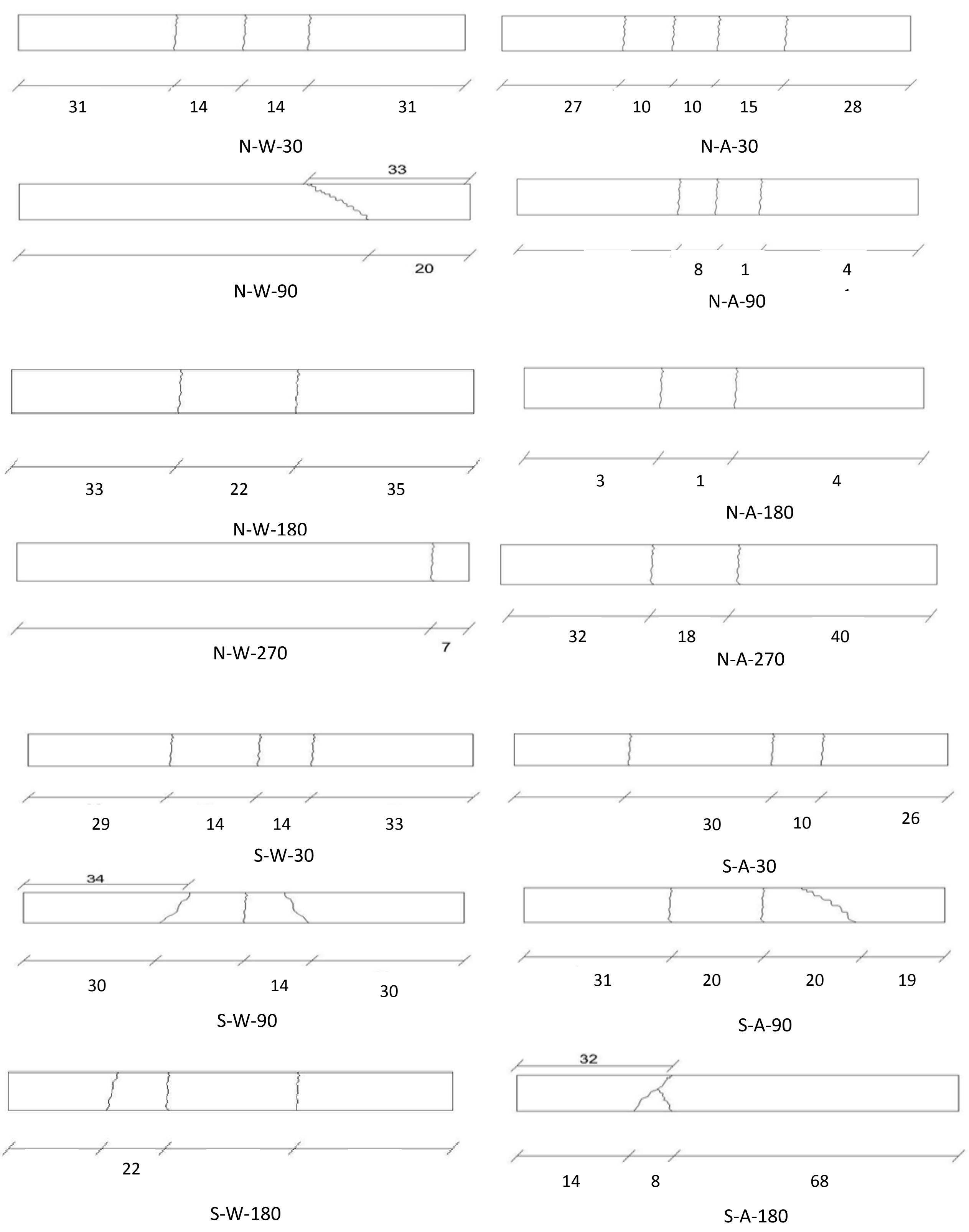


Figure 6. Load-Deflection Relationships of the Specimens Type of Surface Treatment

5.5. Crack Pattern

Fig. (7) shows the sketch of the specimens in order to present a brief description about the crack pattern for each beam. It was noticed that, in normal beams (without coating) which were cured in water, the number of cracks are less than that cured at air. This may be due to the reduction in strength in beams cured at air while there was no difference in the mode of failure for the treated specimens which were cured in water or at air. Also, by using surface treatment, it was noticed that the number of cracks reduced especially in specimens treated by sodium silicate compared with normal specimens (without coating).



N-W-30 N-A-30

N-W-90 N-A-90

N-W-180 N-A-180

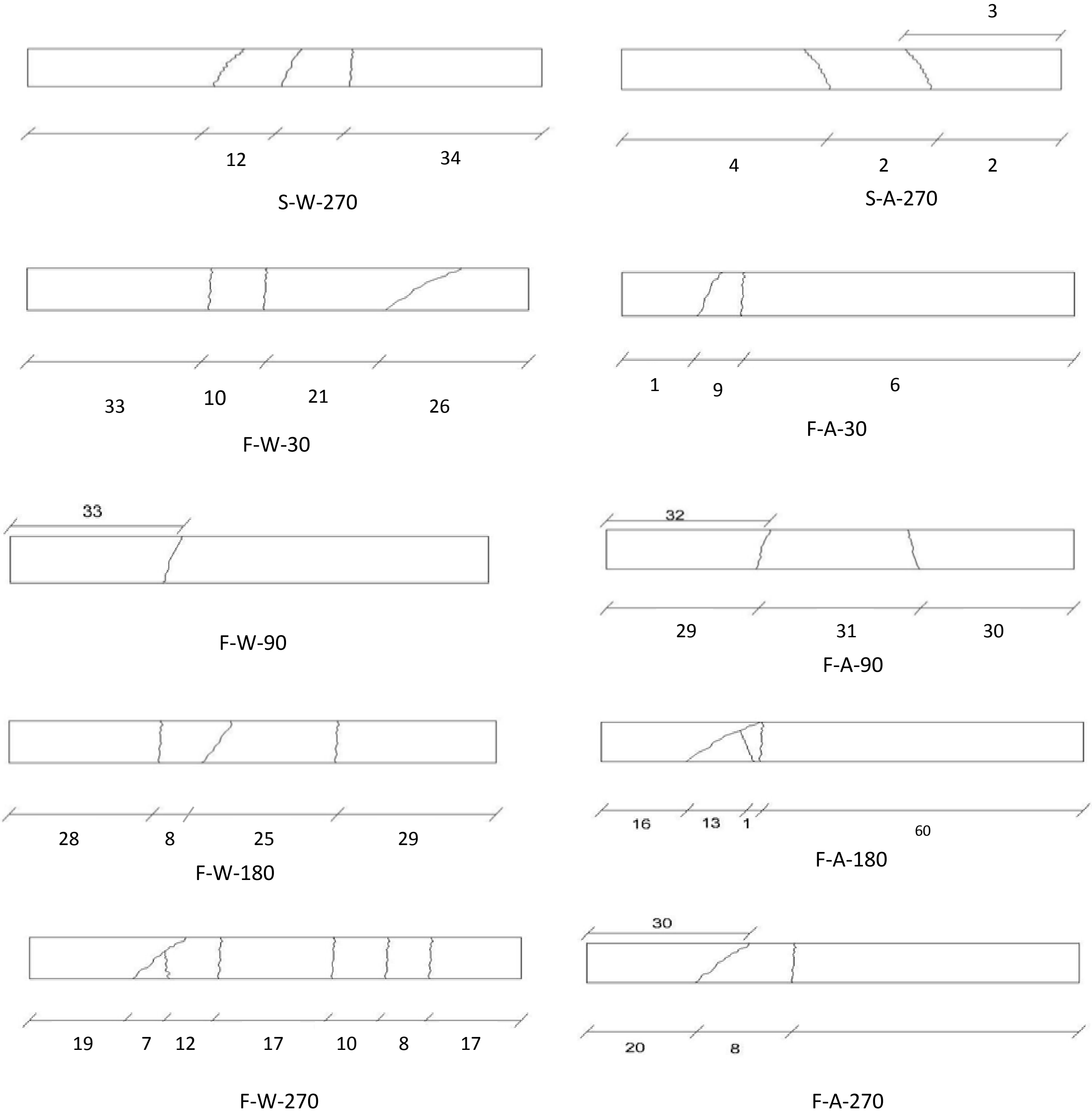
N-W-270 N-A-270

S-W-30 S-A-30

S-W-90 S-A-90

S-W-180 S-A-180

Figure 7 Crack Pattern for the Specimens, all dimensions are in cm.



S-W-270 S-A-270

F-W-30 F-A-30

F-W-90 F-A-90

F-W-180 F-A-180

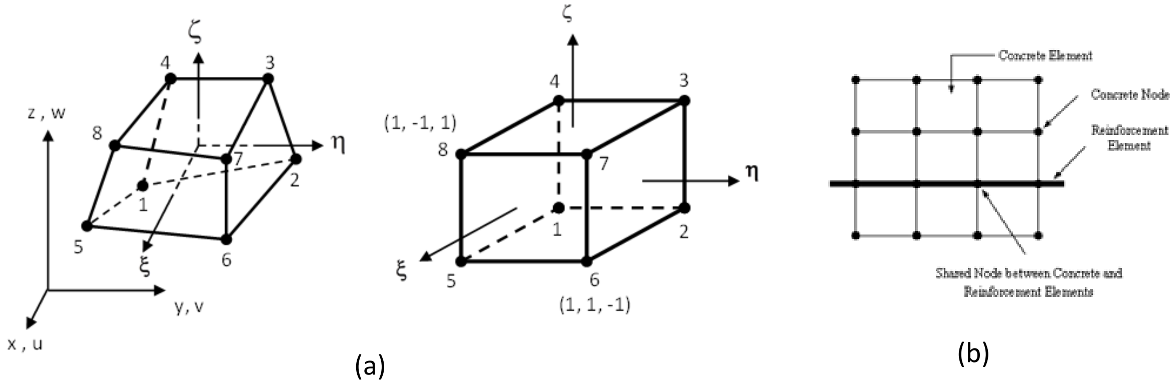
F-W-270 F-A-270

Fig. (7)- Continued.

5.6. Finite Element Formulation

Numerical methods such as the finite element and finite difference have been used to achieve approximate solutions for analysis of concrete structures in a much more realistic way [11, 12]. In this study and in the first part of this section some of the specimens were modeled and analyzed using ANSYS computer program (R.15) in order to show the agreement between experimental work and analytical analysis. While in the second part of this section, a parametric study on two factors was presented which are not studied in the experimental work. The first factor is the steel reinforcement ratio and the second factor represents the use of one point load test. The results are compared with experimental results including the ultimate load, ultimate deflection and crack pattern.

The finite element idealization of reinforced concrete members should be able to represent the concrete crushing, the concrete cracking, the capability of concrete to transfer shear after cracking by aggregate interlock and the interaction between concrete and reinforcement[13]. In this study, three-dimensional brick element with 8 nodes was used to model the concrete elements which named as (SOLID-65) in ANSYS. This element has 8 corner nodes, each node with three degrees of freedom (u, v and w in x, y and z direction respectively). The element is proficient in cracking in three orthogonal directions, plastic deformation and crushing[14]. Fig. (8-a) shows the geometry of this element. On the other hand, the steel reinforcements were represented by using 2-node element named as (LINK-180) in ANSYS. This element has the same properties of 8-node brick elements. It was assumed that the reinforcement is effective in transmitting axial forces only, and good bond is assumed between the concrete and the reinforcing bars. In order to provide the good bond**,** concrete and the reinforcing bar must share the same nodes, so the link element for the steel reinforcing bar was connected between nodes of each adjacent solid element of concrete. As shown in Fig. (8-b). Besides, the support was represented by using three dimensional brick element with 8-node (Solid-185 in ANSYS).



(a) (b)

Figure 8. (a) Three Dimensional 8-node Brick Element, (b) Modeling of Reinforcement white figure without shading or frame[14].

5.7. Tables Modeling and Meshing of the Modeled Specimens

Figs. (9-a,b) shows the modeling of the studied beams. After specifying the volumes and the reinforcement, finite element analysis requires meshing of the model. Before meshing, all the lines are divided into segments of (25mm) length. At first, the mesh of the reinforcement is done by using mesh lines. In order to gain considerable results from SOLID65 element, the use of a rectangular mesh with hexahedron (brick) volume is recommended. Therefore, the mesh is set up such that square or rectangular elements are created as shown in Fig. (9-c).

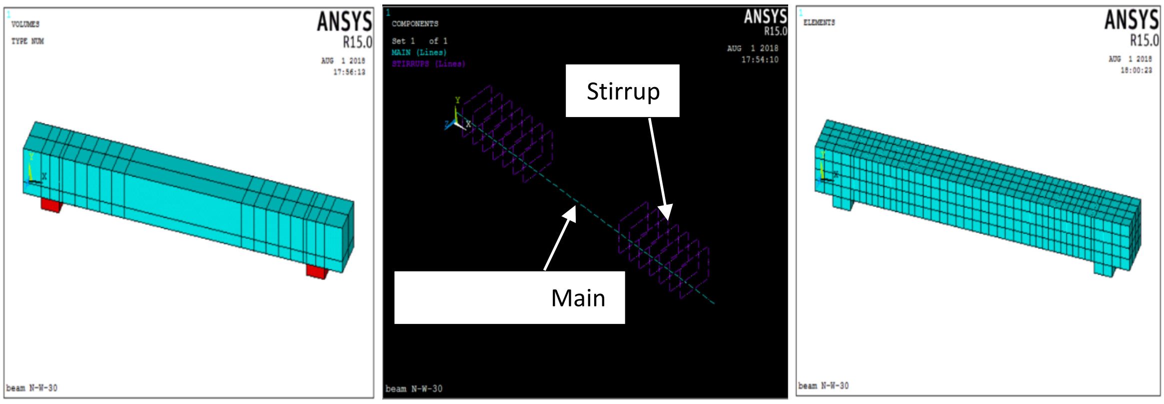


Figure 9. (a) Modeling of Whole Beam, (b) Modeling of Reinforcement, (c) Meshing of the Beam.

5.8. Loads and Boundary Conditions

The boundary conditions need to be applied at points where the supports and loadings exist and positioned it in the same locations as done in the experimental work. For displacement boundary condition, the beam was modeled to be simply supported. For external loads, the load was applied in the same way as in experimental work see Fig. (10).

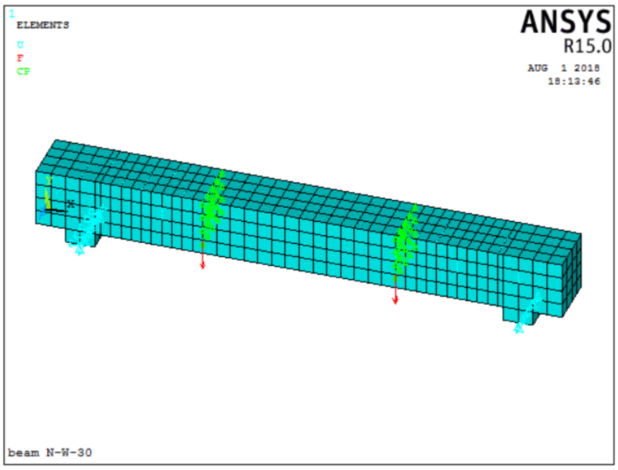


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Figure 10. Load and Displacement Boundary Conditions

5.9. Analysis Results

In this study, three specimens (N-W-30, S-W-30, F-W-30) were modeled to compare the analytical results with the experimental results. In each model, the load is applied in steps as done in experimental work, the models failed at ultimate load. The ultimate load for the finite element model is taken from the last applied load step before the solution diverge due to numerous cracks and large deflections. Table (2) shows comparison in the ultimate load and central deflection between the experimental beams and the finite element models.

Table 2. Comparison of Experimental and Analytical

Beam	Ultimate Load (kN)			Ultimate Deflection at Center (mm)		
	Experimental	Error %	ANSYS	Error %	ANSYS	Experimental
N-W-30	55	8.9	50.1	11.4	4.9	4.4
S-W-30	103	4.6	98.3	15.9	7.3	6.3
F-W-30	60	8.8	54.7	10.7	3.1	2.8

From Table (2), it was concluded that the ANSYS results were underestimate the results of the tested beams, as anticipated. One explanation is that the interlocking between the cracked faces and grain bridging process may slightly cause the extension of the failures of the experimental beams before the final collapse. As it's known, these mechanisms do not exist in the finite element models. As a result, this can help in production of the higher ultimate loads of the experimental beams. Besides, the perfectly plastic stress-strain relationship for the concrete after the ultimate compressive stress might also cause the lower failure load in the finite element models. However, the maximum error in central deflection is found to be approximately (15.9 %). These values can be acceptable and this is because the ANSYS software that consider full interaction between steel rebar and concrete materials, this assumption may not be true in experimental work. Fig. (11) shows the deflected shape of the modeled beams.

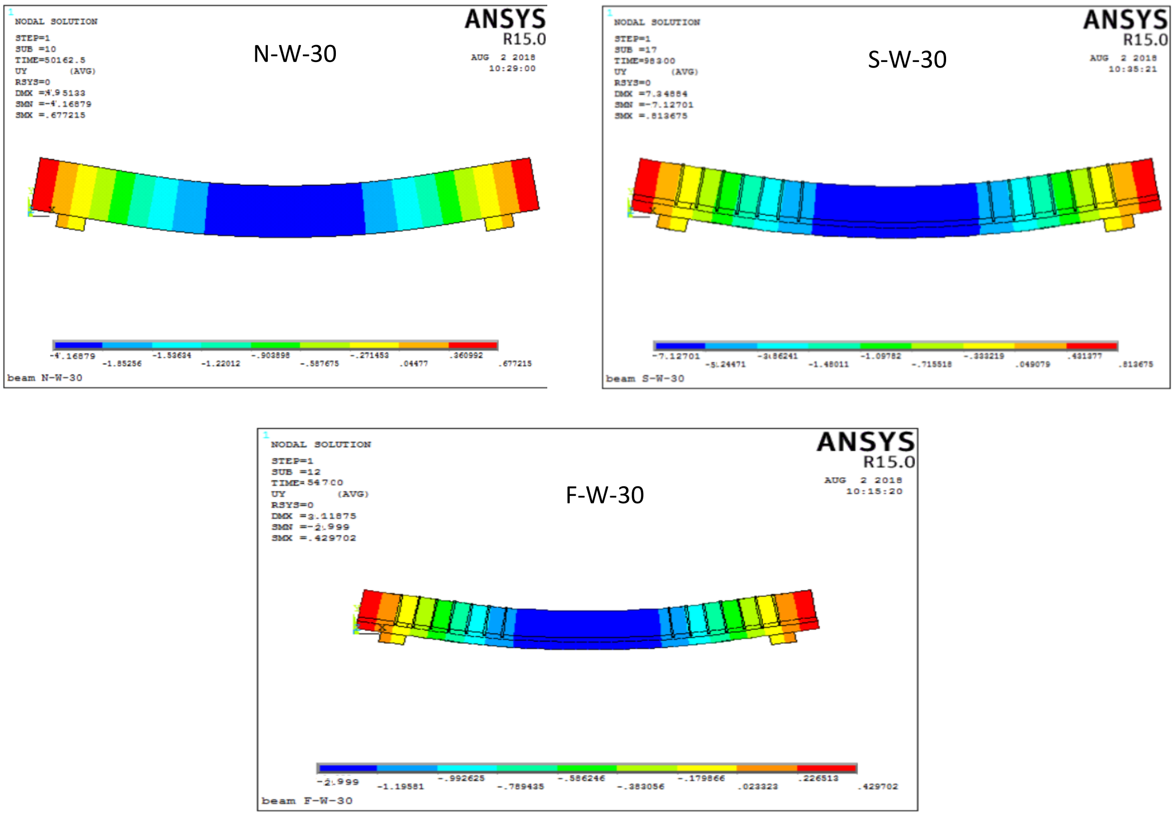


Figure 11. Deflected Shape of the Modeled Specimens at Ultimate Load .

Besides, the ANSYS program records a crack pattern at each applied load step. The cracking sign represented by a circle which appears when the principal tensile stress becomes higher than the ultimate tensile strength of the concrete. The first crack is shown with a red circle outline, while the second crack with a green outline, and the third crack with a blue outline. Fig. (12) shows the crack pattern of the modeled specimens.

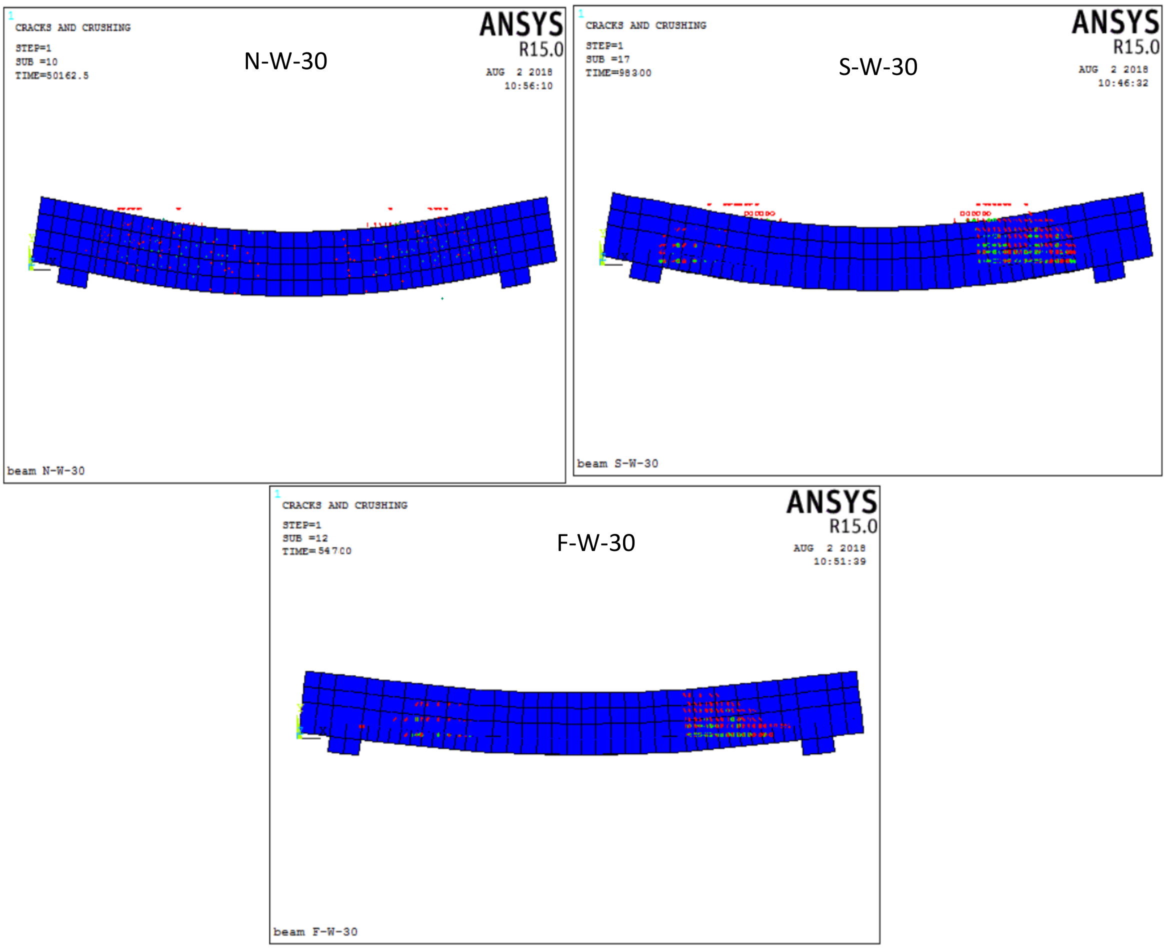
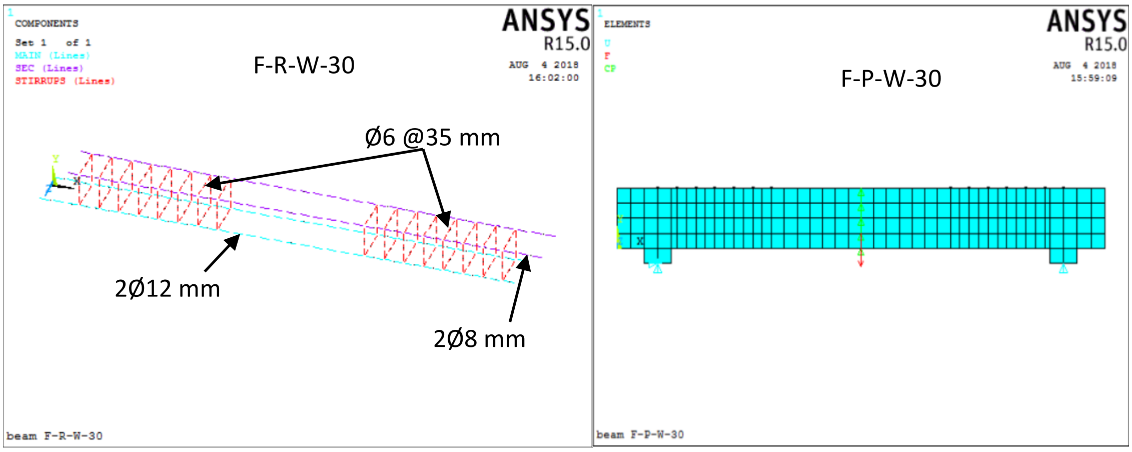


Figure 12. The crack pattern of the modeled specimens

5.10. Parametric Studies

The parametric studies were done about two factors classified in two parts. The first part represents models with higher steel reinforcement ratio compared with the experimental beams. The section reinforced with 2Ø12mm as tension reinforcement and 2Ø8mm as compression reinforcement with stirrups of Ø6@35mm as shown in Fig. (13-a), the dimensions and the characteristics of the first part models are similar to the dimensions and characteristics of experimental beams. The models of the first part labeled as (N-R-W-30, S-R-W-30 and F-R-W-30). While the second part represents the models (N-P-W-30, S-P-W-30 and F-P-W-30) with one point load at test, see Fig. (13-b), with the same steel reinforcement ratio and the same dimensions and characteristics of the experimental beams. The modeling and meshing for the first and second part was done in the same way as the models of the experimental beams.



(a) (b)

Figure 13. (a) Modeling of the Reinforcement for the First Part Models, (b) Modeling of the second Part Models with One Point

5.11. Ultimate Load, Ultimate Deflection and Crack Pattern for the First Part Models

First part models contains the models (N-R-W-30, S-R-W-30 and F-R-W-30). Table (3) shows the results of the ultimate load and ultimate deflection for the first part models. By comparing these results with the results of the experimental beams mentioned in Table (2), it was found that there is an enhancement in the behavior of beams by using higher steel reinforcement ratio. The ultimate load increased by about (22.6 to 30.9 %) while the ultimate deflection decreased by about (25.7 to 65.4 %). Fig. (14) shows the deflected shape for the first part models. While Fig. (15) shows the crack pattern for these models. It is clear from Fig. (15) that the use of higher steel reinforcement ratio change the mode of failure from pure shear, by using minimum reinforcement, to flexure- shear failure.

Table 3. Ultimate Load and Ultimate Deflection of the First Part Models.

Ultimate Load (kN)		Discrepancy Ratio %	Ultimate Deflection at Center (mm)		Discrepancy Ratio %
First Part Models	Experimental Beams		First Part Models	Experimental Beams	
72	55	30.9	1.88	4.4	57.3
126.3	103	22.6	2.18	6.3	65.4
75.7	60	26.1	2.08	2.8	25.7

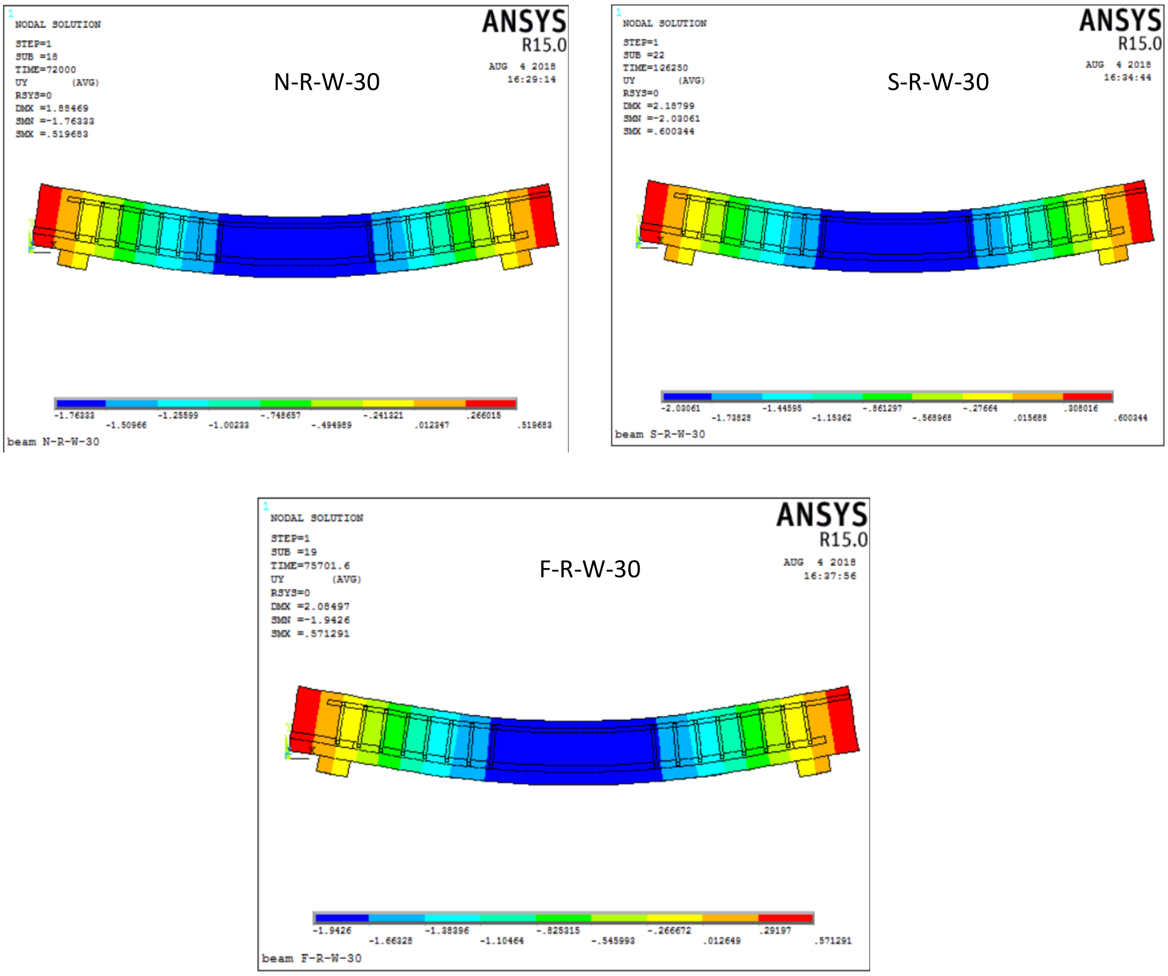


Figure 14. The Deflected Shape for the First Part Models

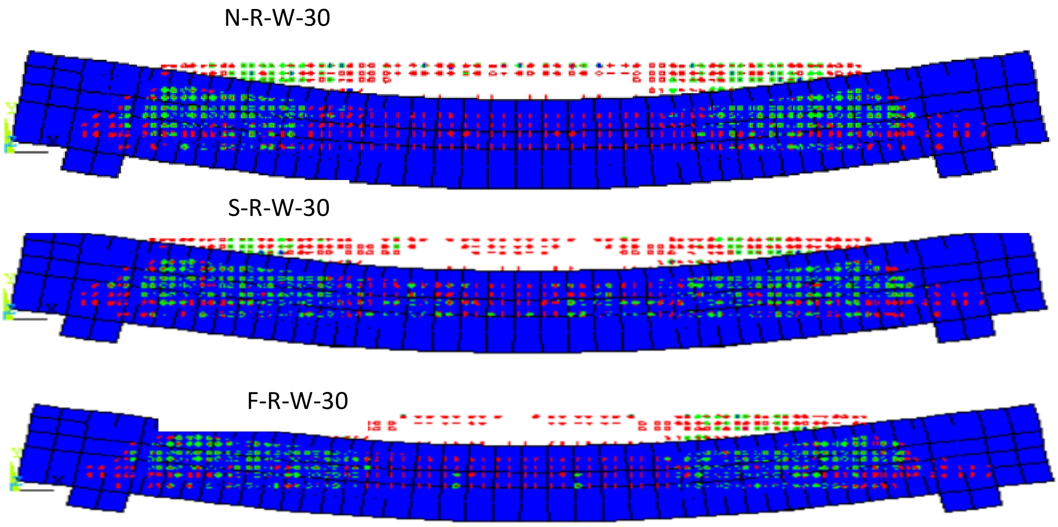


Figure15. Crack Pattern the First Part Models

5.12. Ultimate Load, Ultimate Deflection and Crack Pattern for the Second Part Models

Second part models contains the models (N-P-W-30, S-P-W-30 and F-P-W-30). Table (4) shows the results of the ultimate load and ultimate deflection for the second part models which subjected to one point loading. By comparing these results with the results of the models of the experimental beams mentioned in Table (2), it was found that the ultimate load for these models are higher than the ultimate load of experimental beams by about (7.1 to 14.2 %) due to the use of one point load, while the central deflection is higher than the central deflection of experimental beams by about (12.7 to 29.5 %). Fig. (16) shows the deflected shape for the second part models. While Fig. (17) shows the crack pattern for these models .

Table 4. Ultimate Load and Ultimate Deflection of the Second Part Models.

Ultimate Load (kN)		Discrepancy Ratio %	Ultimate Deflection at Center (mm)		Discrepancy Ratio %
Second Part Models	Experimental Beams		Second Part Models	Experimental Beams	
59	55	7.3	5.7	4.4	29.5
110.3	103	7.1	7.1	6.3	12.7
68.5	60	14.2	3.32	2.8	18.6

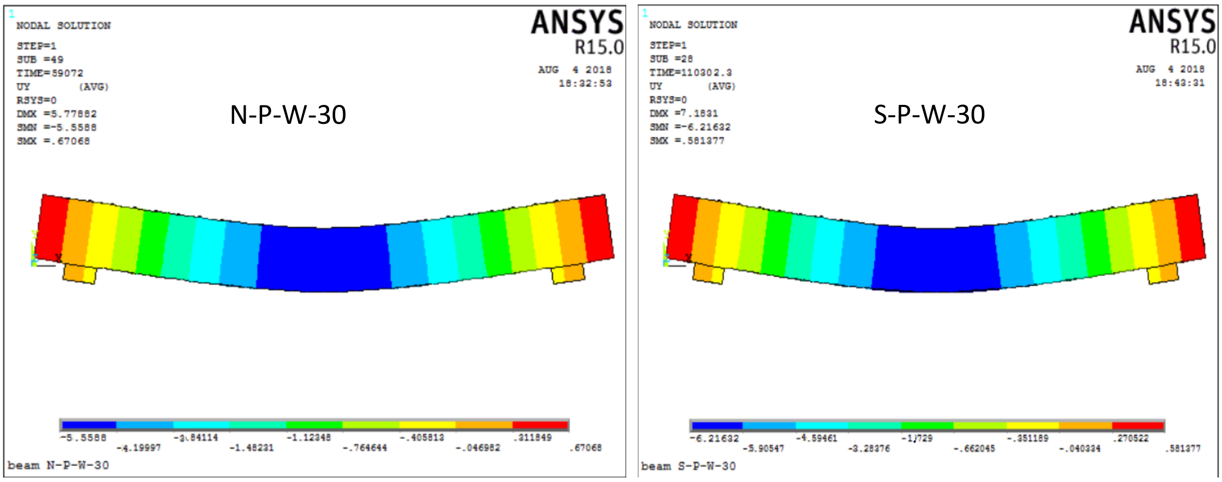


Figure16. The Deflected Shape for the Second Part Models.

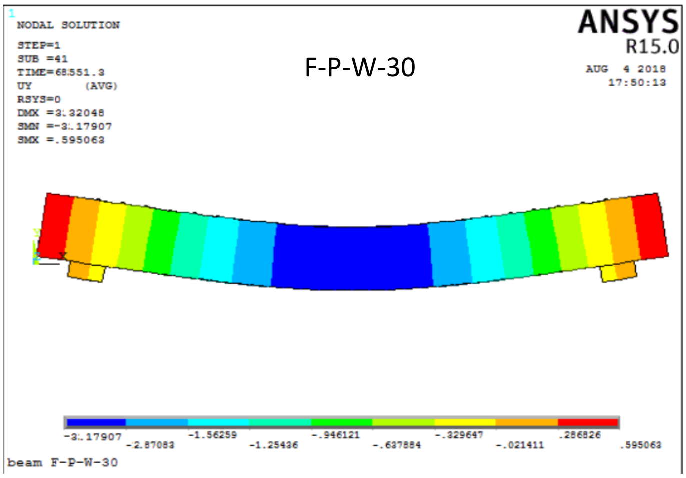


Figure16. Continued

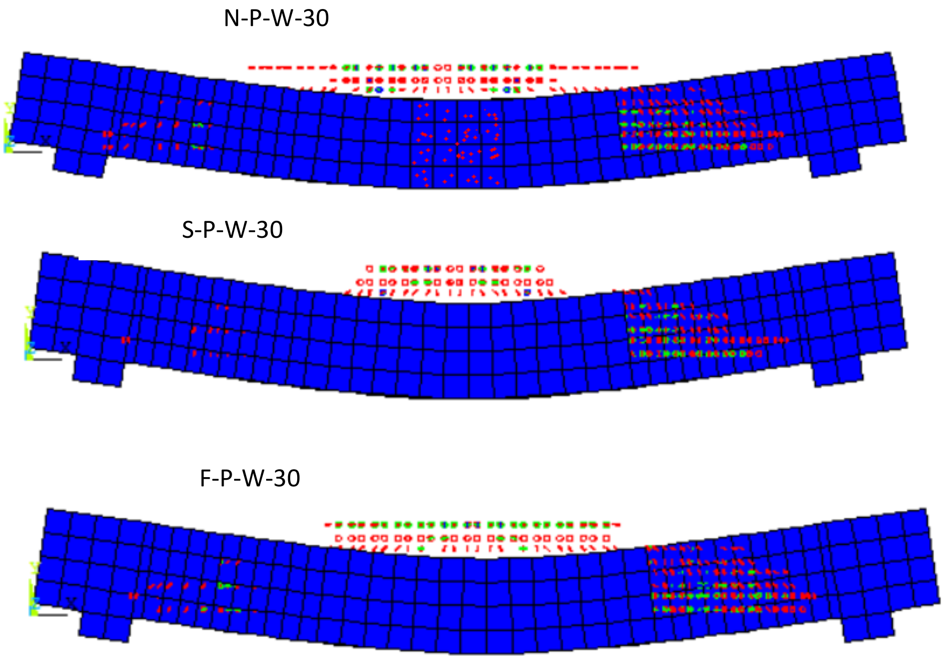


Figure17. Crack Pattern the Second Part Models.

6. Conclusions

From the result, the following conclusions can be drawn

1. There is a noticeable increase in ultimate load in specimens coated with sodium silicate or flunkout compared with specimens without coating.
2. The ultimate load for specimens cured in water is higher than that for specimens cured at air.

3. A significant reduction in ultimate deflection was noticed in specimens coated by sodium silicate or flunkout.
4. The deflection in specimens cured at air is higher than that cured in water at the same load level.
5. In the case of water curing, it was noticed that the use of sodium silicate enhanced the performance of beams compared with specimens without coating and specimens coated with flunkout
6. In normal beams (without coating) which were cured in water, the number of cracks are less than that cured at air, while there was no difference in the mode of failure for the treated specimens which were cured in water or at air.

From the analytical results, the following conclusions can be drawn:

1. The ANSYS models underestimate the strengths of the beams.
2. By comparing the ANSYS results with the experimental results, the maximum error in central deflection is found to be approximately (15.9 %).
3. By increase the steel reinforcement ration, it was found that there is an enhancement in the behavior of beams. The ultimate load increased by about (22.6 to 30.9 %) while the ultimate deflection decreased by about (25.7 to 65.4 %). Besides, the mode of failure was changed from pure shear, by using minimum reinforcement, to flexure- shear failure.
4. By using one point load test, it was found that the ultimate load increased by about (7.1 to 14.2 %) compared to the specimens tested with two point load , while the central deflection is higher than the central deflection of experimental beams by about (12.7 to 29.5 %).

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