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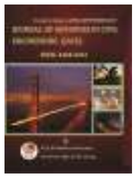

RESEARCH ARTICLE

Creep Performance Analysis of Reinforced Concrete after Fire

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ABSTRACT

On the basis of fire test, through the creep test of reinforced concrete structures after fire under room temperature, the stress-strain curves were concluded; then the test processes were numerically simulated, which were also compared with the physical test results. Here elastic deformation and cooling phenomenon in the process of the experiment, exploratory research, relationship between the deformation and cooling rate were also determined, which provide an important theoretical basis for the residual strength structure, disaster assessment and rebuilt after the fire.

Keywords: Fire test, Reinforced concrete, Creep test, Stress-strain curves, Elastic deformation.

1. INTRODUCTION

With the development of the construction industry, concrete became the first choice of building material. However, the thermal and mechanical properties of steel and concrete decrease with increase of temperature. Research shows that when there is a fire, the structure of the building would not get completely destroyed so that the study on behaviour of reinforced concrete structure after fire is significant.

[1] A large number of domestic and overseas researches have been carried out on test analysis structure deformation after fire. It also included force practical calculation method of concrete-filled rectangular steel tube column after fire. [2] Through the research on reinforced concrete beam fire and the reinforcement repair test, a restored project was proposed. [3] did damage identification on reinforced concrete after fire. [4] analyzed the hysteretic properties of concrete aftermath. [5-10] studied the mechanical properties of concrete columns in the aftermath, where the mechanical properties of the reinforced concrete under the action of fire were analyzed on the experimental study.

But research on rheological properties of specimens after fire and analysis of elastic cooling are stated only by few. This paper is based on experiment and simulation creep of reinforced concrete structures at room temperature after fire, where it carries out research on fire resistance of reinforced concrete structures based on "residual intensity" thermal injury model. It also provides important basis for residual strength structure and disaster assessment and rebuilt after fire.

2. PHYSICAL TEST RESEARCH

2.1. Design and manufacture of test specimens

Tests were carried out in disaster prevention science and safety technology institution of central south university. It includes the fabrication of concrete specimens using 42.5 ordinary Portland cement, medium sand and 4.75mm to 31.5mm and continuous

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gradation of broken pebble with the mixture ratio: C: S: G = 1:2.26:4.12, W/C= 0.62. Size and reinforcement ratio of column and beam section is shown in figure B1.

2.2. Creep test method

Reinforced concrete specimens after fire were fetched out from the furnace and cooled at room temperature. Then using 50t hydraulic jack, constant voltage static load creep test is conducted as illustrated in figure 1(a) and 1(b). Load value is 75% of the ultimate load based on literature [11] at the total load time setting for 8h. At the loading position of beam respectively on 1/3L and 2/3L on beam, the deflection measurement location was carried off for center of beam under the plane due to the test conditions.

Figure 1(a).Experimental method for loading process

Figure 1(b).Experimental method for deflection measurement

3. NUMERICAL SIMULATION AND EXPERIMENTAL RESEARCH

3.1. Simulation method

Make residual stress and residual deformation of specimen after high temperature as initial conditions of creep simulation, set the corresponding parameters in ANSYS and the solve condition to analyze. Then SOLID65 unit and LINK8 unit were selected as the element type of concrete and steel. Using explicit creep model, meshing with sweep slightly partitioning is applied on both sides of the column bottom as the fixed end constraint, at loading vertical static load in beam span length L/3 and 2 L/3.

Based on the above method and reference ultimate load of literature [11], taking 75% of the ultimate load as reduction factor and as creep load and creep total time set to 8h, 13 set of nonlinear analysis program were compiled. It is then solved and corresponding results are obtained. The limit load of literature [11] are only 10 groups where the other three groups of creep load, reached interpolation method to calculate.

As the division of specimen units is close, and the time needed for the calculation of the creep process is long, the general computer is unable to load data and memory. So the high performance computer cluster of institute of rheological mechanics and materials engineering in central south forestry university of science and technology institute attempts to solve arithmetic compiled calculation program.

3.2. Constrictive analysis of the result

We derived the calculated results, using origin software fitting simulation results, and the simulation results were compared with the test results. The stress-strain curve is obtained as shown in figure 2 to figure 6. Figure 6 shows the room temperature creep curves of the specimens which are not through fire. Table A1 shows temperature and load conditions on the fire and load conditions after the fire and the maximum deflection of the specimens.

Contrast to T1, T2 and T3 in table A1, it is not difficult to find that with the reduction of creep load, deflection of the specimens increases. Instead, this is due to the consistent load level of T1, T2, T3, and the temperature is increasing step by step on fire, which shows that the temperature level will affect the residual strength of the specimens after the fire, and will be larger than the effect of the test load after fire. And contrast to figures 3, 4 and 5 also one can come to this conclusion. We compared creep deflection of the specimens in table A1, T1, T4 and T7. With the reduction of creep load, deflection of the specimens increases, because T1, T4 and T7, T10 is consistent on fire, but the load levels increase step by step, which illustrate that the fire load affects the residual strength of the specimens after fire, and the effect is greater than the test load after the fire. Hence the same conclusion is obtained in contrast to specimen T2, T5, T8, T11 and T3, T6, T9, T12. Since the specimen T13 experiences no fire, although the creep load is the biggest, the deflection is lower than the specimen after fire.

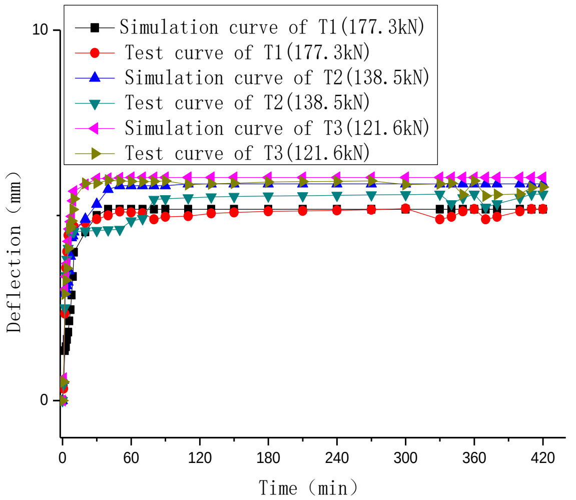

Figure 2.The stress-strain curves of T1, T2, T3

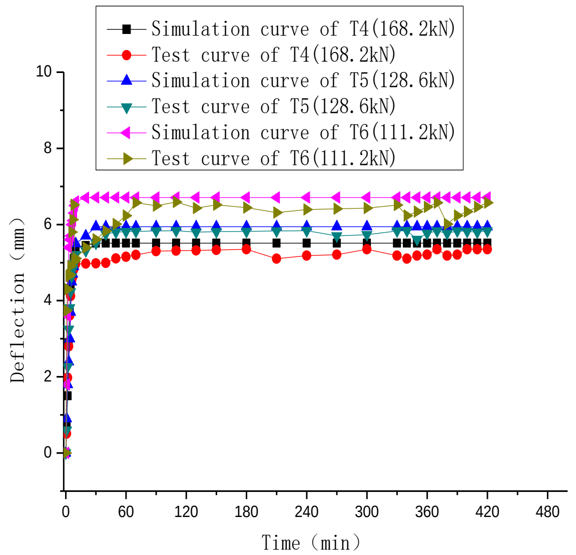

Figure 3.The stress-strain curves of T4, T5, T6

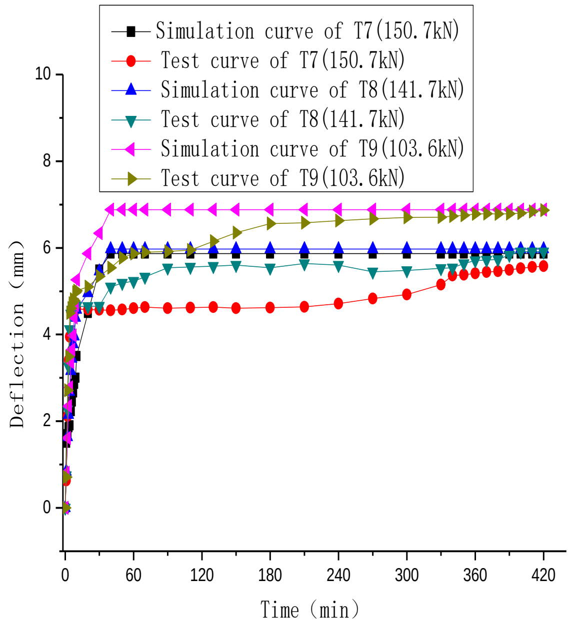

Figure 4.The stress-strain curves of T7, T8, T9

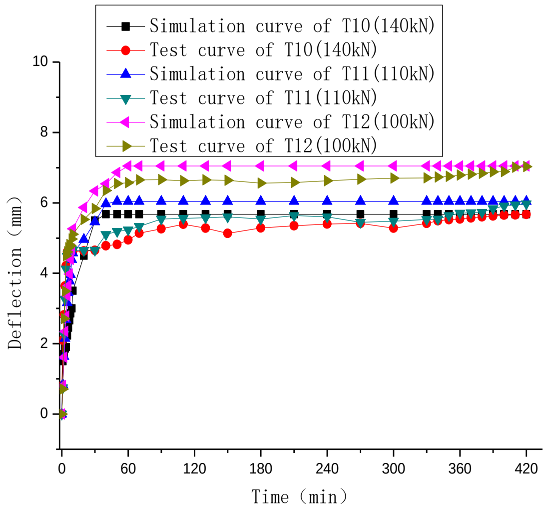

Figure 5.The stress-strain curves of T10, T11, T12

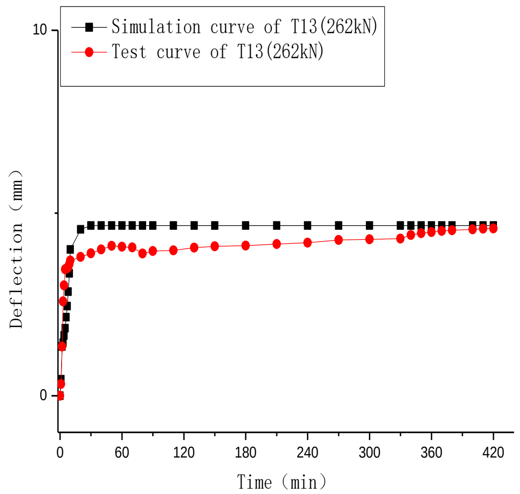

Figure 6.The stress-strain curves of T13

Figure 2 shows that in both the simulated and test curves, the deflection increases rapidly for the first 30min and reached a peak at around 60min, and then leveled off. Then creep coincided basically with the first two stages of the process, namely the initial stage of creep and accelerated creep stage. Simulation curve in the whole test process is relatively smooth; test curve is composed of several obvious turning points, because of jack, mainly by artificial pressure test process, and in the actual operation it is hard to avoid negligence with a long cycle test. The same phenomenon can be also found in figures 3, 4 and 5. From figure 6 also, it can be concluded that creep test curve of the specimens in room temperature and the typical creep curve basic is consistent in the first two stages. Table A1 shows that deflection error between each specimen of physical experiment and numerical simulation is less than 5%. And figure 2 to figure 6 show that the simulation curves are essentially coincident with the test curve, which explain both at room temperature and after the fire, the simulation method of reinforced concrete creep process is effective and feasible.

In order to further verify the creep curve from the aspects of theory, the stress-strain curve generation was substituted into modified Burgers model [12]. The creep equation of the model is given in equation (3.1).

$$\varepsilon(t) = \frac{\sigma}{E_1} + \frac{\sigma-\sigma_s}{\eta_3}t + \frac{\sigma}{E_2}\left[1 - \exp\left[\frac{-E_2 t}{\eta_2}\right]\right](\sigma > \sigma_s) \quad (3.1)$$

This formula can be simplified as in equation (3.2),

$$y = a + bt + c[1 - \exp(-dt)] \quad (3.2)$$

where a, b and c are the model parameters.

The origin software fitting for each specimen found that the fitting result and the stress-strain curve is basic consistent. This also proved the practicability of test and simulation results.

4. ELASTIC DEFORMATION AND COOLING EXPERIMENTAL STUDY

Endothermic cooling phenomenon is a kind of temperature effect in the process of material deformation. There is quite a few scholars at home and abroad who studied this phenomenon. [13-15] discovered the thermo-elastic effect of rubber in 1987 and later confirmed that the metal also has the same nature. [16, 17] aimed at metal materials, using the energy density theory to explain the phenomenon. [18-21] aimed at non-metallic materials, adopting the theory of micro entropy.

This article uses the new purchased SC7000 infrared thermal imager of rheological mechanics and materials engineering central south forestry university of science and technology institute respectively to T12 test specimen after fire and T13 test specimen without fire in the stages of creep test loading. Temperature scanning, scanning for the beam in the middle of a third area are performed, where for the picture of 1 frame per second, the test time is 2.5 minutes. SC7000 infrared thermal imager appearance and scanning position are shown in figures 7(a) and 7(b).

Figure 7(a).Thermal infrared imager SC7000

Figure 7(b).Method of temperature scanning

Figure 8 is shown for the test at the

beginning of the SC7000 images captured by infrared thermal imager. The selection of reference points, including reference point 4, 5, 6, the upper area of longitudinal reinforcement and depth of beam, 1, 2, 3 point is located in the upper reinforcement area, while 7, 8, 9 in the reinforcement area is at the bottom. Using temperature data obtained from the origin software fitting respectively, all specimens are mapped at various points in 2.5 minutes, and the corresponding temperature change curve is shown in figures 10 and B1. Table A2 compares the initial and final temperature of each measuring point. Figures B2 and B3 represent T12 and T13 specimen deformations respectively.

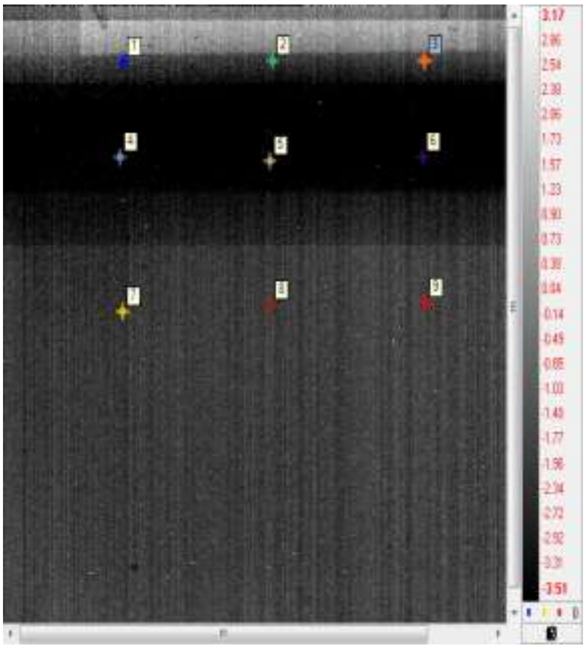

Figure 8.The footage of thermal infrared imager SC7000 and the reference points

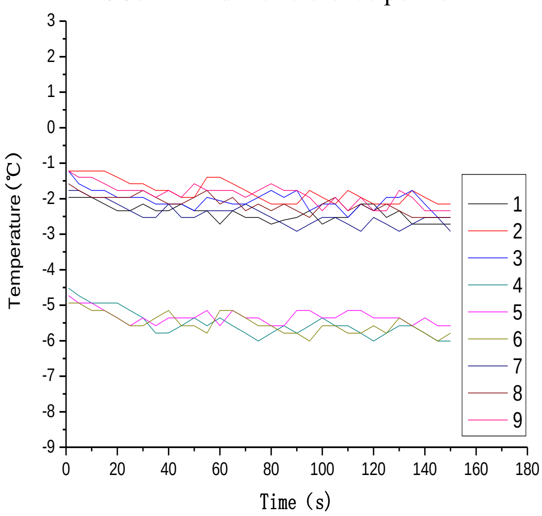

Figure 9.The temperature variation of measuring points at the central area of beam of T12

Figures 9 and 10 indicate that no matter whether the specimen is after the fire or on room temperature, the measuring point temperature decreased with increasing time. It confirmed the phenomenon of elastic deformation and cooling. It also can be seen from figures B2 and B3 that the temperature curve of each measuring point has not plummeted, but stepped down and occasionally rise. This is because the specimen deformation is not elastic, and accompanied by a certain plastic deformation in the loading process, which influenced elastic deformation and cooling. Although the initial temperature of specimen T13 is higher than T12, cooling rate is roughly same as T12 which shows that the initial temperature has no influence on the cooling rate.

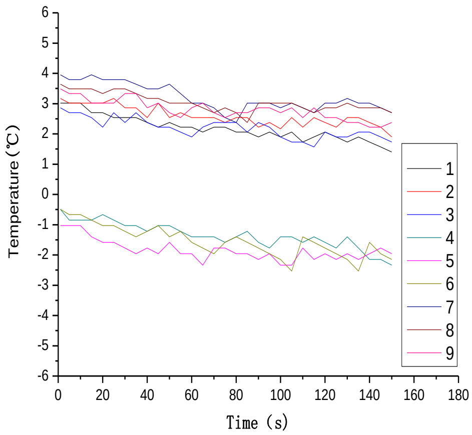

Figure 10.The temperature variation of measuring points at the central area of beam of T13

From table A2, you can see that the temperature of frame beam reinforced area is lower than non-reinforced section in general. The overall cooling rate of T12 is lower than T13, which is due to the high temperature damaged on the specimen T12, reducing its ability to resist deformation. Comparing the cooling rate of the temperature measuring points 1-9 of all specimens, the initial temperature of specimen has no impact on cooling rate, but the deflection deformation has a decisive influence on cooling rate, and greater the deformation, smaller the cooling rate.

5. CONCLUSION AND FUTURE PROSPECT

In this paper, through the study of the creep and cool elastic deformation test analysis of reinforced concrete structures after fire, the following conclusions can be obtained.

- Both the temperature level and the load levels on fire have an impact on the creep deflection of late period, and the influence on phase deflection are larger than the effect of creep load. Simulation and experimental results are basically consistent, which can prove that the simulation method in this paper can be adopted by the better simulation of the creep behaviour of the actual fire, and can save a large number of experiment funds in related areas.
- Creep test results are roughly in line with the first two stages of creep, namely initial creep stage and steady-state creep stage, and can be good fitting through improved Burgers model. It also provides the test and theoretical guidance for further study of reinforced concrete residual strength after fire.
- In this paper, on the basis of predecessors' cool elastic deformation theory, this phenomenon is found for the first time in the reinforced concrete structure load bending test at room temperature and concluded that the for greater deformation, cooling rate is smaller, thus providing reference for future related research.

ACKNOWLEDGEMENT

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APPENDIX A

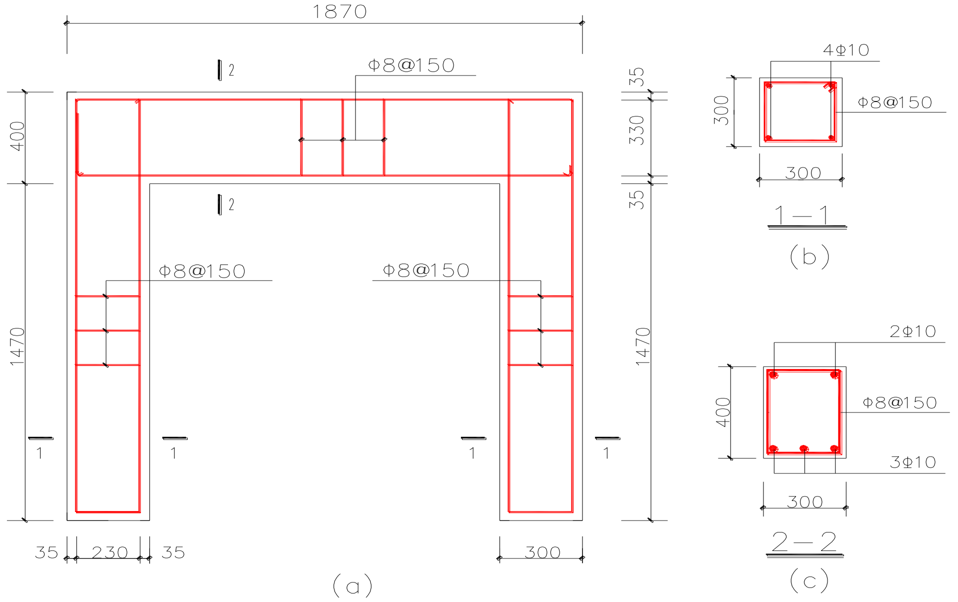
Table A1.Test conditions and deflection values

Specimen Number	Heating Temperature （℃）	Dead load value （kN）	Ultimate load （kN）	Creep load （kN）	Physical test deflection （mm）	Numerical simulation deflection （mm）	Error (%)
T1	600	21	236.4	177	5.17	5.161	0.17%
T2	800	21	184.7	139	5.57	5.849	5.00%
T3	1000	21	162.1	122	5.93	6.021	1.50%
T4	600	28	224.2	168	5.35	5.505	2.80%
T5	800	28	171.5	129	5.83	5.943	1.90%
T6	1000	28	148.3	111	6.57	6.712	2.10%
T7	600	35	201.4	151	5.58	5.871	5.20%
T8	800	35	188.9	142	5.91	5.969	0.99%
T9	1000	35	138.1	104	6.87	6.884	0.20%
T10	600	42	/	140	5.67	5.677	0.12%
T11	800	42	/	110	5.97	6.039	1.15%
T12	1000	42	/	100	7.03	7.054	0.34%
T13	/	/	/	262	4.58	4.662	1.79%

Table A2.Temperature of each point

Measuring point	1	2	3	4	5	6	7	8	9
Initial temperature of T12	-2.34	-1.22	-1.22	-4.52	-4.73	-4.94	-1.77	-1.58	-1.22
Final temperature of T12	-2.72	-2.15	-2.53	-5.58	-5.58	-5.79	-2.92	-2.53	-2.34
Cooling rate of T12	0.38	0.93	1.31	1.06	0.85	0.85	1.15	0.95	1.12
Initial temperature of T13	3.02	3.17	2.86	-0.49	-1.03	-0.49	3.95	3.64	3.49
Final temperature of T13	1.4	1.9	1.73	-2.34	-1.96	-2.15	2.7	2.7	2.38
Cooling rate of T13	1.62	1.27	1.13	1.85	0.93	1.66	1.25	0.94	1.11

APPENDIX B



(a) Form of specimen (b) Reinforcement of frame column (c) Reinforcement of frame beam
Figure B1.Reinforcement and form of the specimen

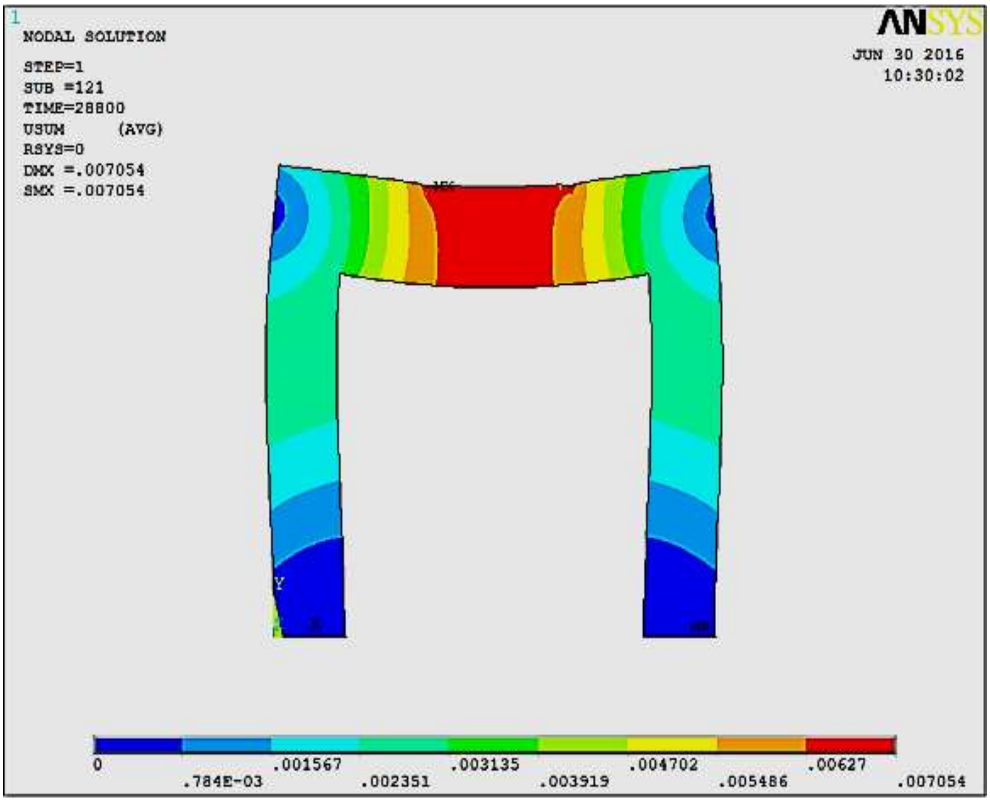


Figure B2.Deformation of T12

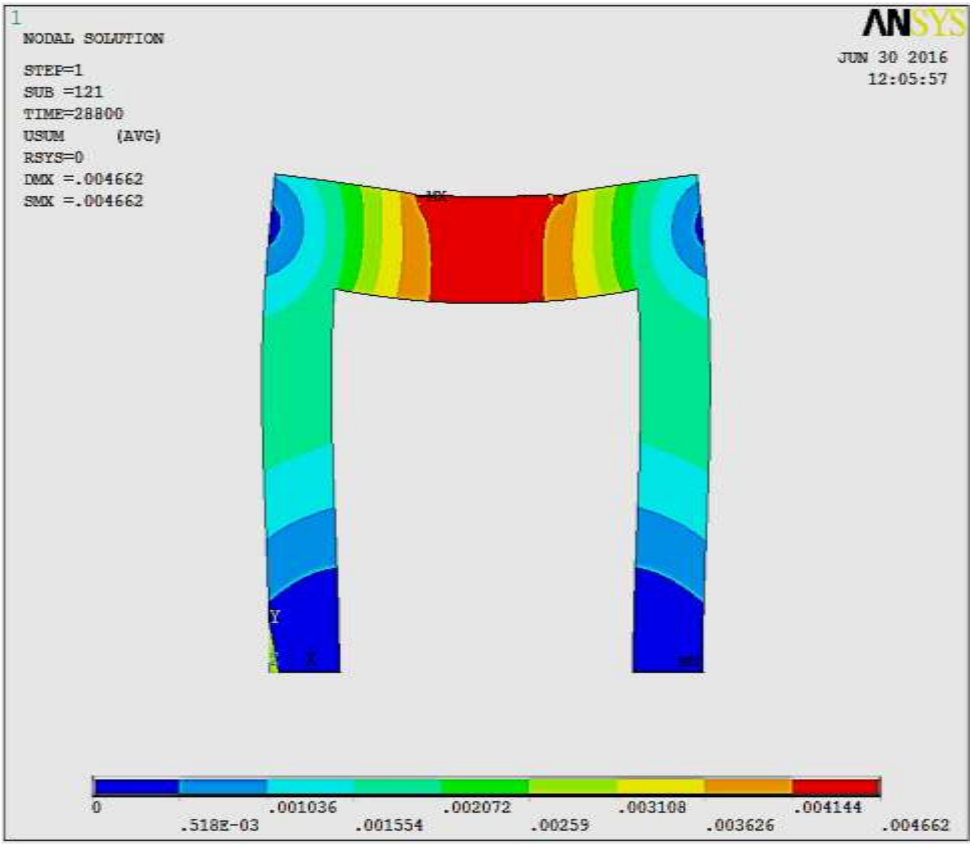


Figure B3.Deformation of T13