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BENDING LOAD ANALYSIS FOR THE SIMULATOR OF FUEL ASSEMBLY

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ABSTRACT

Fuel assemblies always bend for some reasons in the reactor core. To simulate the transportation and the operation of the deformed fuel assemblies inside and outside of the core, the simulator of fuel assembly should be get some expected residual deformation by loading and offloading before being used in the following test. This paper presents three loading-unloading ways and corresponding restraint ways which are used to make the simulator of CEFR fuel assembly be requested permanent deformed. Mean while, finite element program ANSYS are used to calculate the values of load and the corresponding deformation by taking nonlinear material properties into account.

Keywords: Simulator of fuel assembly, CEFR, Bending load, ANSYS

1. FOREWORD

China Experiment Fast Reactor (CEFR) is the first fast breeder reactor in China. Such loads as high radiation, high temperature and pressure will deform the fuel assemblies (FAs) in the core when the fuel assemblies reach to the expected burnup fraction. To simulate the operation and transportation of the deformed fuel assembly in and out of the core, it is necessary to take some experiments on the deformed FA. And the new straight simulator of FA will be bent to be the expected deformed shape.

The simulator of FA in CEFR (hereinafter referred to as simulator) consist of three parts(see Fig.1): handling header segment (820mm) close to the up end, fuel segment (800mm) in the middle part and spike segment (972mm) close to the low end. The cross section of the fuel segment is hexagonal rings as shown as Fig.2. and the external cross-flat distance is 59 mm and the thickness of the wall 1.2 mm. The cross sections of the handling segment and the spike segment are not all the same to the fuel segment. But the three segments are coaxial. According the technical specifications, the FA should be deformed to be in the following shape as shown in Fig.1: The distance from the middle point of the median axis of the fuel segment to the line from the up end to the low end is 15mm and the median axis of the handling segment and the spike segment keep being all in straight line (see Fig.1). In the figure the continuous line and the dashed line are the median axes of FA before and after deformation respectively (the deformation is magnified in the figure). Therefore we need to suppose how to apply the bending load and then determine the values of the load by computation.

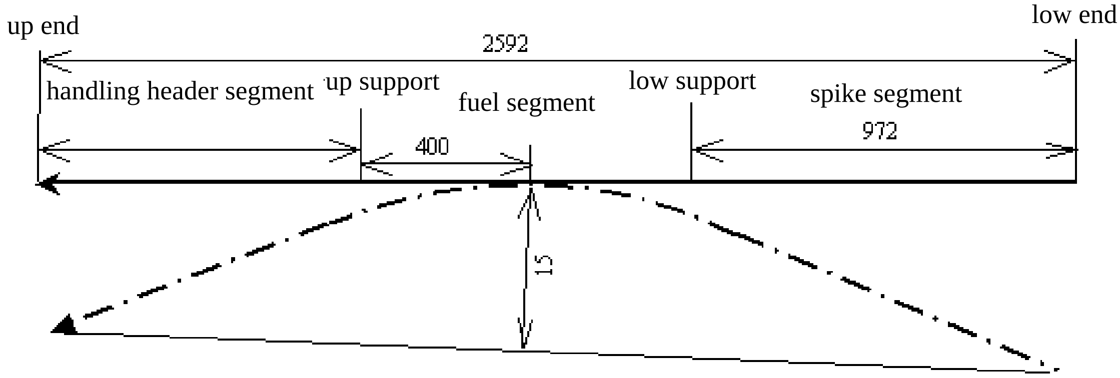

Fig.1 Axis of simulator of fuel assembly before and after being bent

2. MATERIAL PROPERTIES

The material properties of the simulator at room temperature: tensile strength σ_b is 823MPa, yield strength σ_s is 763MPa, stretch ratio at fracture point is 19.6%, Poisson's ratio is 0.33, and Young's modulus E is 2.035×10^5MPa.

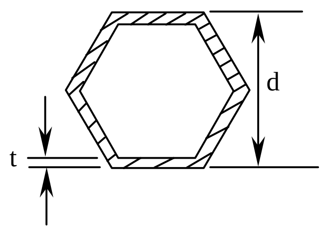

Fig.2 Cross section of the simulator

3. COMPUTATION MODELS AND RESULTS

3.1 MAKING UP STRESS-STRAIN CURVE

For some reason the true stress-strain curve has not been given, which need to be obtain by experiments. This paper presents two imaginary stress-strain curves as shown in Fig.3. and the true one should have been envelop in the two imaginary ones. The points of the two curves are listed in Table 1. Obviously, the results from the true stress-strain curve should be between the results from the two imaginary ones.

Table 1. Points on the stress-strain curves

stress-stain curve 1		stress-stain curve 2	
Strain(%)	Stress(MPa)	Strain(%)	Stress(MPa)
0	0	0	0
0.374939	763	0.404423	823
19.6	823	19.6	823

3.2 COMPUTATION MODEL

It is clear that the bending load should be applied only on the fuel segment to keep the median axes of the handling header segment and the spike segment being a straight line. Three kinds of method of applying the bending load are considered here: 1. pure bending moment load; 2. surface uniformly distributed load; 3. concentrated line load. By increasing the load very slowly from zero to the expected maximum and then decreasing back to zero, the expected residual deformation of FA could be obtained. When the load increases up to one certain value, which is called critical load, FA will come to be part plastic from full elastic. And the expected maximum value is called maximum load during the increasing of the load. The resultant load can be determined by the following steps: 1. Estimating the critical load by theoretic analysis [1] or by

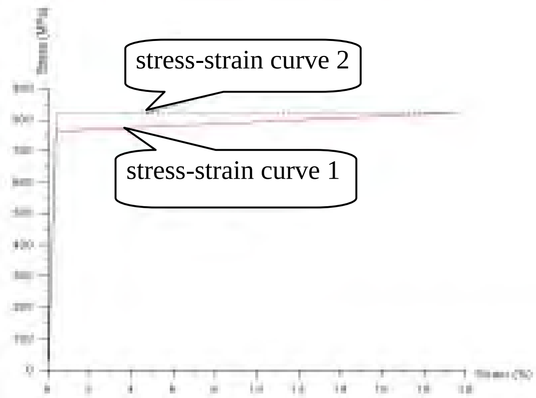

Fig.3 Stress-strain curves for material

FEM; 2. Computing the residual deformation greater than the expected one by applying a load much greater than critical load and decreasing the load successively; 3. Determining the maximum load by dichotomy till the residual deformation (i.e. the distance 15mm) reach the acceptable deviation to the expected one. The critical and maximum loads are listed in Table 2 in chapter3.3.4.

The fuel segment is simulated by shell elements in the model. The spike segment and the handling header segment are load free, so the two segments are simulated to be not in real shape but hexagonal cross section similar with the fuel segment.

3.3 RESULSTS

3.3.1PURE BENDING MOMENT LOAD AND CONSTRAINT

The z-direction is the horizontal axis along the length of FA. The y-direction is the vertical axis perpendicular to two flats of the simulator cross section. And the x-direction can be determined according to the right-handed rule. It is shown as Fig.4. The simulator is held at the low support and applied x-moment at the up support. The moment increases sub-statically from zero up to the maximum value and decreases back to zero. The critical load and the maximum load and corresponding deformation is listed in Table 2 of chapter3.3.4 in detail.

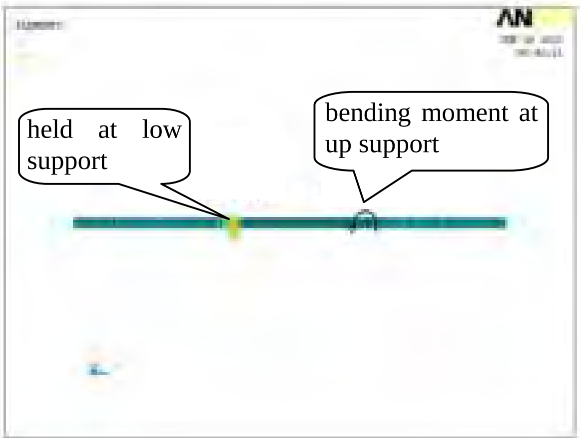

Fig.4 Pure bending moment load and constraint

3.3.2 SURFACE UNIFORMLY DISTRIBUTED LOAD AND CONSTRAINT

The x-direction, y-direction and z-direction are identical with those in Fig.4. The simulator is simply supported both at the low support and the up support. The distributed load is applied along the fuel segment as shown in Fig.5. Similarly, the load increases quasi-statically from zero up to the maximum value and decreases back to zero. The critical load and the maximum load and corresponding deformation is listed in Table 2 of chapter3.3.4 in detail.

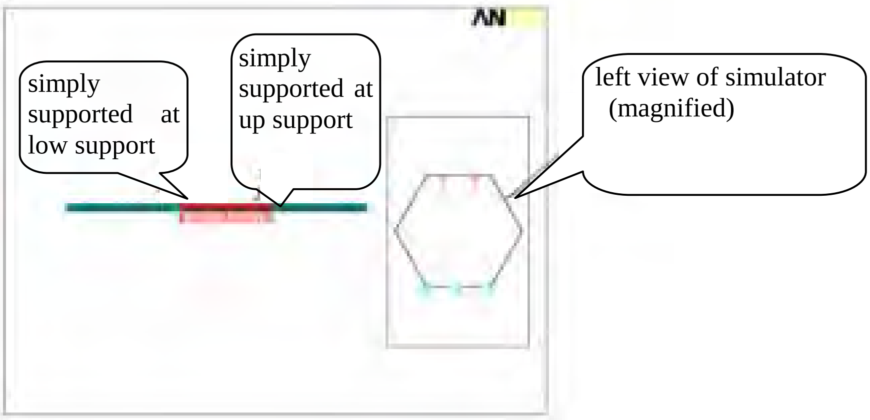

Fig.5 Surface uniformly distributed load and constraint

3.3.3 CONCENTRATED LINE LOAD AND CONSTRAINT

The x-direction, y-direction and z-direction are identical with those in Fig.4. The simulator is simply supported both at the low support and the up support. The concentrated line load is applied along the exactly midline of the fuel segment as shown in Fig.6. Similarly, the load increases sub-statically from zero up to the maximum value and decreases back to zero. The critical load and the maximum load and corresponding deformation is listed in Table 2 of chapter3.3.4 in detail.

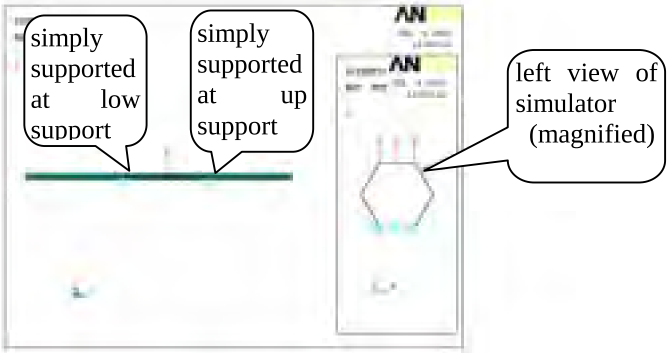

Fig.6 Concentrated line load and constraint

3.3.4 LOAD AND CORRESPONDING DEFORMATION

The deformations of the simulator at maximum load by stress-strain curve 1 are shown as Fig.7, Fig.8 and Fig.9, respectively. And the deformations are similar with those by stress-strain curve 2.

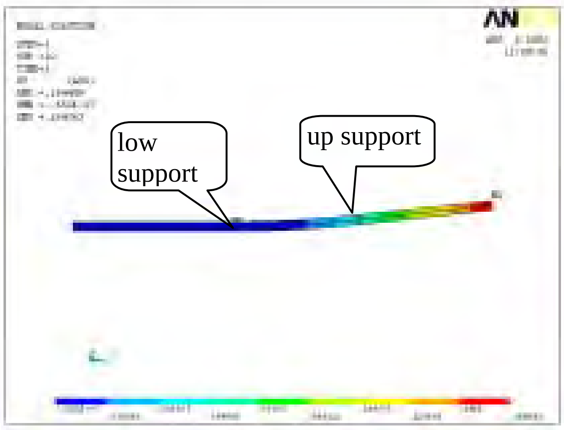

Fig.7 Deformation at maximum bending moment

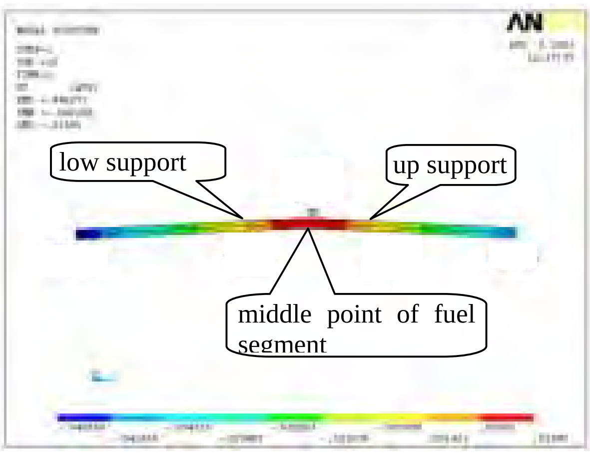

Fig.8 Deformation at maximum surface uniformly distributed load

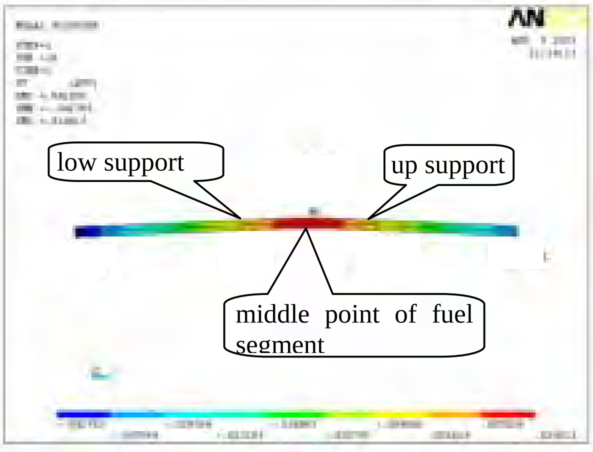

Fig.9 Deformation at maximum concentrated line load

The critical loads and the maximum loads and the corresponding deformations are listed in Table 2.

Table 2. Loads and the corresponding deformations[1]

		Pure bending moment load		Surface distributed load		Concentrated line load	
		Stress-strain curve 1	Stress-strain curve 2	Stress-strain curve 1	Stress-strain curve 2	Stress-strain curve 1	Stress-strain curve 2
Critical load		2953N·m	3185N·m	1.140 MPa (52713N)[2]	1.230MPa (56875N)[2]	14760N	15750N
Deflection at critical load (mm)	Middle point of fuel	9.55	10.35	9.95	10.51	7.27	7.75
	Low end	0	0	32.65	34.52	23.00	24.52
	Up end	122.15	131.77	27.52	29.09	19.42	20.70
	Up support	39.04	42.11	0	0	0	0
Maximum load		3200N·m	3438N·m	1.348MPa (62331N)[2]	1.448MPa (66955N)[2]	19524 N	20946 N
Deflection at maximum load (mm)	Middle point of fuel segment	12.79	13.63	15.88	16.73	14.01	14.74
	Low end	0	0	49.18	51.95	41.78	44.02
	Up end	164.36	174.16	41.49	43.82	35.28	37.17
	Up support	52.51	55.64	0	0	0	0
Load back to zero		0	0	0	0	0	0
Deflection at load back to zero (mm)	Middle point of fuel segment	2.54	2.56	4.44	4.44	4.44	4.46
	Low end	0	0	11.51	11.49	11.45	11.47

	Up end	33.13	33.19	9.72	9.71	9.68	9.70
	Up support	10.56	10.58	0	0	0	0

Note: ①The deflections are absolute value. The deflections will change direction with the load direction's changing, but the absolute value will be the same.

②The value in the cell is the pressure (in MPa) distributed on the surface of simulator. And the value in the parentheses is the resultant force (in N) of the pressure.

4. CONCLUSIONS

Three kinds of method of applying the bending load are given to get the expected residual deformation of the simulator. Taking the inelasticity of the properties into account, the corresponding constraints and the loads are obtained in this paper by using finite element method. The true loads should be between the computed loads by stress-strain curve 1 and those by stress-strain curve 2.

REFERENCES

[1] R. J. Roark, W. C. Young, (1988), Formulations of Stress and Strain, pp.45