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IMC Post: A Comparison of QC Tensile Tests, and Finite Element Analysis Results

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Rodulfo Alforque and John Sondericker

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Introduction

Several injection-molded composite(IMC) posts, Ultem2100 and Ultem2200, had been tested under a quality control (QC) procedure that was described in an earlier technical note by L. Wolf[1]. His calculations indicated that the post would experience approximately 7000 psi under the worst loading condition consisting of 3000 lbs. of cold mass weight and 12,500 lbs. of hydrostatic end thrust. The cross-sectional area of the post is about 4.9 sq. in., hence an axial stress of 7000 psi would translate into 34,300 lbs. of pure tensile load. However, a correction factor that he postulated out of the results of his specimen tests, would make the room-temperature tensile load to approximately 32,000 lbs., or 16 tons. This load would impart a tensile stress of 6530 psi which is less than half the rated tensile yield stress; Hence, it was expected that the posts will easily pass the QC tensile tests.

A high incidence of failure, however, was noted. Therefore, in order to understand this unexpected occurence, a review of the tensile test procedure was done and a numerical study was conducted using the finite element approach. The computer simulation using the finite element code ANSYS revealed that an IMC post under test in the existing setup actually would experience higher levels of stresses due to multi-axial stress conditions.

Background

Prior to the actual tensile test, a rough visual check was done to determine the texture and uniformity of material flow during the molding process. Visual inspection and judgment of flaws were based simply on experience. Nevertheless, those posts that looked questionable were still tested anyway, and the final verdict was handed down by the "*make, or break*" decision of the testing machine!

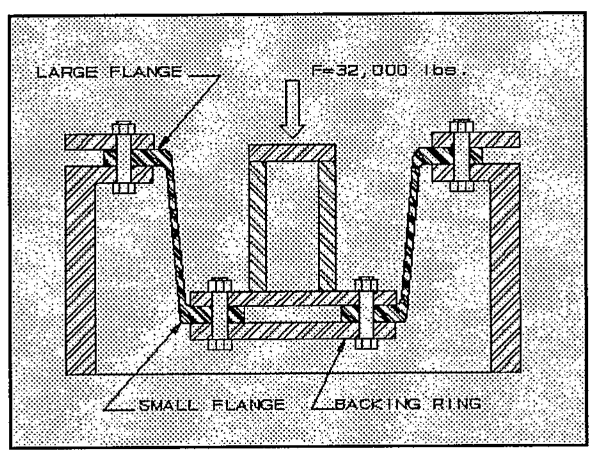


Fig. 1: Prelim Test Setup

During the development stage of the IMC post, a preliminary test fixture made of steel was used. This fixture had mounting holes that matched the hole pattern on the larger flange of the post. Through this holes, the IMC post was rigidly bolted and fixed unto the steel fixture as shown in Fig. 1. The load was then gradually applied up to a maximum of 32,000[1] lbs. or up to the failure point. The success rate was quite good especially for those posts that passed the initial visual test.

But the test fixture as described above, required drilling mounting holes on the flanges of the IMC post, and it was obviously not practical to use for a few thousand posts. In order to avoid the machining process, and qualify the post "*as received*", a new aluminum fixture was designed as shown in Fig. 2. The effect of the mounting bolts was replaced by the clamping action of a large nut. This design, however, would now allow radial sliding of the large flange as compared to a full restraint in the previous bolted connection design. It should be noted also that in both cases there might be some induced torsion or twisting on the post if the flanges rotated elastically as the load was gradually increased. Obviously, this effect would diminish the capacity of the post to pass the test due to increased discontinuity stresses at the flange and cylinder junction; And making matters worst, the IMC post was weakest in shear!

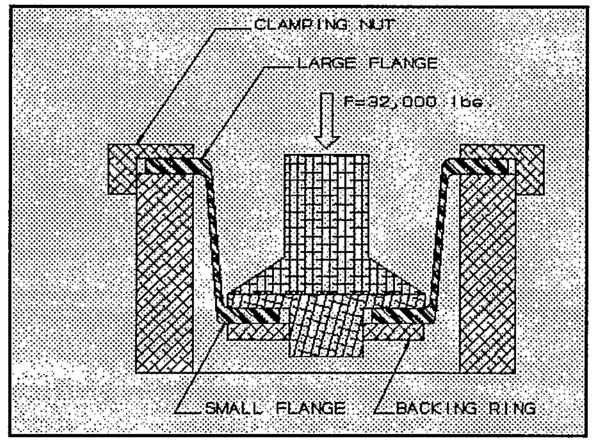


Fig. 2: Current Test Setup

The first set of posts tested with this new fixture, resulted in a 100% rate of failure; Breakage uniformly occurred near the smaller flange. Review of the fixture design revealed a flaw that resulted in a loading condition that enhanced bending at the smaller flange causing a severe combined stress overload around it. This was confirmed by a finite element model as described later in the subsequent section. Therefore, the fixture was modified in order to minimize the bending moment on the small flange.

Using the modified fixture, however, still resulted in failures. This time, though, the failure rate was roughly 50% and the posts were failing near the larger flange indicating a shift in stress concentration. Since the failure rate was unacceptable, further numerical calculations were undertaken. The foregoing sections describe the finite element analysis that simulated various boundary conditions.

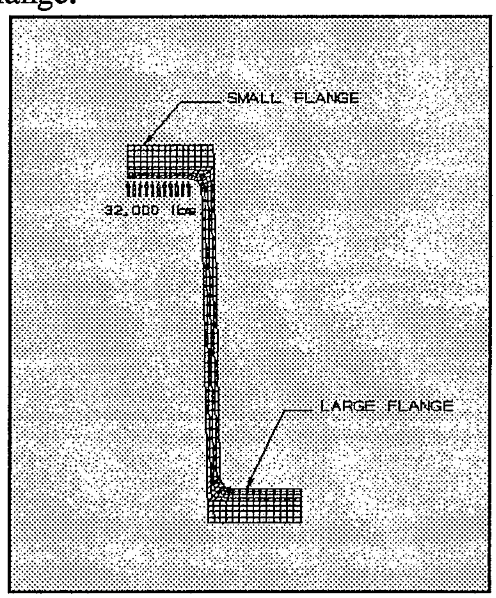


Fig. 3: FEA Model

Finite Element Analysis

a) Finite Element Model

The post was modeled with 376 two-dimensional axisymmetric elements using ANSYS Stif42, as shown in Fig. 3. Pressure loading, equivalent to a total load of 32,000 lbs. was applied to the inner part of the smaller flange as shown. With this loading condition, the following boundary conditions were analyzed:

Table 2: Stresses

Stresses, psi	Case #1	Case #2	Case #3
σ_1 (max/min)	13,567/ (-4,408)	78,656/ (-7,354)	15,299/ (-8,311)
σ_2 (max/min)	5,997/ (-6094)	18,810/ (-32,745)	6,535/ (-8,823)
σ_3 (max/min)	2,597/ (-10,819)	9,732/ (-45,625)	5,282/ (-12,165)
SIGE	11,235	68,364	12,711
SI	12,908	74,315	14,552

In the preceeding table, the principal stress components, σ_1, σ_2, & σ_3 are the roots of the following cubic equation,

$$\begin{vmatrix} (\sigma_x-\sigma) & \tau_{xy} & \tau_{xz} \\ \tau_{xy} & (\sigma_y-\sigma) & \tau_{yz} \\ \tau_{xz} & \tau_{yz} & (\sigma_z-\sigma) \end{vmatrix} = 0$$

where σ_x, σ_y, σ_z, τ_{xy}, τ_{yz}, & τ_{xz} are the elemental direct stresses.

Then, from the principal stress components, the Von-Mises stress is evaluated as follows:

$$SIGE = \sqrt{\frac{1}{2}((\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2)}$$

Furthermore, the Tresca stress is:

$$SI = \max(abs(\sigma_1-\sigma_2), abs(\sigma_2-\sigma_3), abs(\sigma_1-\sigma_3))$$

The rated strength for the IMC post are as shown in Table 1. Failure will obviously occur when the applied stress exceeds the yield stress of the material. Failure may manifest itself as a permanent deformation on ductile materials or as a complete breakage or rupture especially for brittle materials. Comparing the values of the applied stresses as shown in Table 2 to the respective material yield stress shown in Table 1, enables one to deduce the following conclusion.

Case #1) Large Flange fully restrained; minimal bending on small flange due to a stiff backing ring. This simulates the behaviour of the post when tested using the old steel fixture,

Case #2) Large flange fixed vertically, but sliding radially; Small flange, fully free, hence allowed to bend; This simulates the most extreme case where there is no backing ring supporting the smaller flange, and

Case #3) Large flange fixed vertically, but sliding radially; minimal bending on small flange. This is the case after the aluminum fixture was modified.

The material properties of the IMC post are shown in Table 1:

Table 1: Material Properties

	Ultem 2100	Ultem 2200
Tensile Strength, psi	16,600	20,100
Flexural Strength, psi	28,000	30,000
Compressive Strength, psi	22,000	28,700
Shear Strength, psi	13,000	13,500
Tensile Modulus, psi	650,000	1,000,000
Poisson's Ratio	0.4	0.4
Thermal Conductivity, Btu-in/hr-ft^2-°F	1.22	1.43
Thermal Expansion, in/in-°F	1.8 x 10-5	1.4 x 10-5

b) Results

Failure criterion theory indicates that the maximum energy of distortion theory (Von-Mises), as well as the maximum shear theory (Tresca) are reasonable failure estimates for the design of ductile materials. Whereas for brittle materials, the maximum normal stress theory is more widely used; This theory maintains that a material subjected to multi-axial stresses will fail when the maximum normal stress reaches the tensile yield point. For purposes of comparison, however, all of the above stresses are included in this report.

The stress levels for the three(3) cases being considered here are summarized in Table 2. Appendix A also shows some plots from ANSYS Post1 postprocessor. These values were calculated for Ultem2200 but would also apply to Ultem2100 for the same loading and boundary conditions. The calculated results for the two materials would only differ in displacements, which were not of significant concern in this analysis; Ultem2100 would exhibit more deformation since its elastic modulus is only 65% that of Ultem2200.

Conclusions, and Recommendations

Let us assume for a moment that the IMC post is a brittle material, and use the maximum normal stress theory as the failure criterion. The maximum principal stress from Table 2 will be compared to the tensile strength as given in Table 1.

Now, the max. stress in Case #1 is definitely below the yield strength of 16,600 psi for Ultem2100, and 20,100 psi for Ultem2200. On the other hand, the very high stress levels in Case #2 explains the 100% rate of failure that was observed when the unmodified aluminum fixture was used in testing; This case also accentuates the importance of a stiff backing ring. Case #3 shows an increase in the stress levels with respect to Case #1 by a modest 13% pushing the working stress quite close to the yield strength of Ultem2100, but still well below that of Ultem2200. It would be obvious then to expect that more Ultem2200 would pass the test. But test results using the modified aluminum fixture did not show a significant difference in strength between Ultem2100, or Ultem2200, i. e. Ultem2200 posts were failing at load levels similar to Ultem2100!

This observation, however, can probably be explained by considering the torsional effects induced by the elastic rotation of the flanges, and coupled to this is the fact that both materials have almost the same shear strength, namely 13,000 psi for Ultem2100, and 13,500 psi for Ultem 2200. Although Ultem2200 is slightly stronger by a meager 500 psi, it has about double the amount of glass as the Ultem2100, hence more brittle and more susceptible to cracking due to discontinuity stresses at the flange and cylinder junction!

At any rate, some posts that passed the QC tensile test using the modified aluminum fixture were also re-tested using the old fixture, and they all passed, thus confirming the FEA prediction.

It should be noted, however, that the IMC post is not a truly brittle material such as glass or even gray cast iron. It exhibits some ductility and its yield point is above the proportional limit. Therefore, one could argue that the failure criterion should be the Von-Mises, or Tresca criterion. It would be prudent, then, to evaluate and compare all of them with the material yield stress as was done previously for the maximum principal stresses.

Finally, separate shear tests were conducted using those posts that had been qualified by the tensile tests. A separate technical note shows that the current stress levels, and not 7000 psi as originally thought, are necessary for the posts to withstand 12,500 lbs. of hydrostatic thrust and 3000 lbs. of cold mass dead weight. Therefore, a serious effort will be undertaken to build a test fixture that will impose at least the boundary conditions of the prelim steel fixture, but also provide the convenience and practicality of the aluminum fixture.

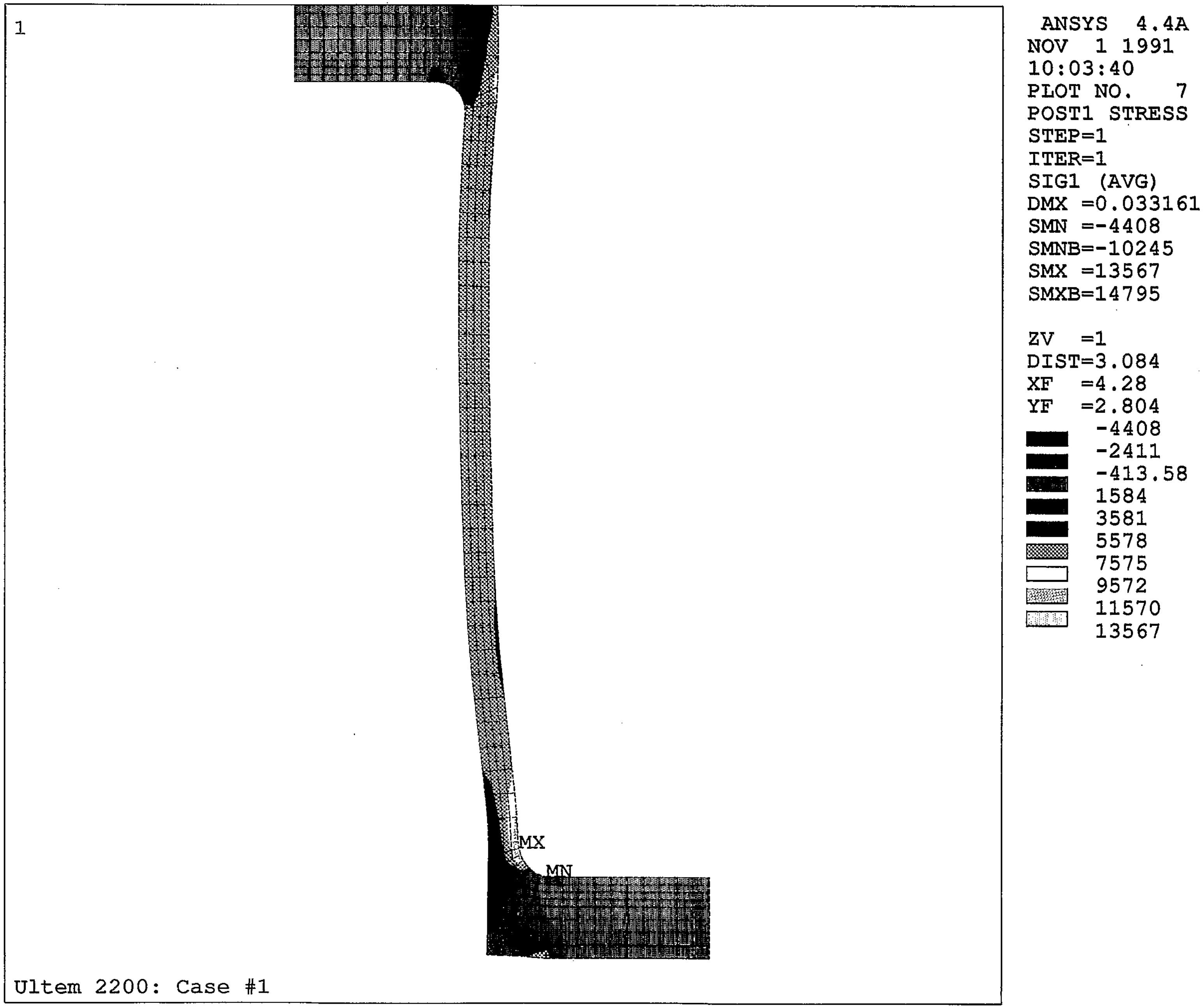
Acknowledgement

The aluminum fixture was designed by Chris Goggin, and Manny Grau. The tests were performed by Bob Dagradi, Mark Sardizinski, and Chris White.

References

(1) AD/RHIC-78, Tensile Tests for Quality Control of Injection Molded Composite Posts, by Lawrence J. Wolf, August, 1990.

APPENDIX A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MN
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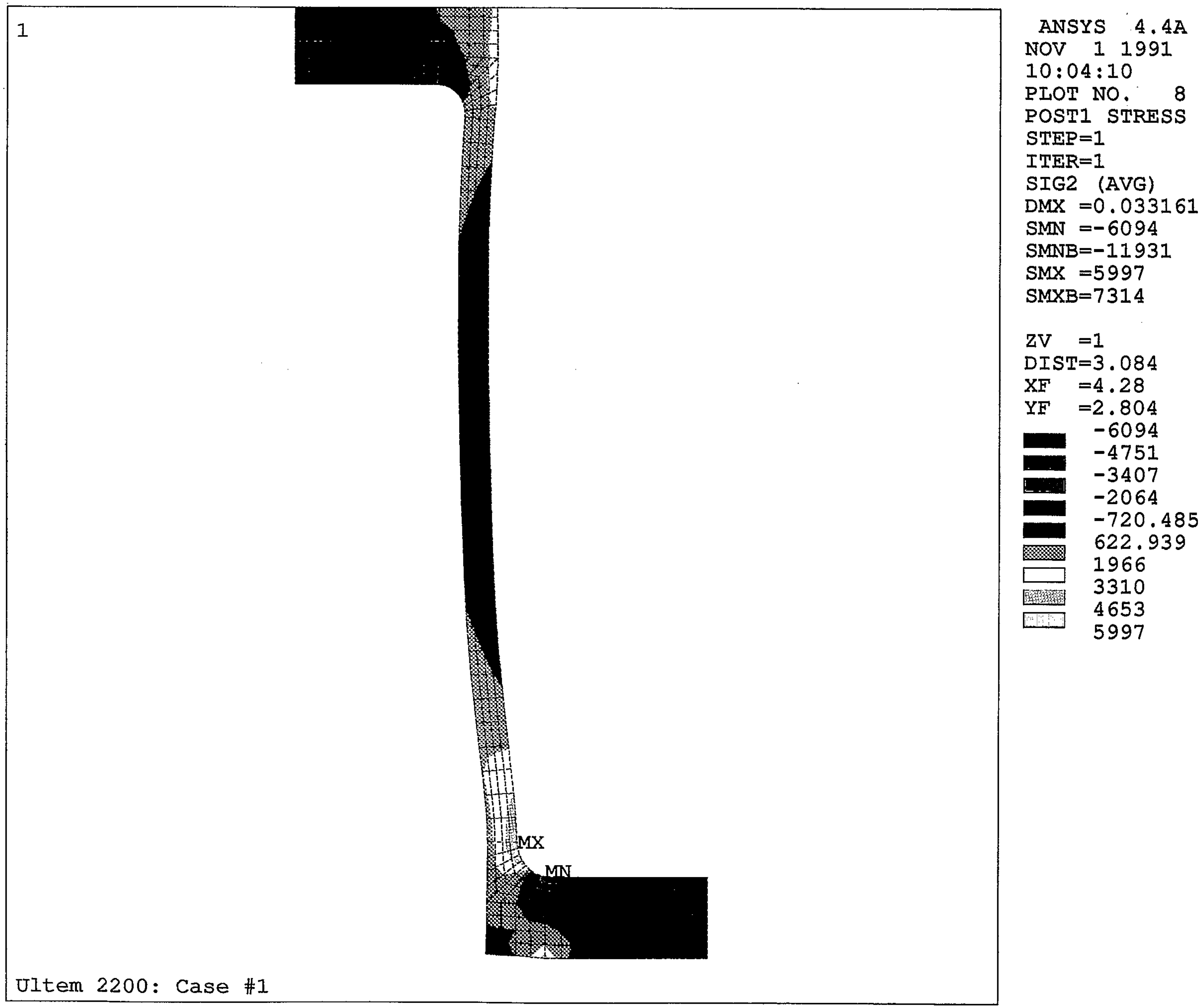
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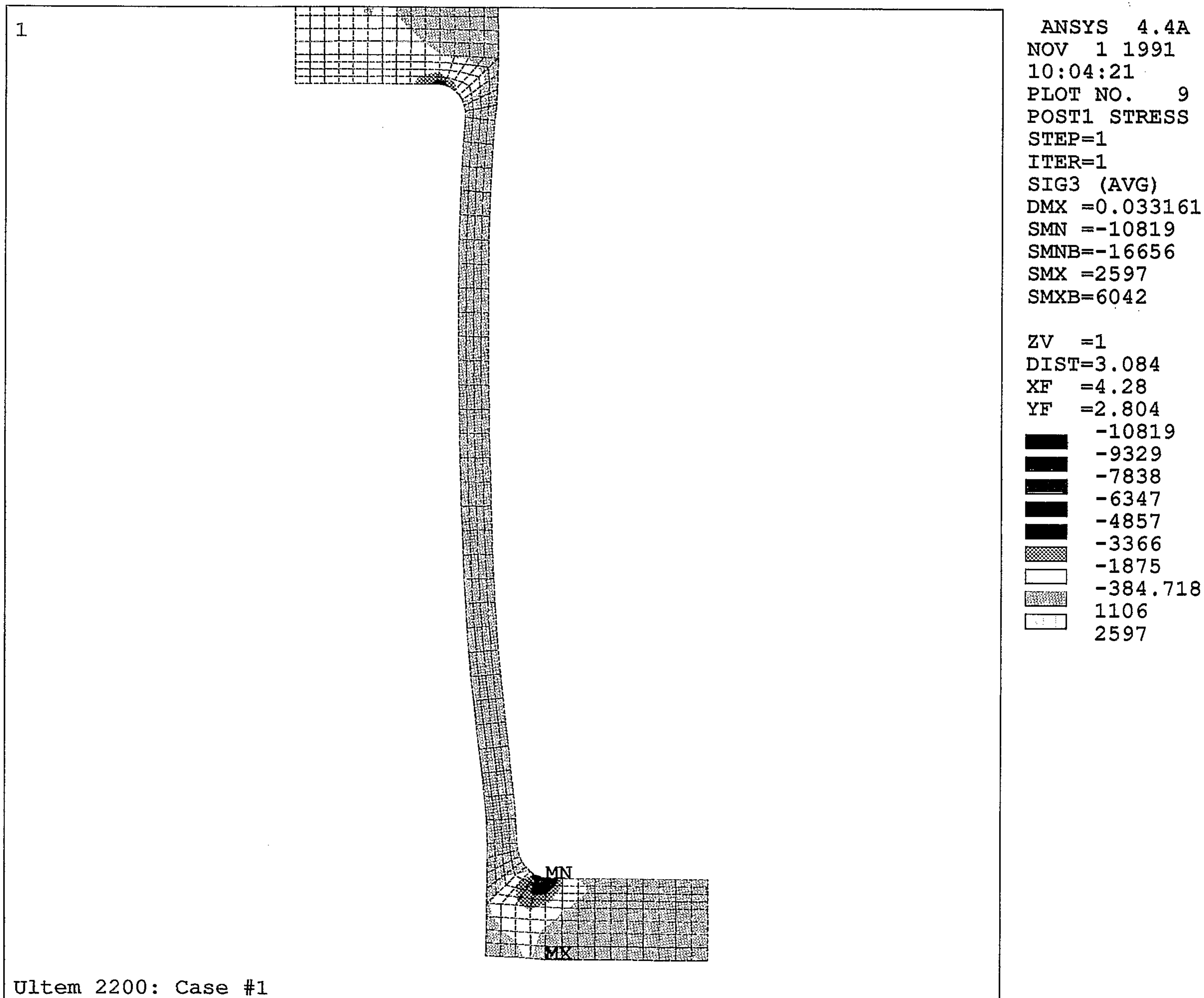
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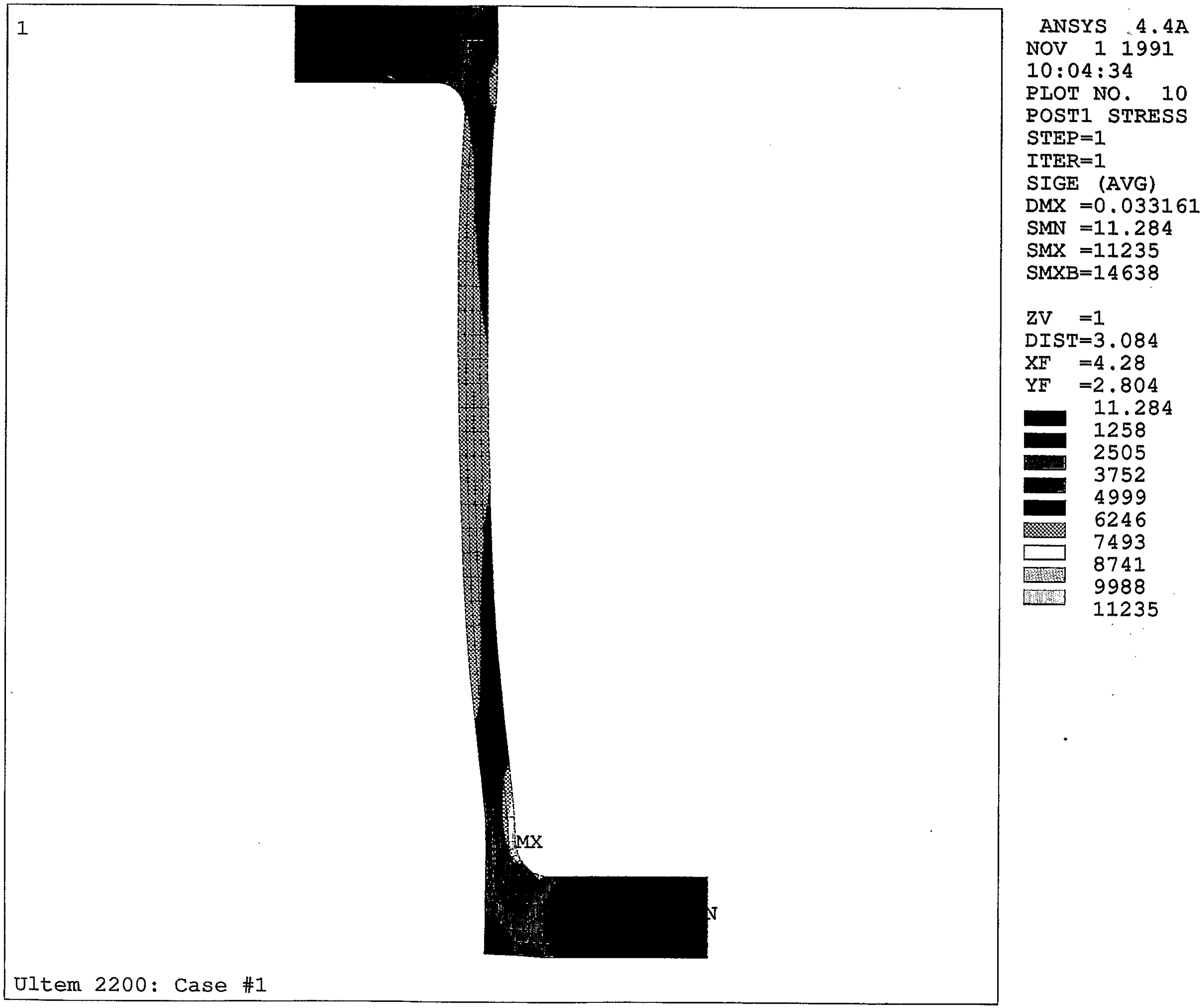
MN
MX
Ultem 2200: Case #1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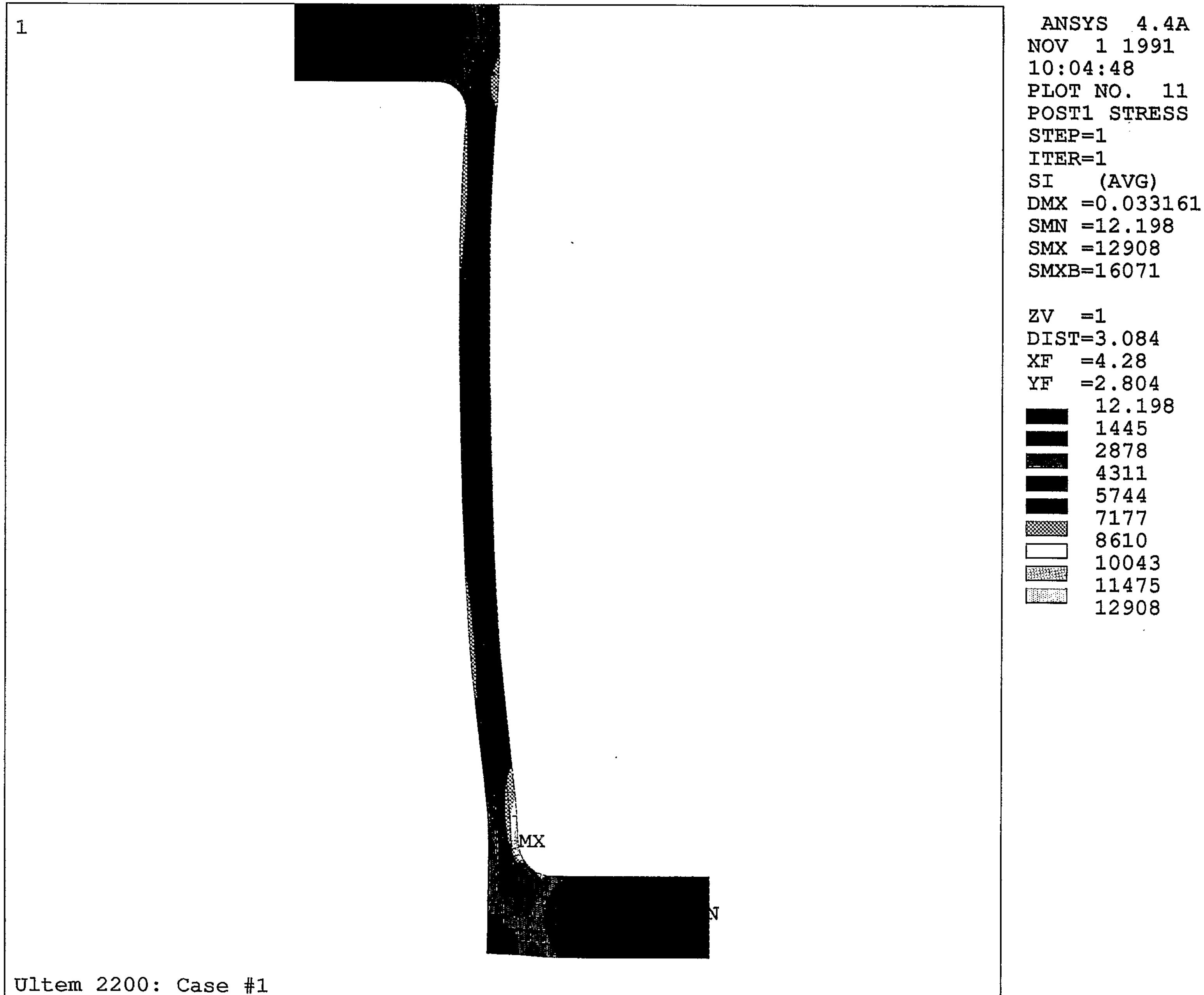
N
Ultem 2200: Case #1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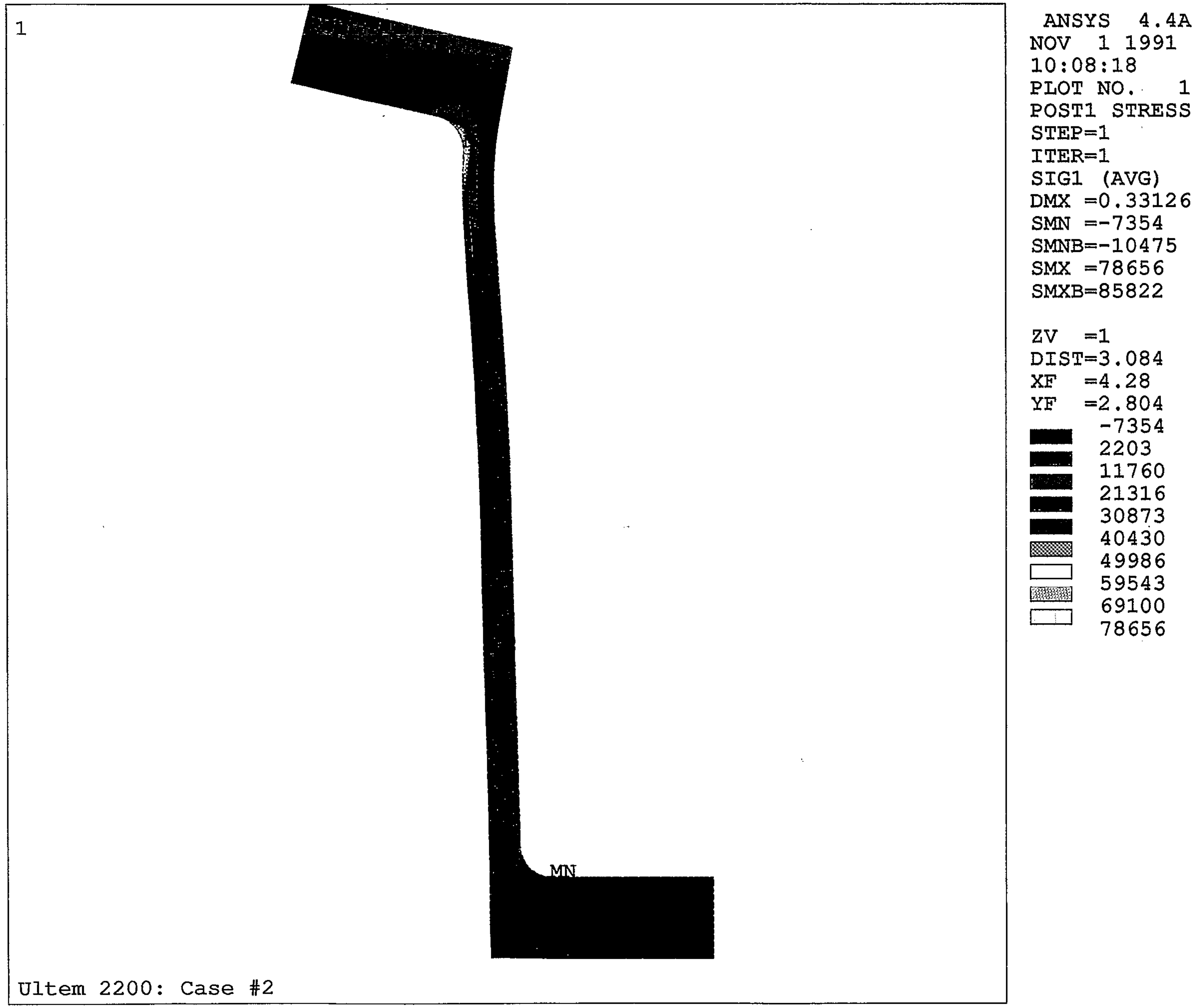
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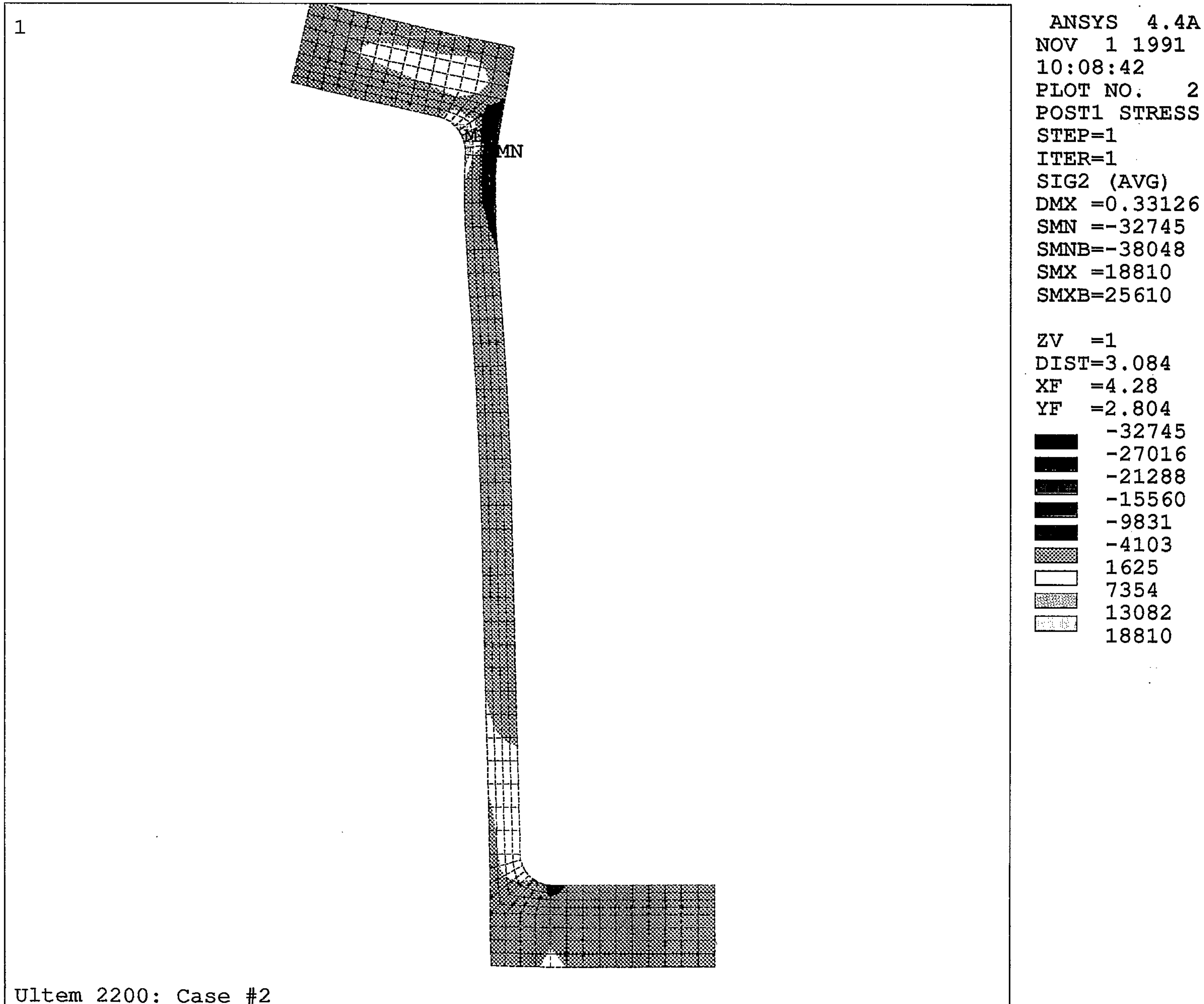
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YF =2.804
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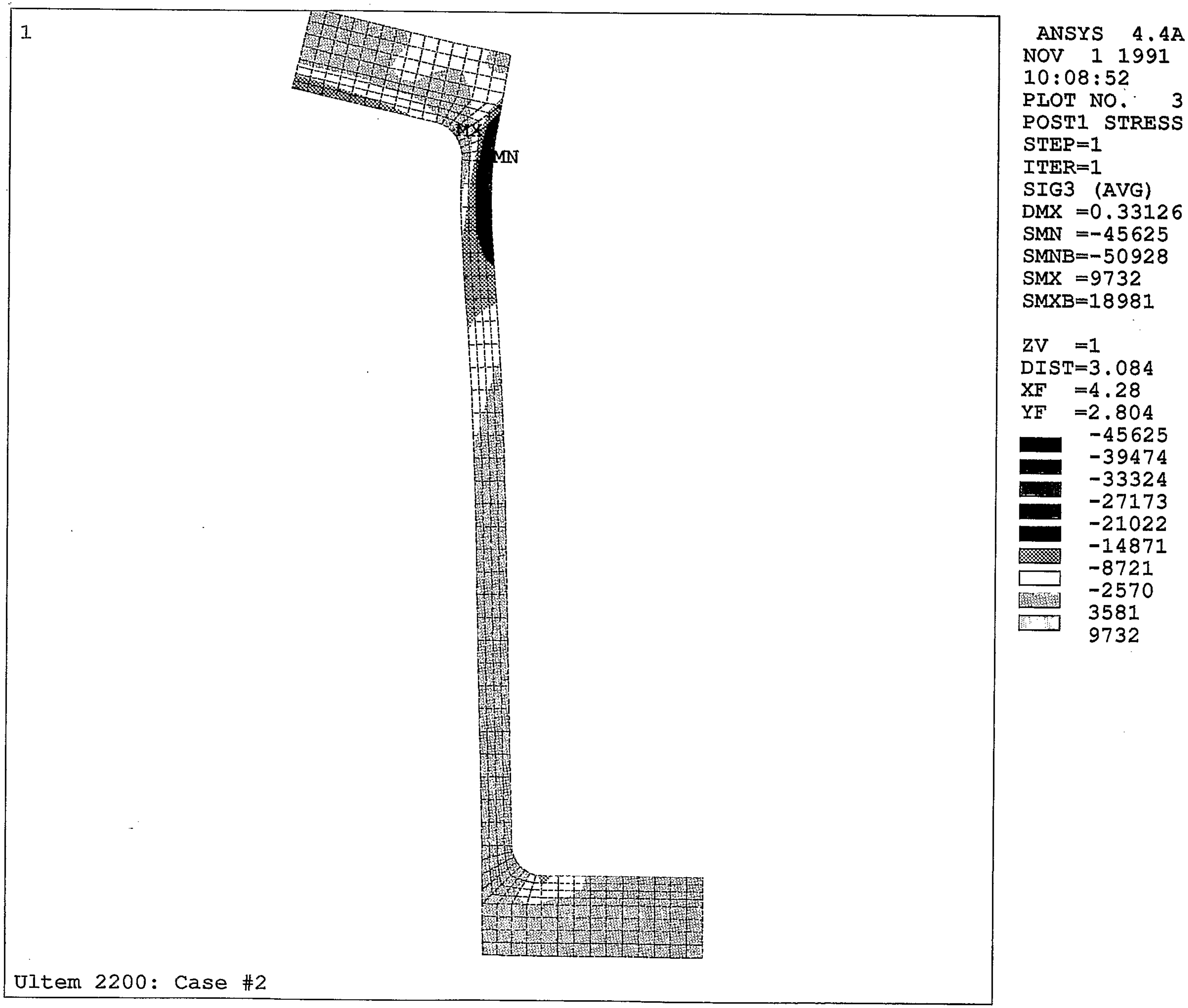
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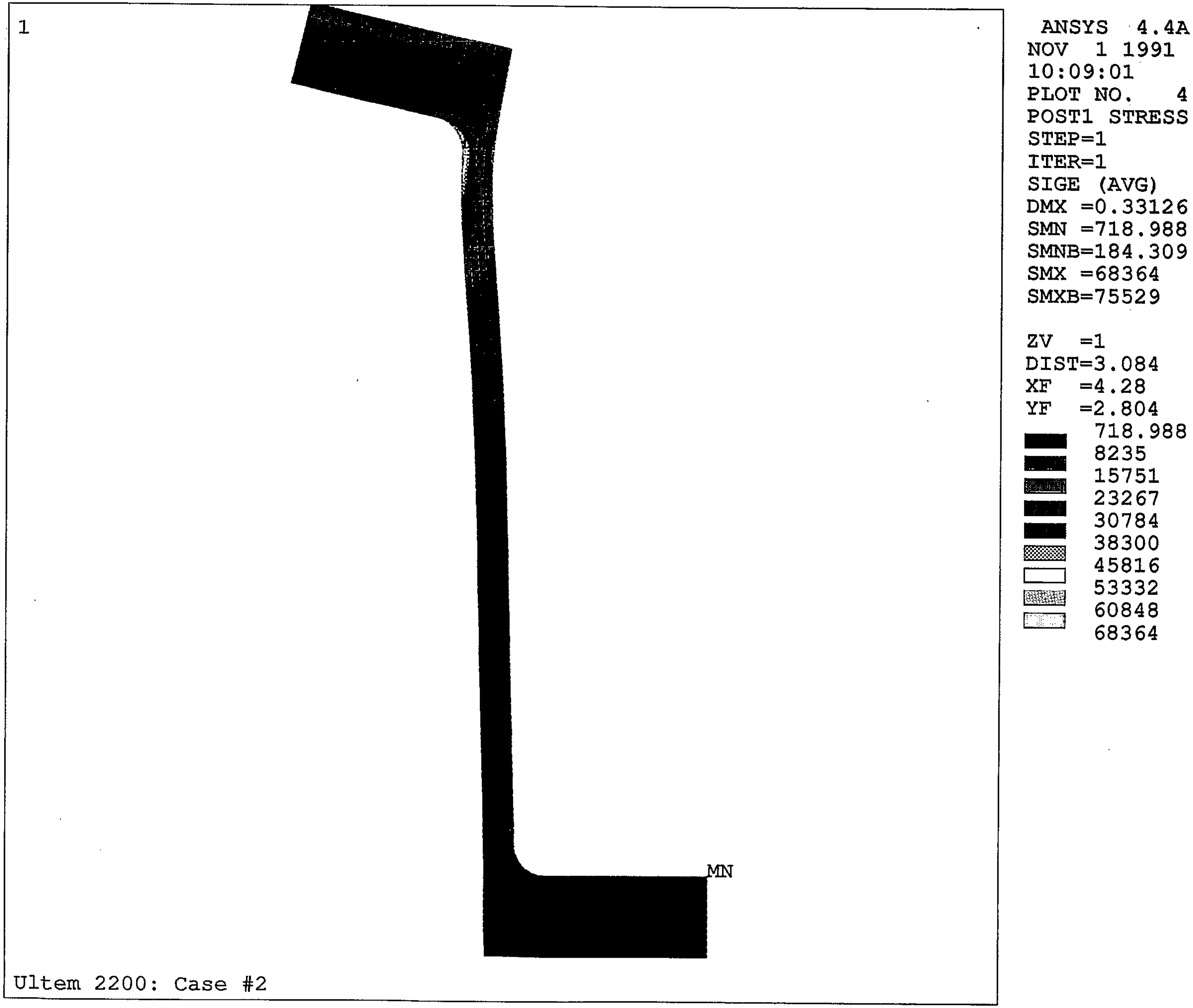
Ultem 2200: Case #2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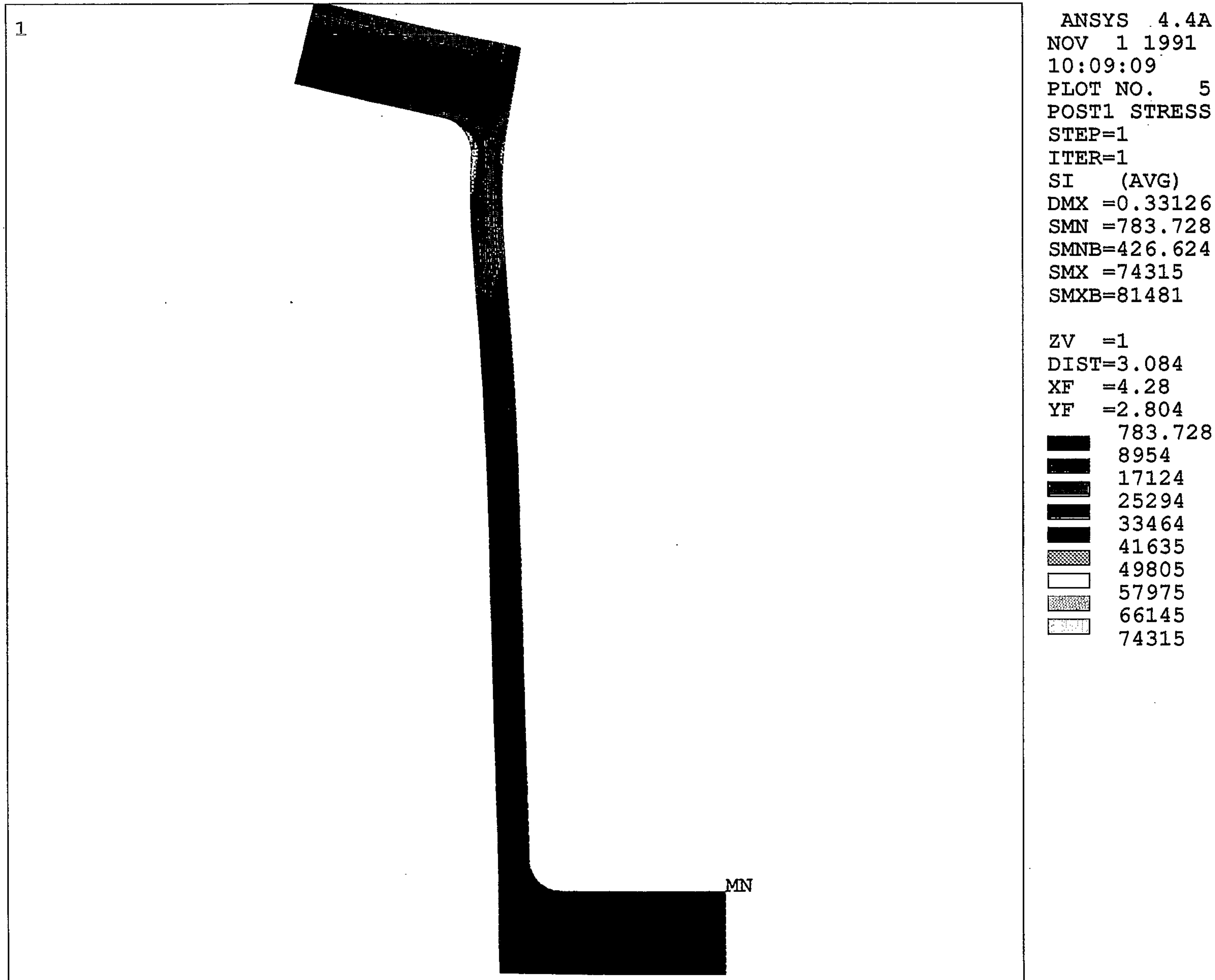

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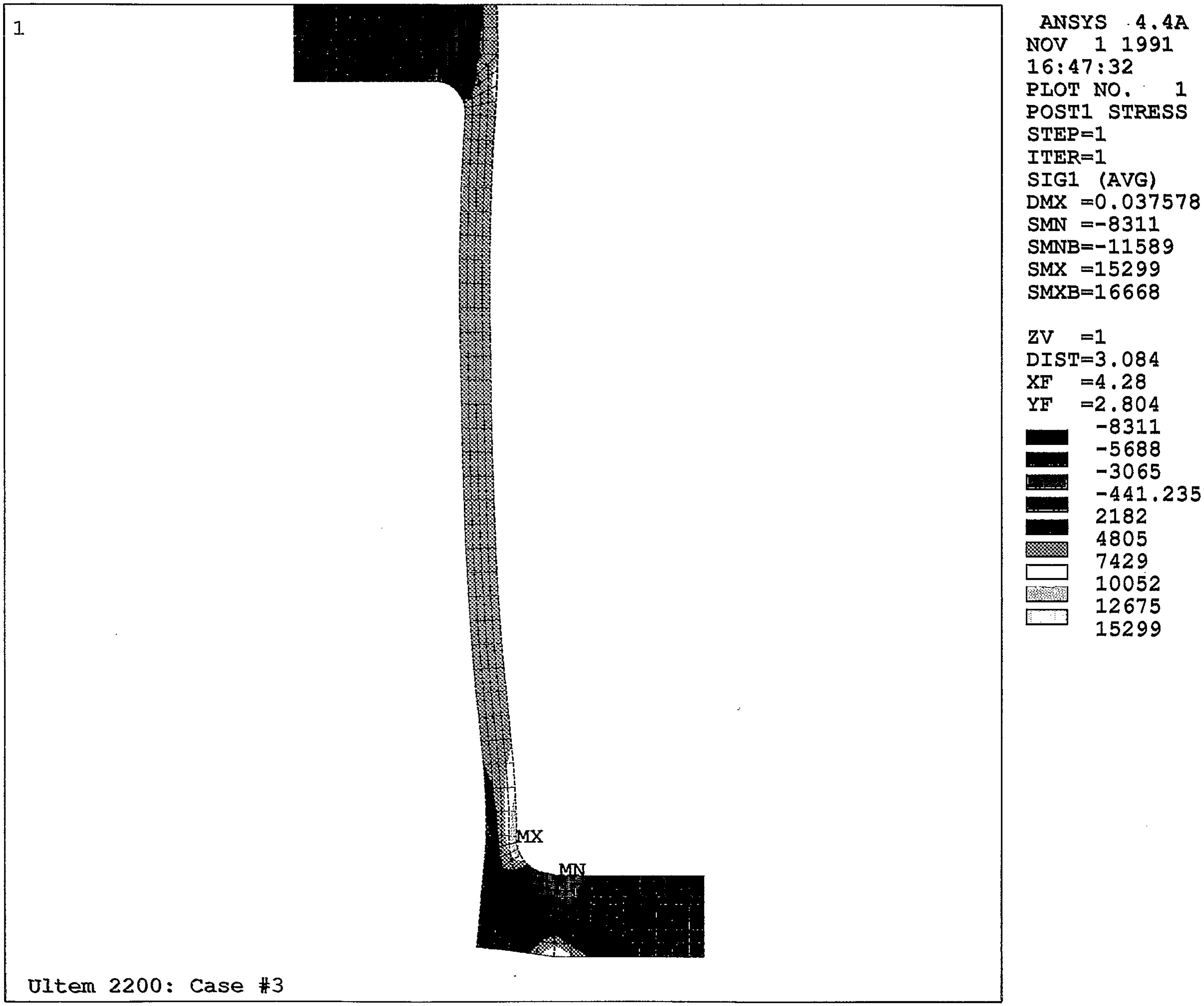
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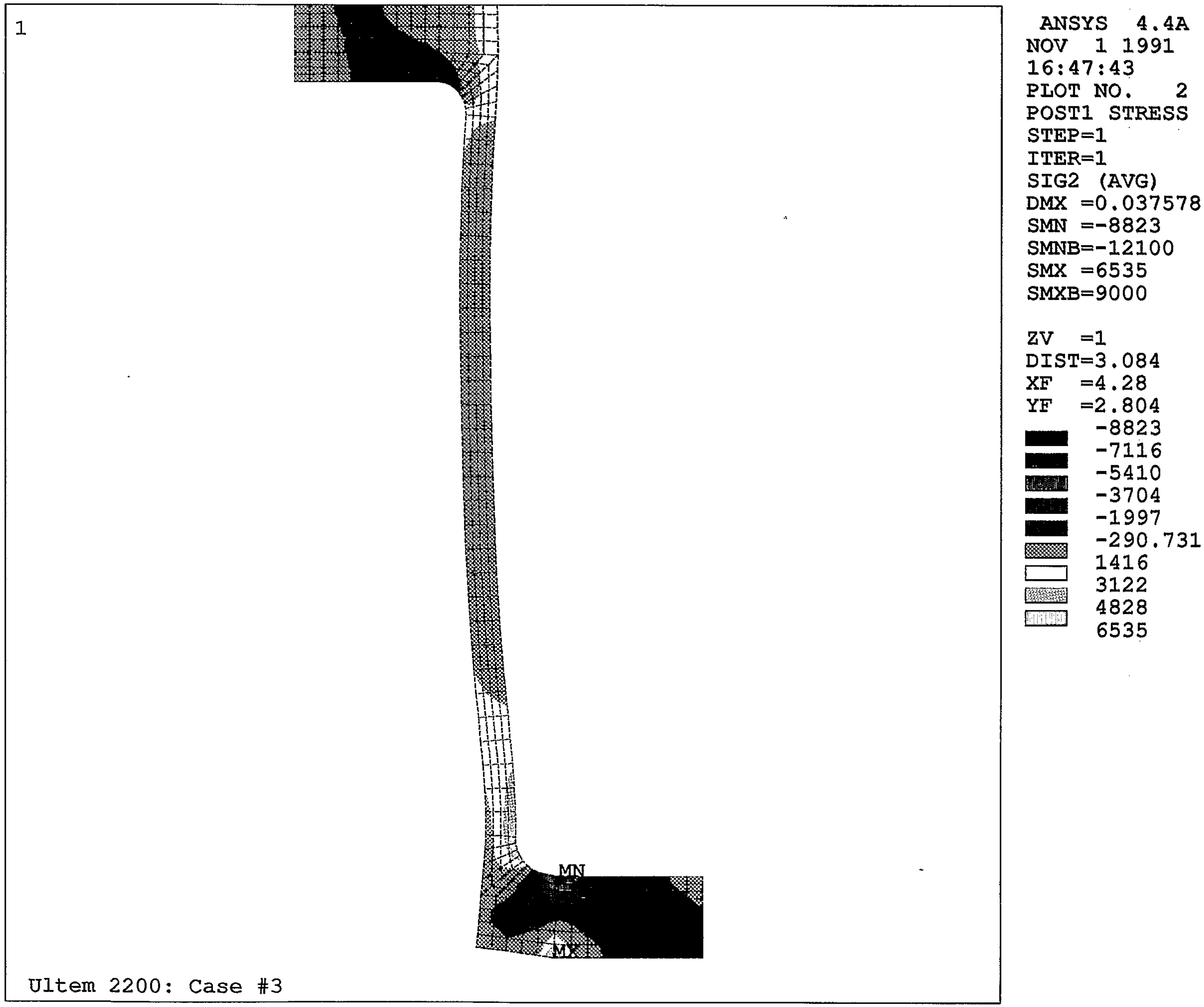
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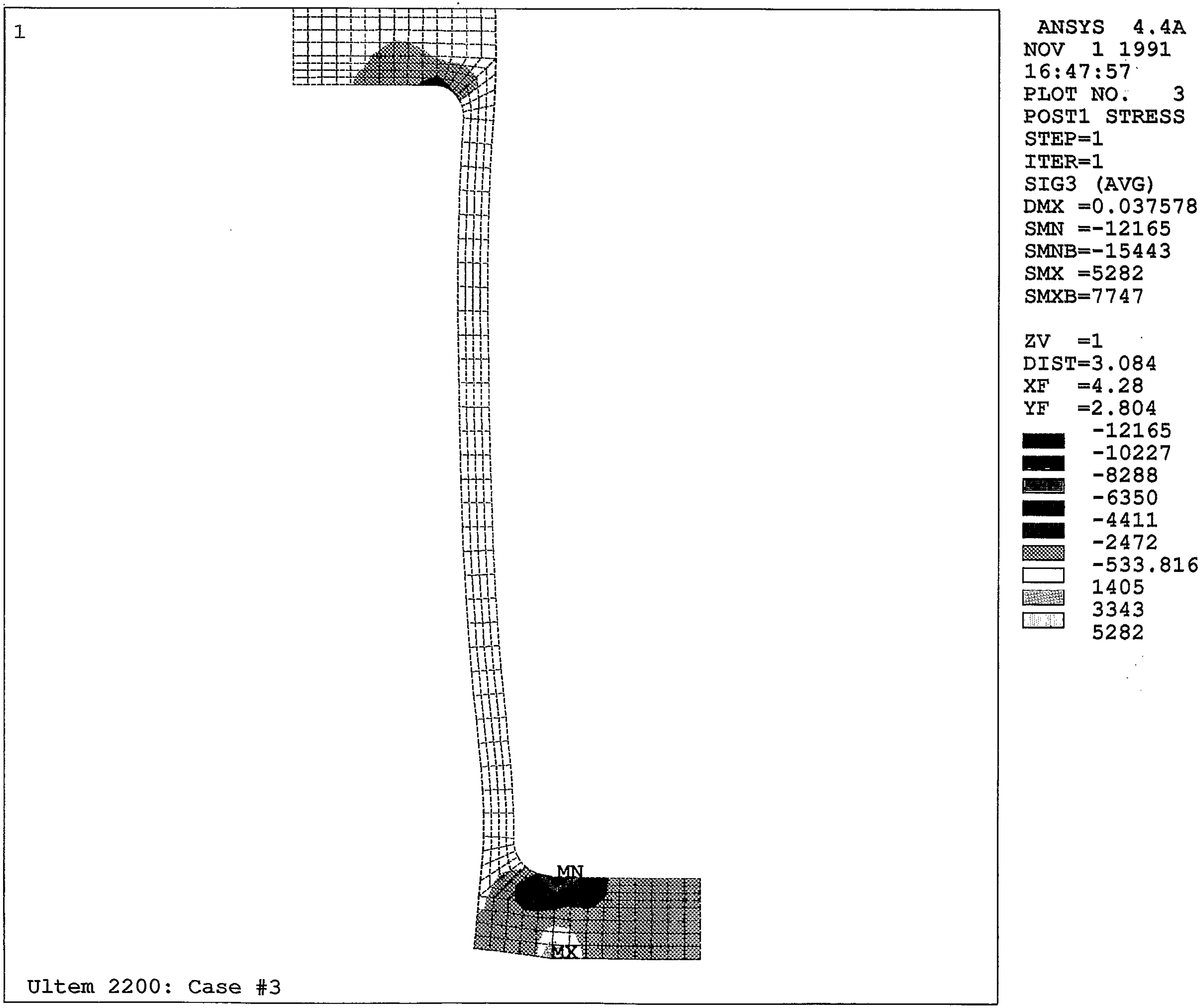
Ultem 2200: Case #3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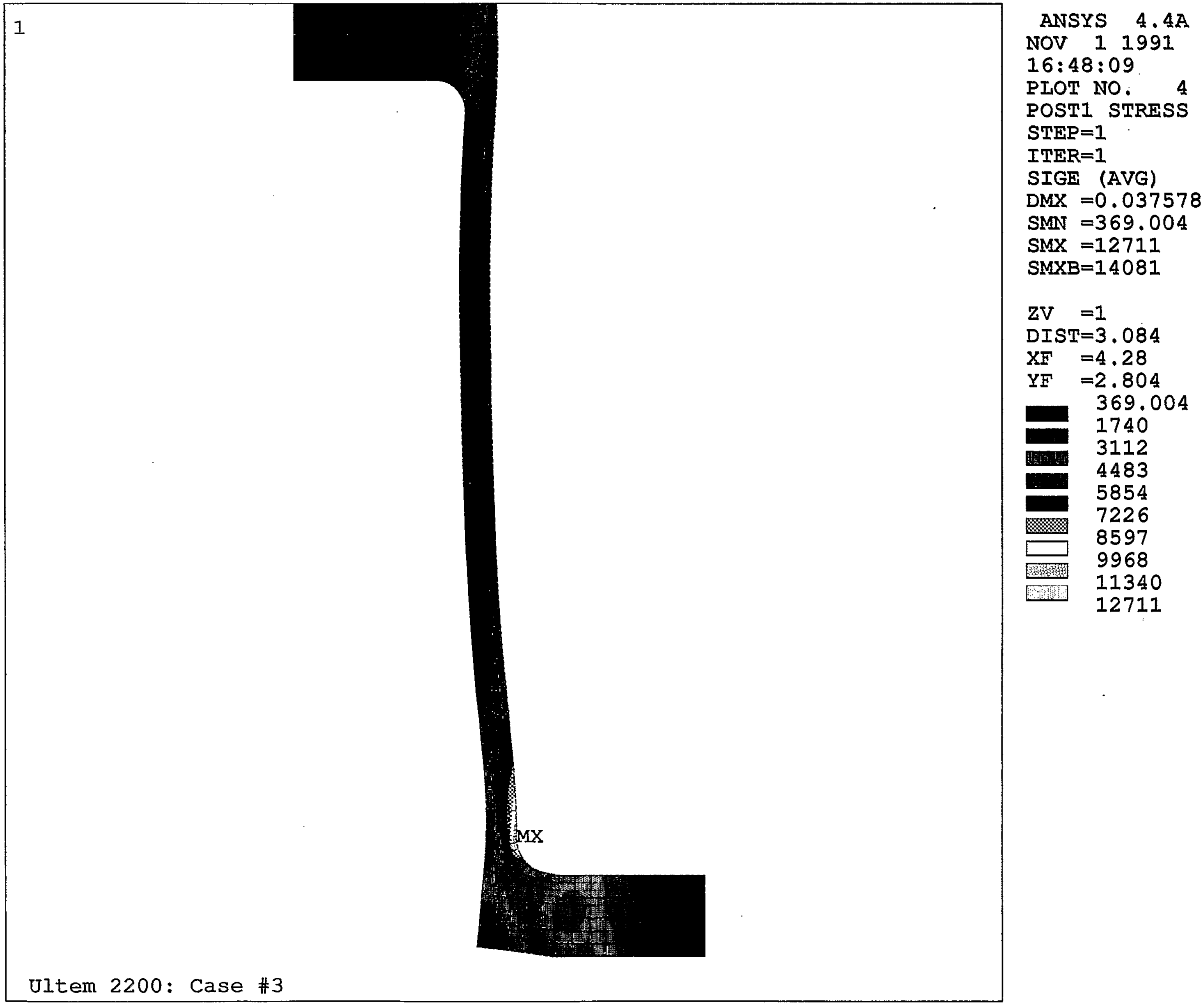
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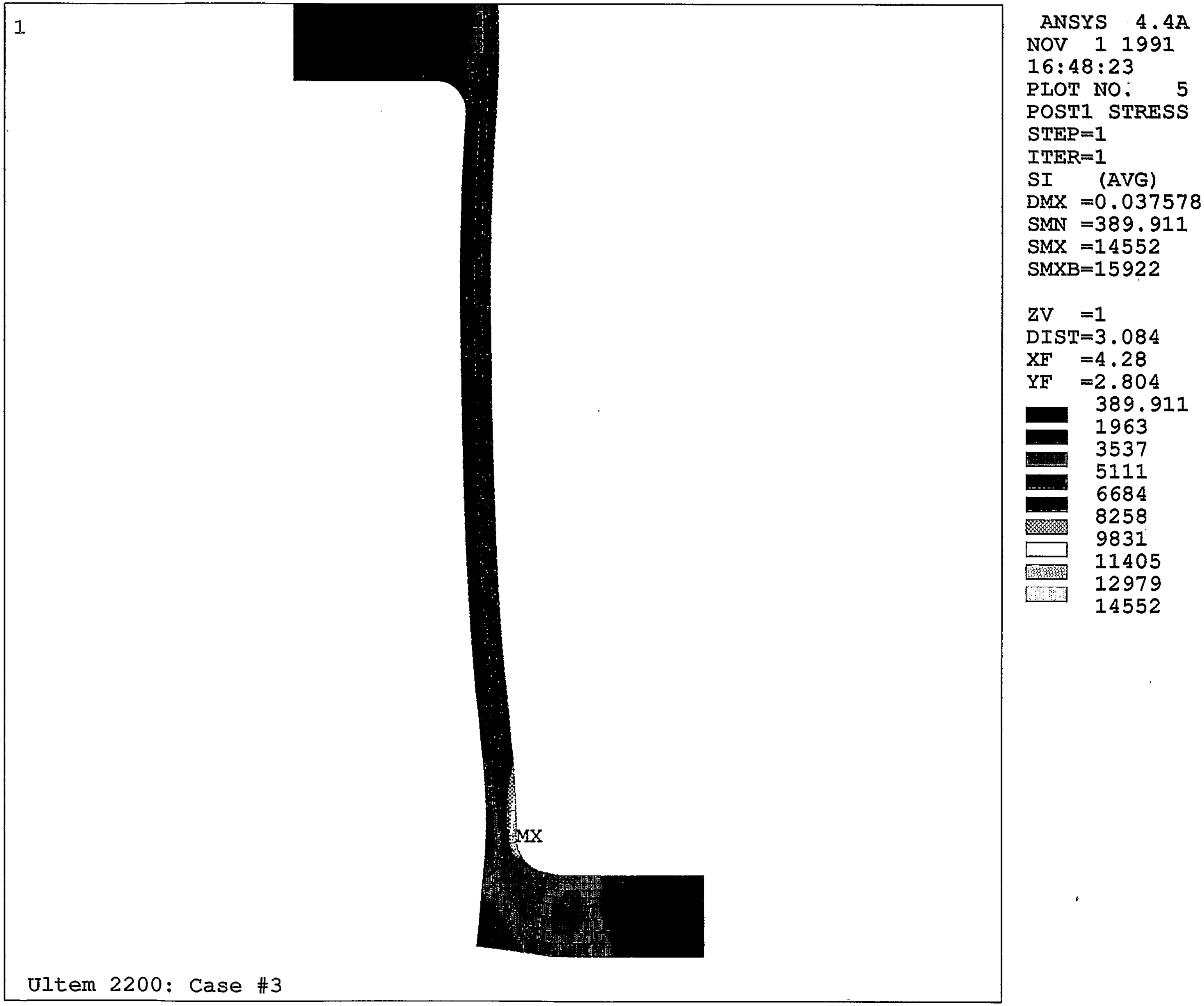
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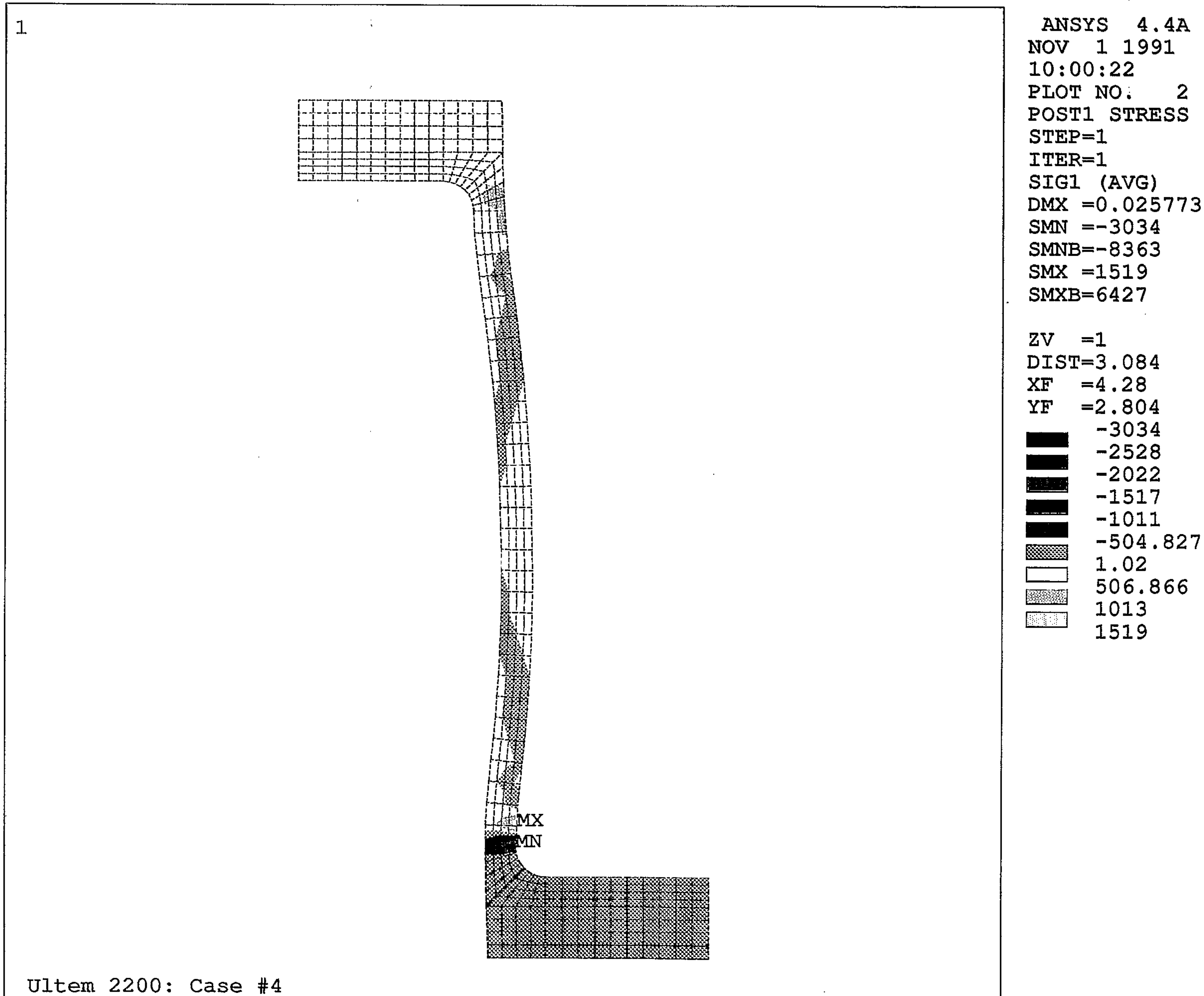

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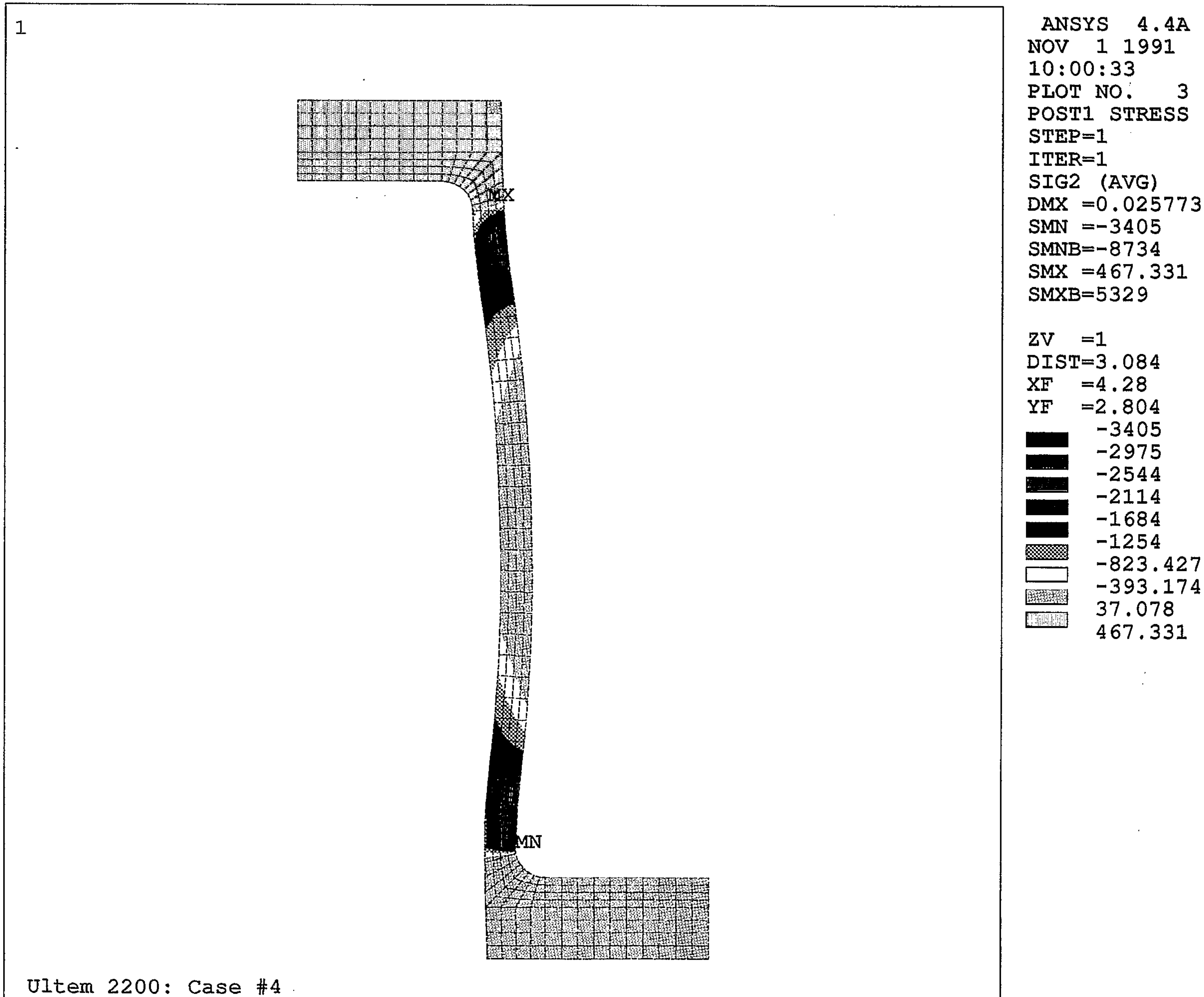

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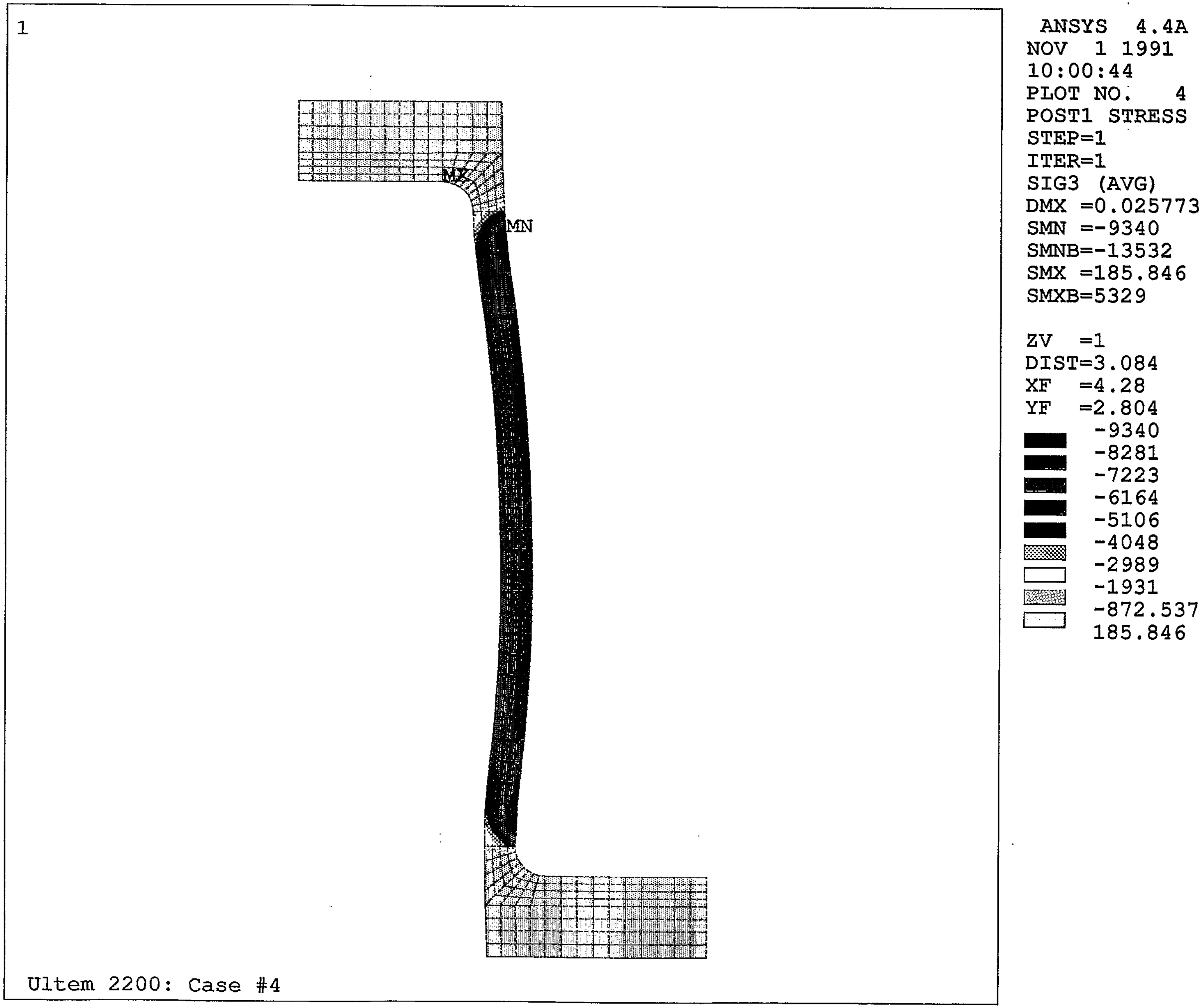

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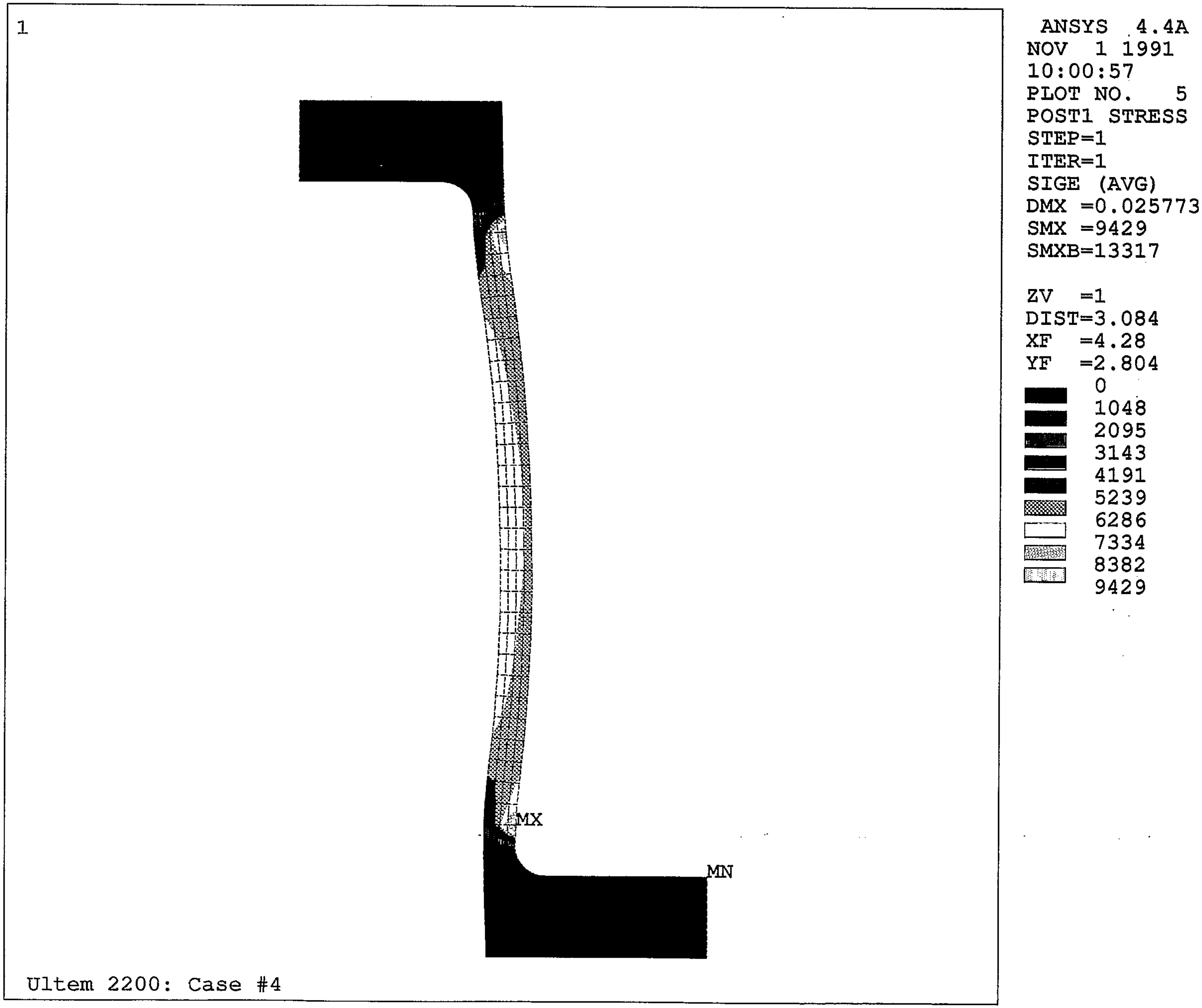
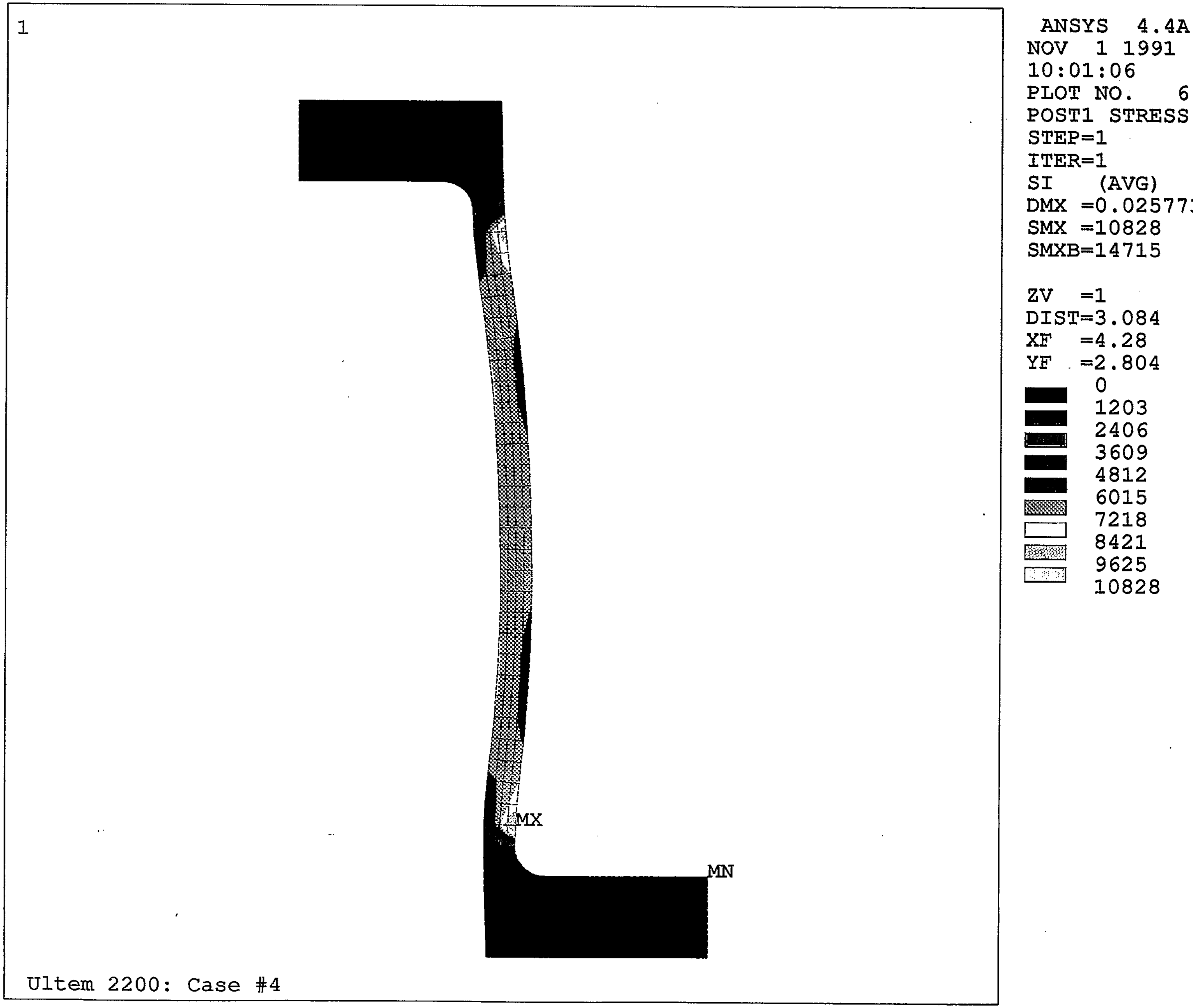


Ultem 2200: Case #4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2406
3609
4812
6015
7218
8421
9625
10828
MX
MN
Ultem 2200: Case #4