Copy with Steve Long's #31 personal notes

FENOC

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Howard W. Bergendahl
Vice President - Nuclear

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Attachment 1 Contains
Proprietary Information Pursuant
to 10 CFR 2.790

Docket Number 50-346

License Number NPF-3

Serial Number 1-1282

July 20, 2002

Mr. James E. Dyer, Administrator
United States Nuclear Regulatory Commission
Region III
801 Warrenville Road
Lisle, IL 60532-4351

Subject: Response to Request for Additional Information Related to the Davis-Besse Nuclear Power Station Safety Significance Assessment

Dear Mr. Dyer:

This letter responds to the NRC Region III Request for Additional Information (RAI) dated May 6, 2002, related to the Safety Significance Assessment of the Davis-Besse Nuclear Power Station (DBNPS) Reactor Pressure Vessel Head as was submitted by FirstEnergy Nuclear Operating Company (FENOC) letter Serial Number 1-1268 on April 8, 2002. FENOC's response to the RAI was provided on June 12, 2002, by FENOC letter Serial Number 1-1277, except for the response to RAI Question 1.d, which required additional time to perform the required analyses. This letter provides the FENOC response to Question 1.d.

Question 1.d of the RAI requested "The estimated areas of exposed clad material that would cause the cladding to fail at normal operating pressure for clad thicknesses of 0.297" and 0.125"." Elastic-plastic finite element stress analyses were performed by Structural Integrity Associates (SIA), Inc., to determine the failure pressure for various exposed clad area values. Attachment 1 provides a proprietary version of this calculation. Attachment 2 provides a non-proprietary version of this calculation. The results of these conservative analyses show that failure is predicted to occur for an exposed clad area of approximately 47.5 in^2 at operating pressure (2185 psig) with a clad thickness of 0.125 inches and for an exposed clad area in excess of 82.0 in^2 at operating

5-13

[redacted] EXS

pressure (2185 psig) with a clad thickness of 0.297 inches. For comparison, the exposed clad area of the actual cavity is approximately 20.5 in^2.

If you have any questions or require further information, please contact Mr. Patrick J, McCloskey, Manager - Regulatory Affairs, at (419) 321-8450.

Sincerely yours,

for H.W. Bergendahl

Attachments

cc: USNRC Document Control Desk
D.V. Pickett, DB-1 NRC/NRR Project Manager
S.P Sands, DB-1 NRC/NRR Backup Project Manager
C.S. Thomas, DB-1 Senior Resident Inspector
Utility Radiological Safety Board

Docket Number 50-346
License Number NPF-3
Serial Number 1-1282
Attachment 3

Framatome ANP Affidavit for
Structural Integrity Associates, Inc., File W-DB-01Q-305

(3 Pages Follow)

AFFIDAVIT

COMMONWEALTH OF VIRGINIA)
) ss.
CITY OF LYNCHBURG)

1. My name is James F. Mallay. I am Director, Regulatory Affairs, for Framatome ANP ("FRA-ANP"), and as such I am authorized to execute this Affidavit.

2. I am familiar with the criteria applied by FRA-ANP to determine whether certain FRA-ANP information is proprietary. I am familiar with the policies established by FRA-ANP to ensure the proper application of these criteria.

3. I am familiar with the information enclosed with a letter from FirstEnergy Nuclear Operating Company (Howard Bergendahl) to the NRC (James Dyer) consisting of a calculation package prepared by Structural Integrity Associates (File No.: W-DB-01Q-305) referred to herein as "Document." Information contained in this Document has been classified by FRA-ANP as proprietary in accordance with the policies established by FRA-ANP for the control and protection of proprietary and confidential information.

4. This Document contains information of a proprietary and confidential nature and is of the type customarily held in confidence by FRA-ANP and not made available to the public. Based on my experience, I am aware that other companies regard information of the kind contained in this Document as proprietary and confidential.

5. This Document has been made available to the U.S. Nuclear Regulatory Commission in confidence with the request that the information contained in the Document be withheld from public disclosure.

6. The following criteria are customarily applied by FRA-ANP to determine whether information should be classified as proprietary:

(a) The information reveals details of FRA-ANP's research and development plans and programs or their results.

(b) Use of the information by a competitor would permit the competitor to significantly reduce its expenditures, in time or resources, to design, produce, or market a similar product or service.

(c) The information includes test data or analytical techniques concerning a process, methodology, or component, the application of which results in a competitive advantage for FRA-ANP.

(d) The information reveals certain distinguishing aspects of a process, methodology, or component, the exclusive use of which provides a competitive advantage for FRA-ANP in product optimization or marketability.

(e) The information is vital to a competitive advantage held by FRA-ANP, would be helpful to competitors to FRA-ANP, and would likely cause substantial harm to the competitive position of FRA-ANP.

7. In accordance with FRA-ANP's policies governing the protection and control of information, proprietary information contained in this Document has been made available, on a limited basis, to others outside FRA-ANP only as required and under suitable agreement providing for nondisclosure and limited use of the information.

8. FRA-ANP policy requires that proprietary information be kept in a secured file or area and distributed on a need-to-know basis.

9. The foregoing statements are true and correct to the best of my knowledge, information, and belief.

____

SUBSCRIBED before me this 12th

day of July, 2002.

____

Ella F. Carr-Payne
NOTARY PUBLIC, STATE OF VIRGINIA
MY COMMISSION EXPIRES: 8/31/05

ELLA F. CARR-PAYNE
Notary Public
Commonwealth of Virginia
My Commission Exps. Aug. 31, 2005

COMMITMENT LIST

The following list identifies those actions committed to by the Davis-Besse Nuclear Power Station (DBNPS) in this document. Any other actions discussed in the submittal represent intended or planned actions by the DBNPS. They are described only for information and are not regulatory commitments. Please notify the Manager - Regulatory Affairs (419-321-8450) at the DBNPS of any questions regarding this document or associated regulatory commitments.

COMMITMENTS	DUE DATE
None	

Docket Number 50-346
License Number NPF-3
Serial Number 1-1282
Attachment 2

Structural Integrity Associates, Inc.
File Number W-DB-01Q-305
"Elastic-Plastic Finite Element Stress Analyses of Davis-Besse RPV Head Wastage Cavity with Different Enlarged Areas and Thicknesses"

(29 Pages Follow)

Non-Proprietary Version

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STRUCTURAL INTEGRITY Associates, Inc.	CALCULATION PACKAGE	FILE No: W-DB-01Q-305 PROJECT No: W-DB-01Q

PROJECT NAME: Operability and Root Cause Evaluation of the Damage of the Reactor Pressure Vessel Head at Davis-Besse

CLIENT: First Energy Corporation

CALCULATION TITLE: Elastic-Plastic Finite Element Stress Analyses of Davis-Besse RPV Head Wastage Cavity With Different Enlarged Areas and Thicknesses

PROBLEM STATEMENT OR OBJECTIVE OF THE CALCULATION:

Develop a finite element models to evaluate the effects of wastage cavity growth for clad thicknesses of 0.125 inches and 0.297 inches.

Document Revision	Affected Pages	Revision Description	Project Mgr. Approval Signature & Date	Preparer(s) & Checker(s) Signatures & Date
0	1 – 29 Project CD-Rom	Original Issue	7/8/02	7-8-02 7-8-02

1.0 INTRODUCTION

During recent in-service inspections of the reactor pressure vessel (RPV) head and penetrations at Davis-Besse, significant wastage was observed in the vicinity of control rod drive mechanism (CRDM) No. 3. An initial investigation of the cavity was performed in order to understand the existing structural margin given different clad thickness values [1]. In the Reference 1 evaluation, the average measured clad thickness of 0.297 inches and the minimum measured thickness of 0.24 inches were considered. Subsequently, concerns were raised about the possibility of growth of the wastage cavity and how this growth will affect the structural margins. There was also a concern of the possibility of the cladding reaching the minimum specified thickness of 0.125 inches.

Initial investigations of the enlarged cavities were performed in a second calculation, which evaluated the effects of a cavity twice the original size of the cavity using the minimum measured thickness clad thickness of 0.24 inches [2].

This calculation is a follow up to the analyses performed in References 1 and 2 by evaluating clad thicknesses of 0.297 inches and 0.125 inches for cavities up to four times the original cavity.

2.0 TECHNICAL APPROACH

The evaluations will be performed using a three-dimensional finite element model (similar to those used in References 1 and 2), which accurately models the reactor pressure vessel head, the penetrations in the vicinity of the wastage, those CRDM attachment welds that are directly affected by the cavity and enlarged wastage areas. Similar to the References 1 and 2 evaluations, elastic-plastic material properties of the materials of the various components will be used to determine the limiting pressure.

2.1 Finite Element Model

The finite element model was constructed using the ANSYS finite element software package [3] and are based on the 3-D models developed in References 1 and 2. As such, the basic dimensions, material properties and assumption used in the original model development in References 1 and 2 remain valid. Any variations from Reference 1 and 2 modeling will be documented in the following sections. An example of the model can be seen in Figure 1. In summary, a series of full 360° model were created and includes the following:

- Closure head
- Closure head cladding
- Upper closure flange
- CRDM housing tubes 1, 3, 6, 7 and 11
- J-groove attachment weld and butter for CRDM tube No. 3 (All cavity sizes)
- J-groove attachment weld and butter for CRDM tube No. 11 (Most cavity sizes)
- Enlarged wastage cavity

A total of seven evaluations will be performed for various cavity sizes and clad thickness. The 0.125 inch clad was evaluated using the original cavity and cavities that were twice, three times and four times larger than the original cavity. The 0.297 inch clad was evaluated using cavities that were twice, three times and four times larger than the original cavity. The original cavity was previously evaluated for 0.297 inch clad thickness in Reference 1.

2.1.1 CRDM-to-Head Weld

For these evaluations, the J-groove attachment weld and butter were explicitly modeled only for Tubes 3 and 11. The one exception is in the case of the 0.125 inch clad evaluation for the original size cavity (20.5 in²). For that evaluation only, the J-groove weld for Tube 11 was also not explicitly modeled.

For all of the finite element models in this evaluation, the remaining modeled Tubes; 1, 6, and 7 (and Tube 11 for the original cavity 0.125 inch clad case) the CRDM tubes are attached only at the stainless clad.

The weld prep butter was assumed not to be part of the attachment between the vessel and the inconel tube. In addition, the cover fillet applied to the J-groove weld was not modeled.

2.1.2 Enlarged Wastage

References 1 provided a basic layout of the original modeled wastage. The exposed clad for this original cavity was approximately 20.5 in². Reference 2 expanded the wastage cavity to twice the original area, 41.0 in² for 0.24 inches of clad thickness. In addition, Reference 2 included expanded results for the 0.297 inch clad case for the original cavity (20.5 in²).

The self-similar enlarged cavity reproduced the same shape by scaling up the original cavity dimensions until the exposed clad area reaches the desired values. In this case the exposed clad areas investigated are 20.5 in² (A), 41.0 in² (2A), 61.5 in² (3A) and 82 in² (4A). See Figures 2 through 5 for the resulting exposed clad area and transition region. The decision to limit the cavity growth value to 4A for this evaluation is to ensure that Tube 11 is not fully exposed. As will be shown later in this calculation package, for the 0.297 inch cladding thickness, significantly more area of the cavity can be exposed before failure is predicted at the operating pressure of 2185 psig.

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3.0 MATERIALS

[redacted]

4.0 LOADING

A uniform temperature of 605°F [4] was applied over all models with the stress free temperature being 70°F.

A pressure load is applied incrementally to the inside surface of the hemispherical head, the external surfaces of the CRDM tube sections inside the vessel, the inside surfaces of the CRDM tubes and to the closure flange face out to a radius of 84.8115 inches [5] until instability is reached.

In addition, a cap pressure was applied to the outside free end of the CRDM tubes to simulate line load in each tube. Note that the applied cap load was actually applied in the negative direction in ANSYS, thus providing a traction load.

No other operating loads were applied since previous preliminary evaluations have shown that these loads do not have any significant effect on the limiting pressure. This includes closure loads such as bolt pre-load, gasket squash loads and ledge/spring loads.

5.0 FAILURE CRITERIA

In this elastic-plastic analysis, the failure criterion is set such that the maximum strain cannot exceed the ultimate tensile strain. Hence for the stainless steel cladding where the maximum strain is expected to occur, the maximum equivalent total strain is limited to the maximum strain of 11.15% (corresponding to the ultimate strain for the stainless steel cladding in Reference 6) through the thickness of the component.

It was concluded from the analyses performed in Reference 7 that a better prediction of actual failure pressure is the pressure at which numeric instability is reached in the ANSYS program. Hence, the pressure at which numeric instability occurred for each of the cases considered in this evaluation is also presented.

6.0 RESULTS

The resulting failure pressures for the 0.125 inch and 0.297 inch clad thickness are shown in Table 1. Also included are the pressures at which instability occurred. Figures 6 and 7 present the same data graphically. Also plotted on Figures 6 and 7 for comparison is the normal operating pressure of 2185 psig.

Table 1
Failure Pressure for Enlarged Wastage

Clad Thickness (in)	Exposed Clad Area (in²)	Failure Pressure (psi)	
		11.15% Criteria	Instability
0.125	20.5	~3480[2]	3667.7
	41.0	~2443[2]	3298.9
	61.5	~1775[2]	2551.6
	82.0	~1638[2]	2281.1
0.297	20.5	~5649[3]	7000[1]
	41.0	~4657[3]	6481.7
	61.5	~3627[3]	5899.9
	82.0	~3041[3]	4172.0

[1] Results from Reference 1.
[2] Interpolated from Analysis Results See Table 2 on the following page.
[3] Interpolated from Analysis Results See Table 3 on the following page.

Tables 2 and 3 present the through-wall strain distribution for the location that first exceeds the 11.15% failure criterion. Note that for each cavity size, two sets of strains are listed, which bound the 11.15% criteria. Between these two sets of strains is a linearly interpolated set of results to approximate the 11.15% criteria.

Figures 8 through 21 present total Von Mises strain versus the applied pressure at outside surface, middle and inside surface of the clad at a given location. The locations of interest include the point where the through-wall strain first exceeds the 11.15% failure criteria, the location of the maximum Von Mises strain and at the approximate center of the exposed clad region. The failure location in each of these cases is not the same due to the wastage configuration.

Table 2
Through Wall Total Von Mises Strain at Failure of 11.15% Strain Criteria Location
0.125 inch Clad Case

Clad Thickness (in)	0.125											
Cavity Size (in²)	20.5	20.5	20.5	41.0	41.0	41.0	61.5	61.5	61.5	82.0	82.0	82.0
Pressure (psi)	3365	3480[1]	3547	2438	2443[1]	2722	1722	1775[1]	1916	1617	1638[1]	1780
Clad OD	8.9	11.15[1]	12.4	11.0	11.15[1]	18.0	9.1	11.15[1]	16.8	10.7	11.15[1]	14.2
	13.7	16.2[1]	17.6	11.9	12.0[1]	18.9	10.7	12.8[1]	18.6	16.7	17.2[1]	21.0
	18.7	21.3[1]	22.8	13.6	13.7[1]	20.9	14.2	16.4[1]	22.5	23.5	24.1[1]	28.7
Mid-Plane	23.0	25.7[1]	27.2	15.7	15.9[1]	23.3	18.6	21.0[1]	27.4	28.5	29.2[1]	34.2
	27.2	29.9[1]	31.4	18.3	18.5[1]	26.1	23.8	26.2[1]	32.7	32.8	33.6[1]	38.7
	31.4	34.1[1]	35.6	20.7	20.8[1]	28.2	29.3	31.6[1]	37.8	37.1	37.8[1]	42.9
Clad ID	34.7	37.3[1]	38.8	27.3	27.4[1]	29.6	33.1	35.3[1]	41.3	39.9	40.6[1]	45.7

[1] Linearly Interpolated Results to Approximate 11.15% Failure Criteria

Table 3
Through Wall Total Von Mises Strain at Failure of 11.15% Strain Criteria Location
0.297 inch Clad Case

Clad Thickness (in)	0.297											
Cavity Size (in²)	20.5	20.5	20.5	41.0	41.0	41.0	61.5	61.5	61.5	82.0	82.0	82.0
Pressure (psi)	5600[2]	5649[1]	5800	4409	4657[1]	4850	3448	3627[1]	3742	2826	3041[1]	3115
Clad OD	26.8[2]	27.1[1]	28.0[2]	20.5	21.6[1]	22.5	9.9	11.15[1]	12.0	9.7	11.15[1]	11.7
	14.0[2]	14.3[1]	15.2[2]	10.8	11.6[1]	12.2	11.8	13.3[1]	14.2	11.5	13.2[1]	13.8
	10.8[2]	11.15[1]	12.3[2]	9.1	11.15[1]	12.8	12.4	13.9[1]	14.9	12.0	13.7[1]	14.3
Mid-Plane	15.0[2]	15.4[1]	16.9[2]	13.9	16.5[1]	18.6	12.3	13.8[1]	14.8	11.9	13.6[1]	14.2
	22.3[2]	22.9[1]	24.9[2]	19.6	23.2[1]	26.0	12.3	13.8[1]	14.7	11.9	13.6[1]	14.2
	33.9[2]	34.8[1]	37.6[2]	26.6	31.1[1]	34.6	12.6	14.0[1]	15.0	12.2	14.0[1]	14.6
Clad ID	44.6[2]	45.6[1]	49.0[2]	31.7	36.9[1]	40.9	13.3	14.8[1]	15.8	12.8	14.7[1]	15.4

[1] Linearly Interpolated Results to Approximate 11.15% Failure Criteria
[2] Results from Reference 2.

7.0 CONCLUSIONS

The analyses presented in this evaluation have shown that for the 0.125 inch cladding thickness, considering the criterion based on the uniform elongation of 11.15%, failure is predicted to occur when the wastage cavity is over 47.5 in^2 (as shown in Figure 6) for an operating pressure of 2185 psig, which is over two times the original cavity size. If the failure criterion is based on when numeric instability occurred, up to four times the area of the original cavity can be tolerated before failure is predicted.

For the 0.297 inch cladding thickness, both the 11.15% uniform elongation criteria and that based on numeric instability predicted that up to four times the area of the original cavity can be tolerated without predicting failure (as shown in Figure 7). Linearly fitting the 11.15% criteria data indicates that failure will occur at exposed clad area of approximately 102.5 in^2, which is five times the original cavity area.

8.0 REFERENCES

1) Structural Integrity Associates Calculation W-DB-01Q-301, Rev. 1, "Elastic-Plastic Finite Element Stress Analysis of Davis-Besse RPV Head Wastage Cavity."

2) Structural Integrity Associates Calculation W-DB-01Q-302, Rev. 0, "Elastic-Plastic Finite Element Stress Analysis of Enlarged Davis-Besse RPV Head Wastage Cavity."

3) ANSYS/Mechanical, Revision 5.7, ANSYS Inc., December 2000

4) Letter DBE-01-000133, Dated September 13, 2001 from Prasoon Goyal (First Energy) to Dick Mattson (SI), SI File W-ENTP-11Q-219P.

5) Framatome Technologies Technical Document 33-1201205-02, Rev. 2, "Stress Report Summary for Reactor Vessel, Toledo Edison Company, Davis-Besse Unit No. 1," SI File W-ENTP-11Q-219P

6) Email of from B.R. Grambau (Framatome ANP) to N. Cofie (SI), "308 Stress –Strain Curve," March 15, 2002, SI File W-DB-01Q-202.

7) Structural Integrity Associates Calculation W-DB-01Q-304, Rev. 0, "Evaluation of Failure Criterion Used in Elastic-Plastic Analysis of Davis-Besse RPV Head Wastage."

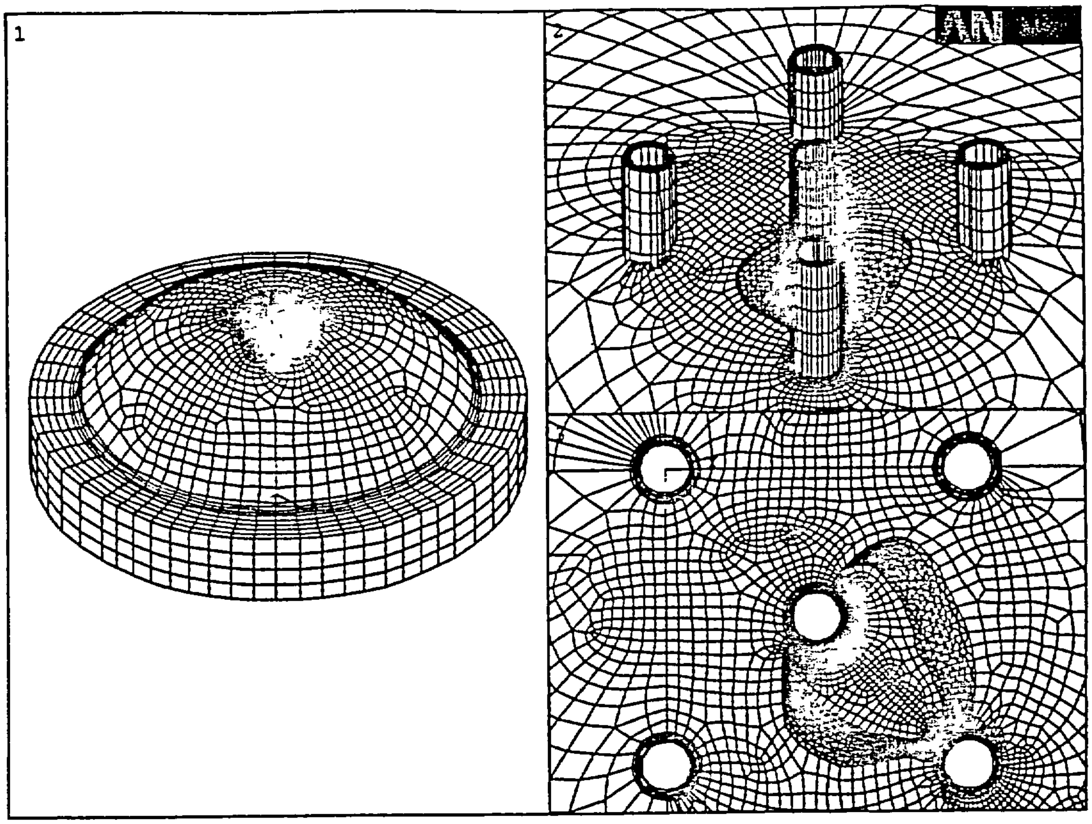


Figure 1 – Typical Finite Element Model

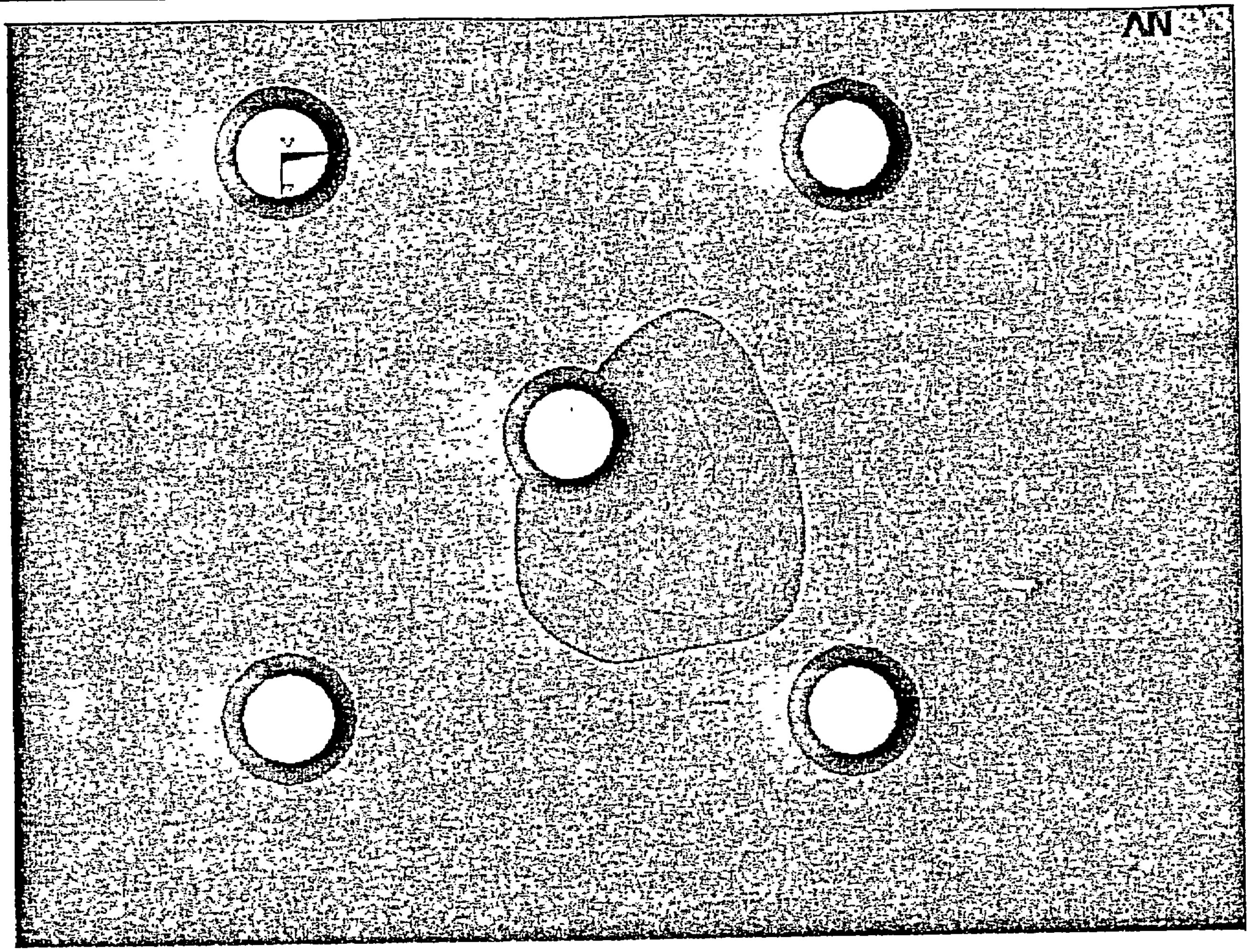


Figure 2 – Original Cavity Layout (per Reference 1 and 2)
Exposed Clad Area = 20.5 in^2 (A)

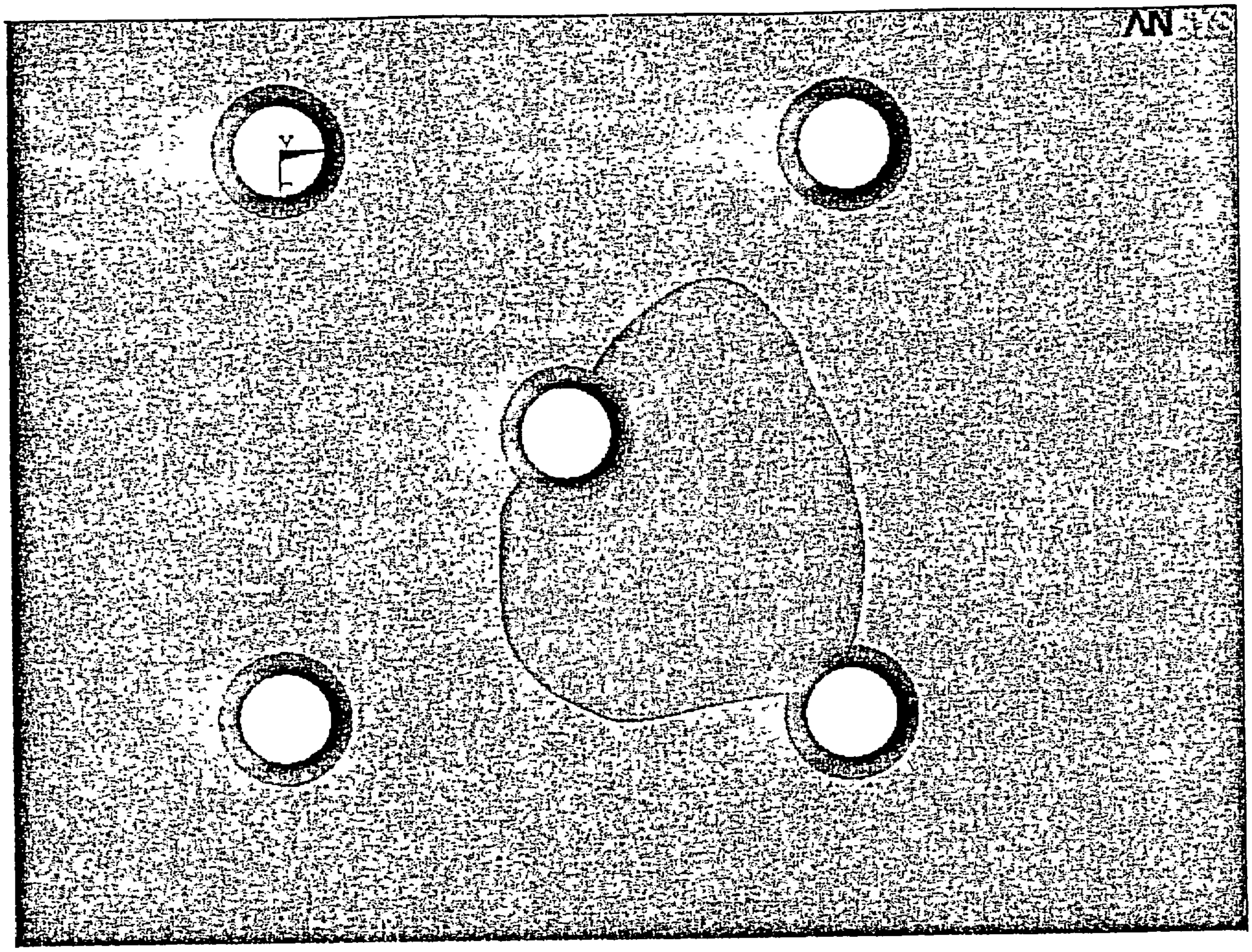


Figure 3 – Enlarged Self-Similar Cavity Layout
Exposed Clad Area = 41.0 in² (2A)

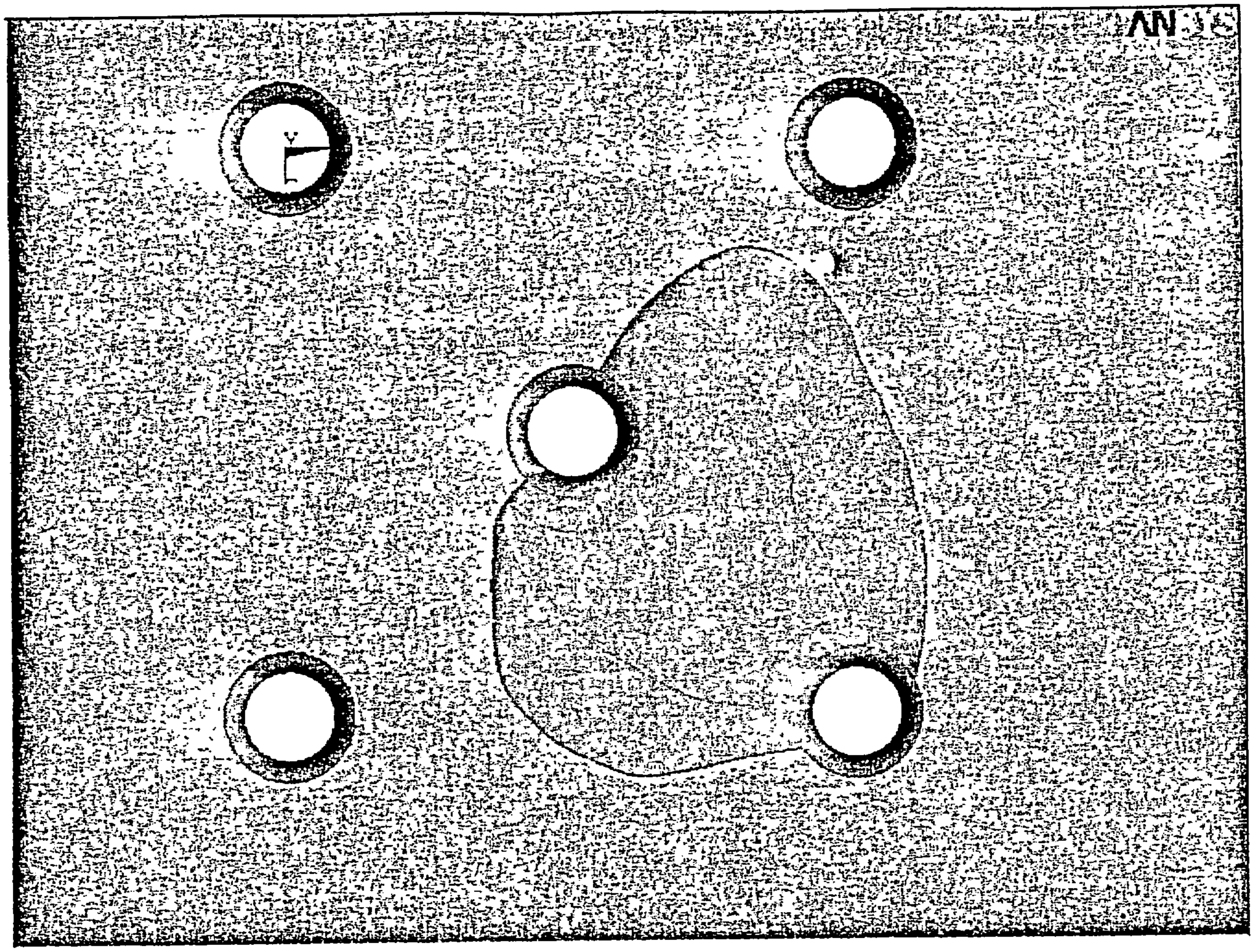


Figure 4 – Enlarged Self-Similar Cavity Layout
Exposed Clad Area = 61.5 in² (3A)

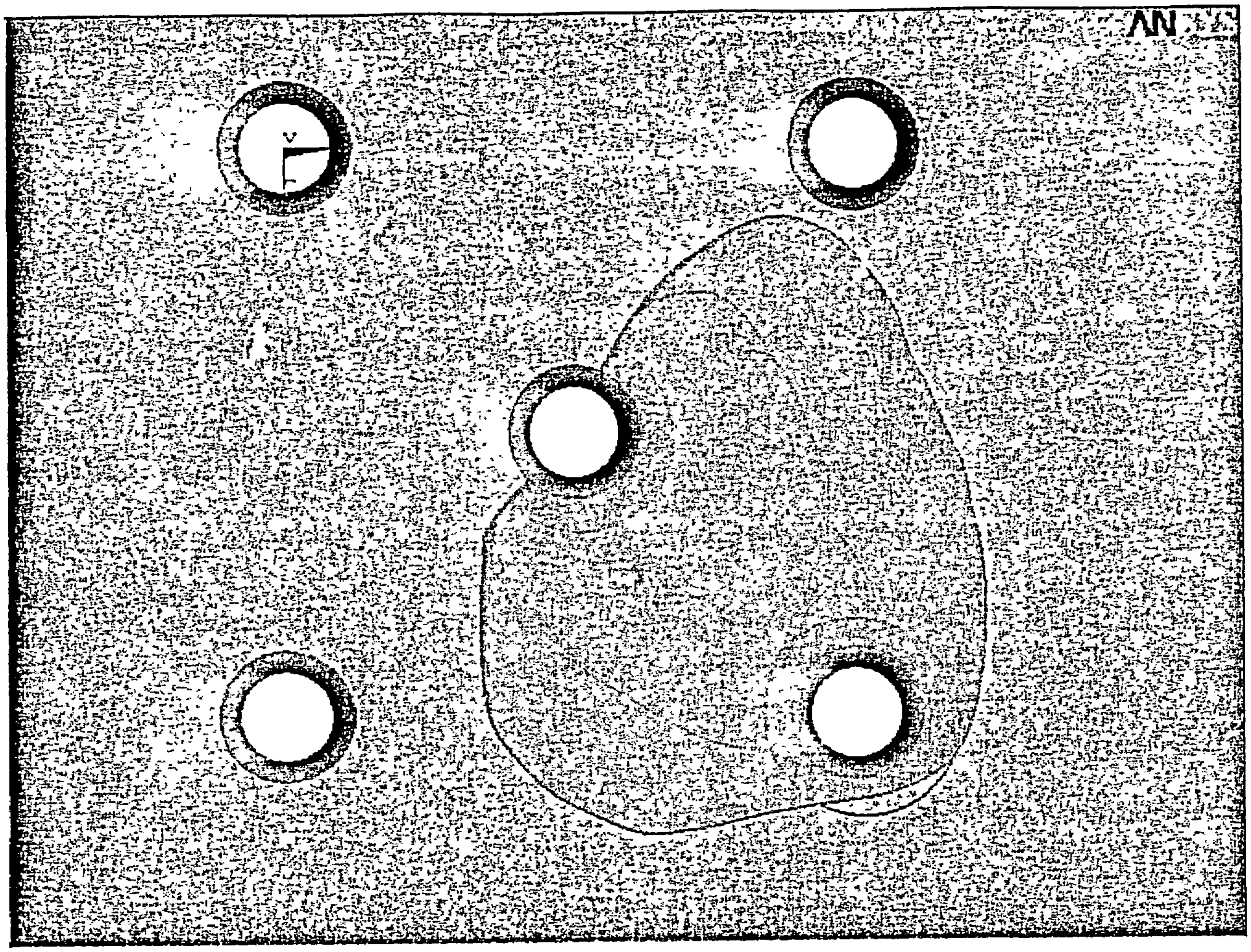


Figure 5 – Enlarged Self-Similar Cavity Layout
Exposed Clad Area = 82.0 in² (4A)

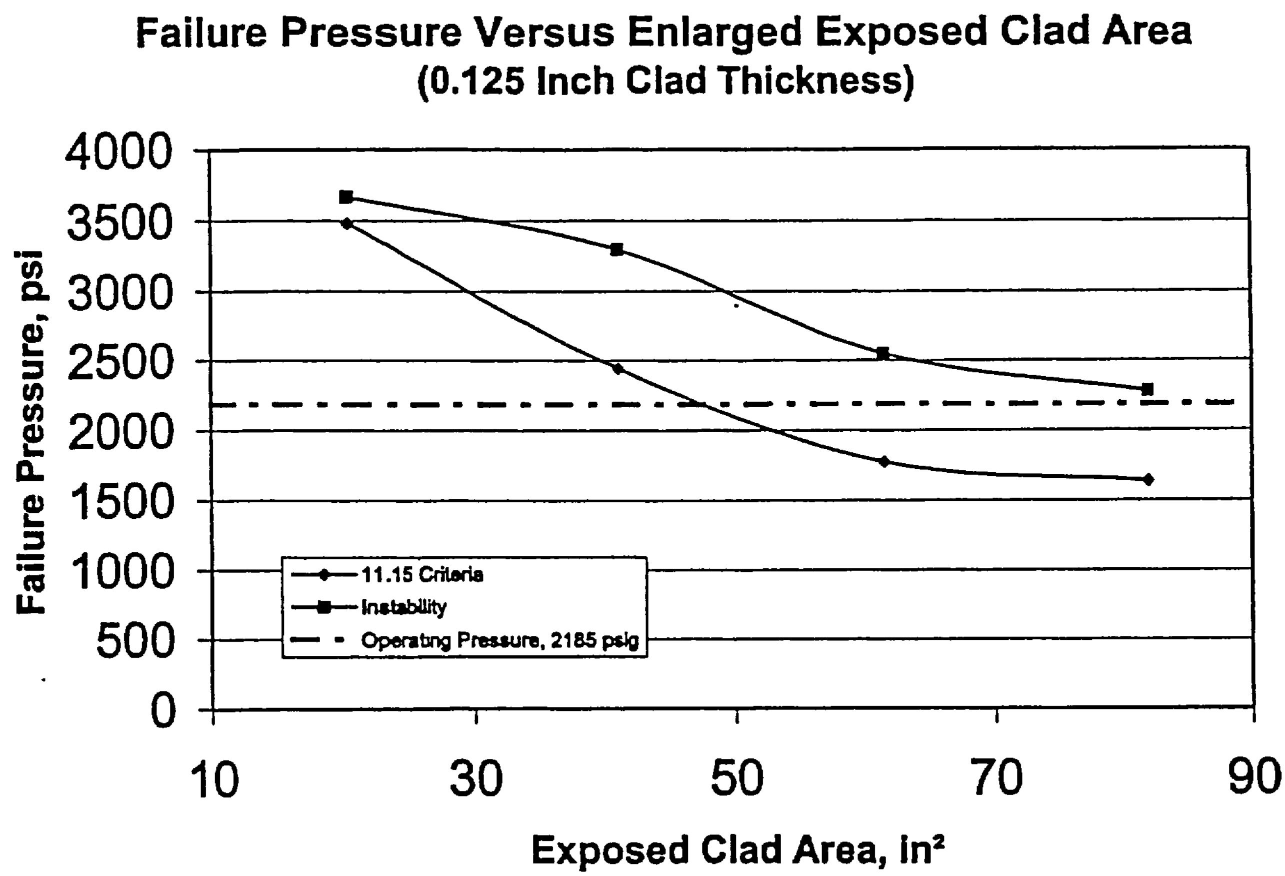


Figure 6 – Failure Pressure Versus Cavity Exposed Area, Clad = 0.125 inches

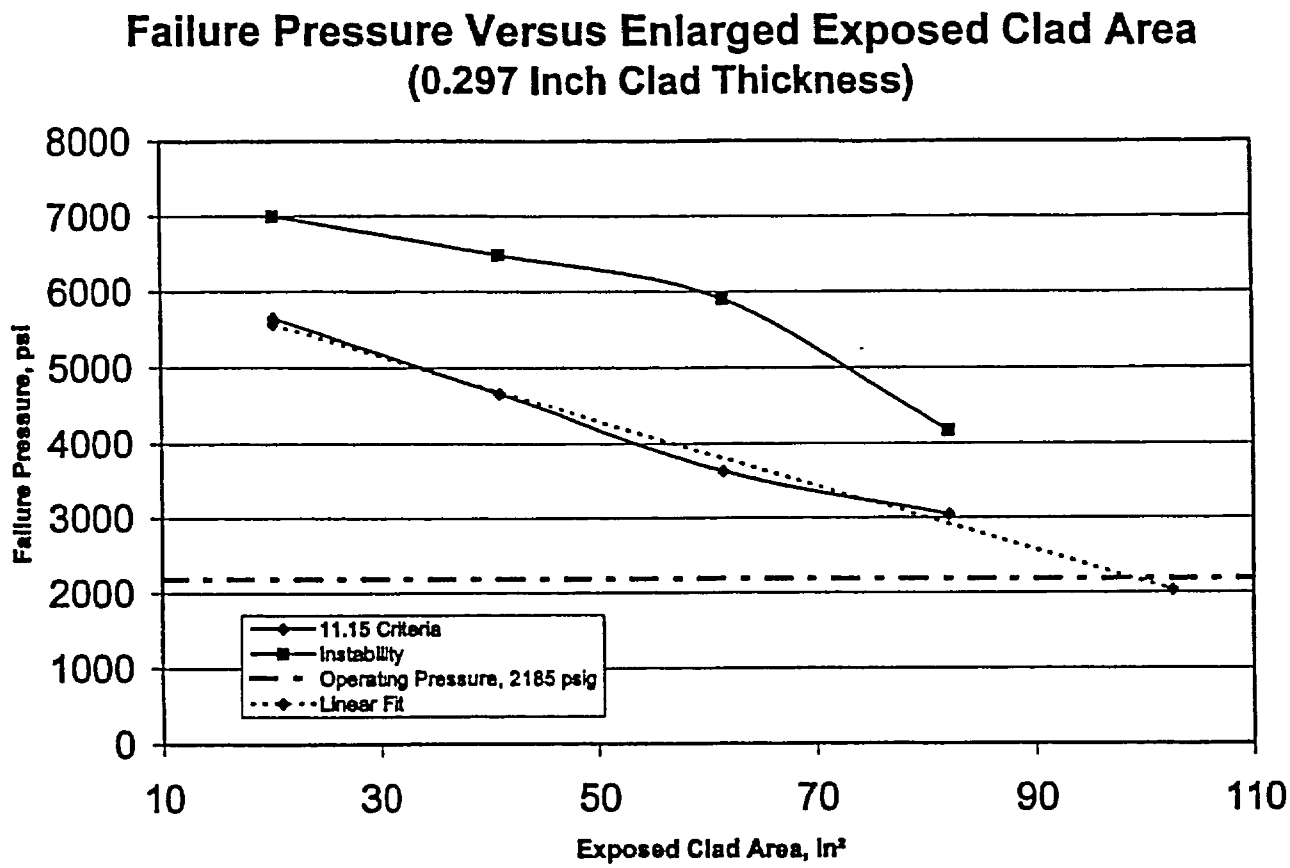


Figure 7 – Failure Pressure Versus Cavity Exposed Area, Clad = 0.297 inches

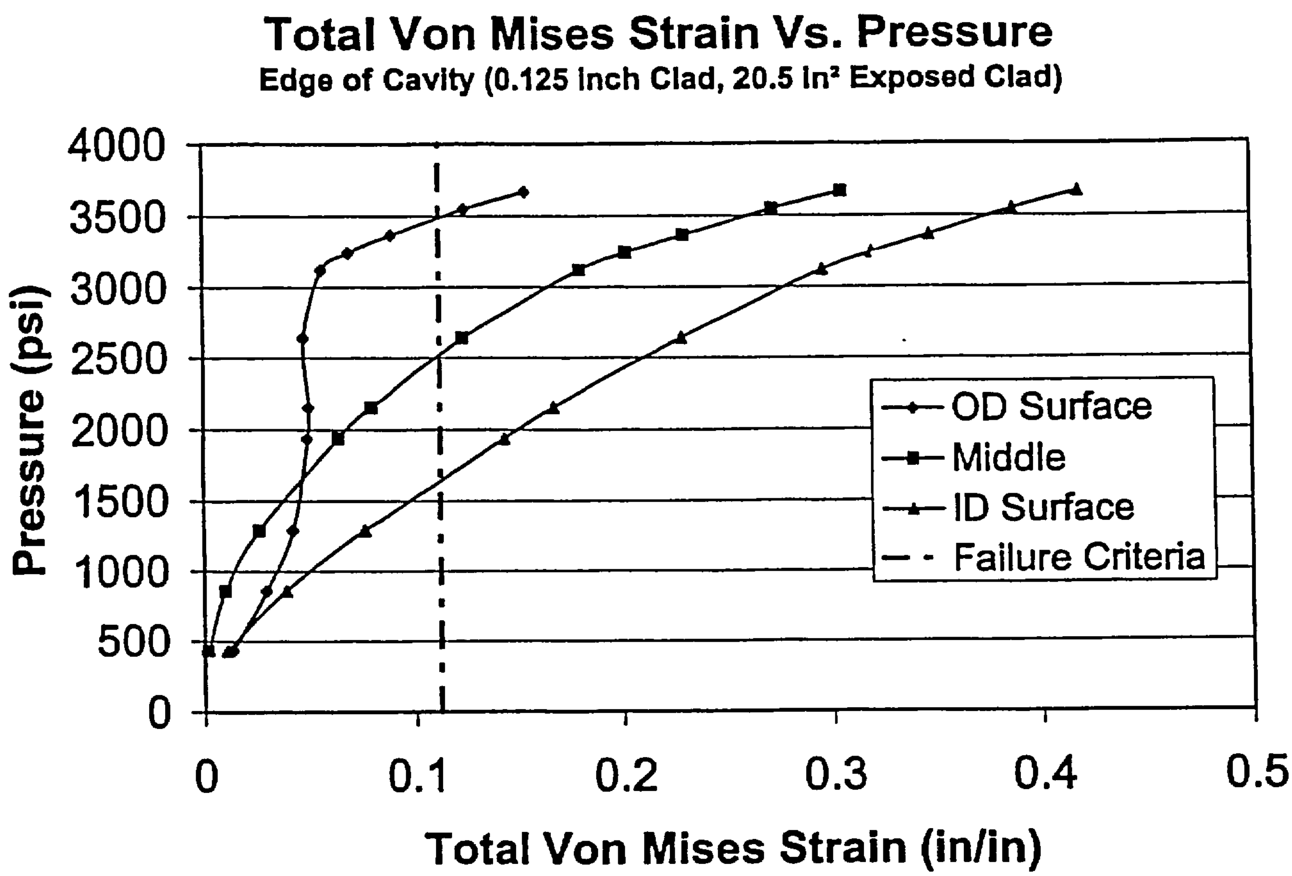


Figure 8 – Total Von Mises Strain Versus Pressure, Location at 11.15% Criterion Failure (0.125 Inch Clad, 20.5 in² Exposed Area)

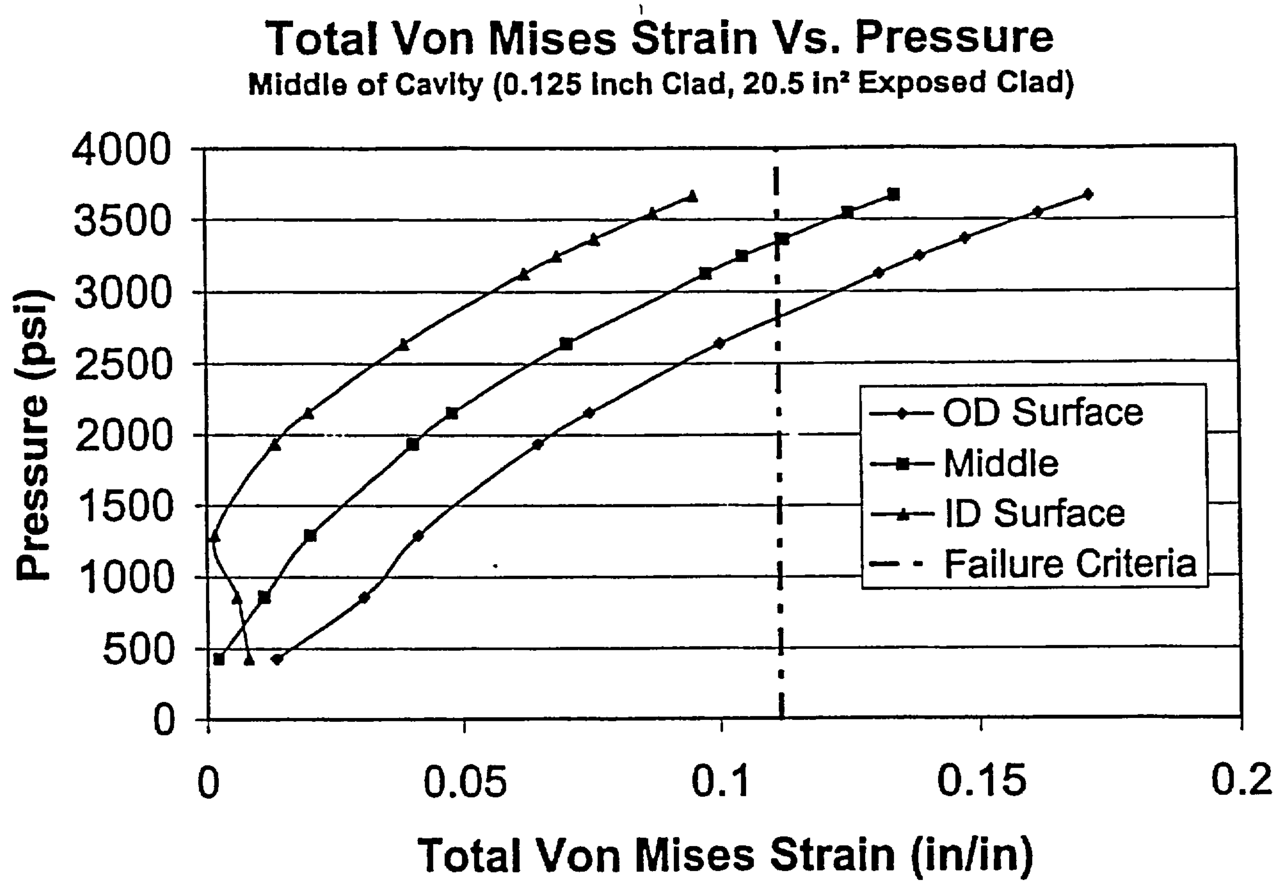


Figure 9 – Total Von Mises Strain Versus Pressure, Middle of Exposed Clad Region (0.125 Inch Clad, 20.5 in² Exposed Area)

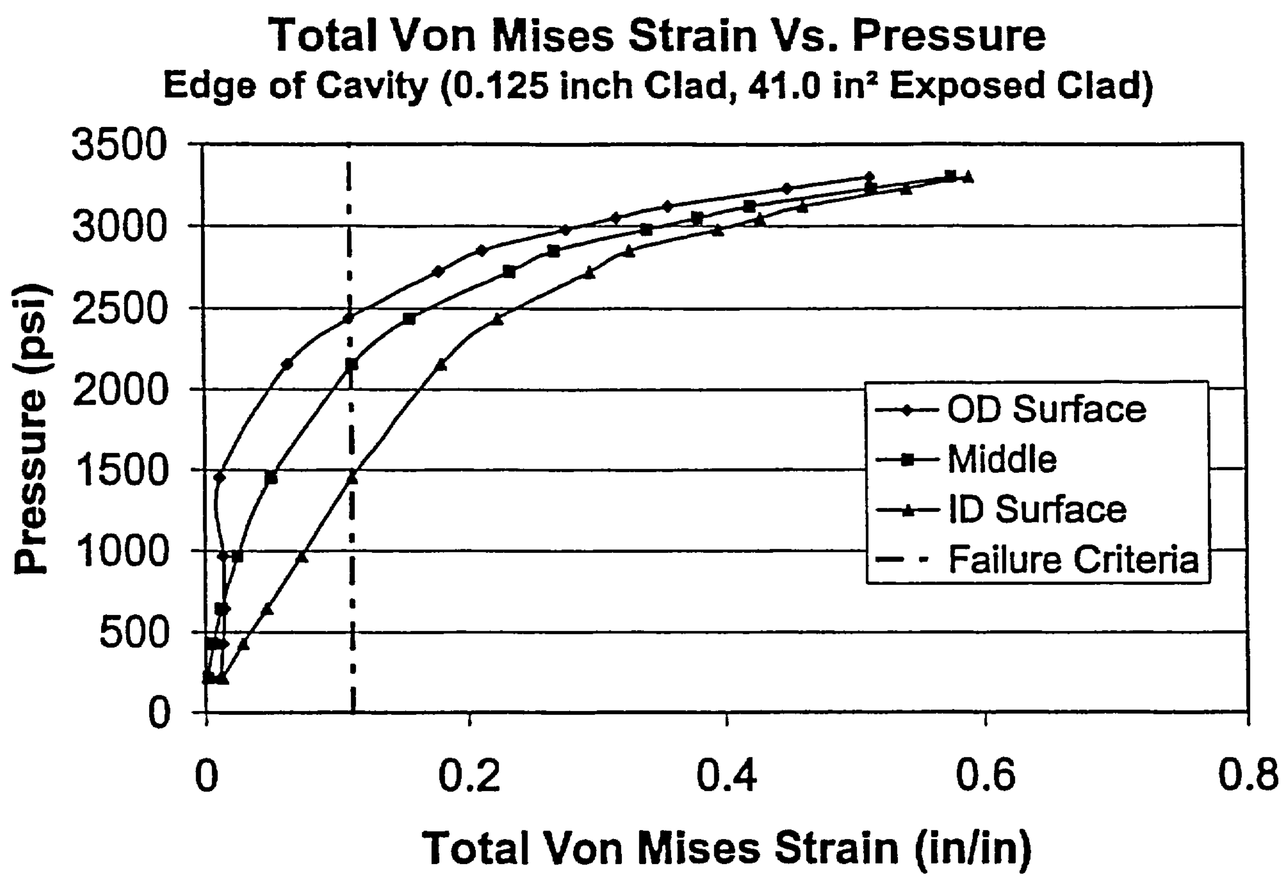


Figure 10 – Total Von Mises Strain Versus Pressure, Location at 11.15% Criterion Failure (0.125 Inch Clad, 41.0 in² Exposed Area)

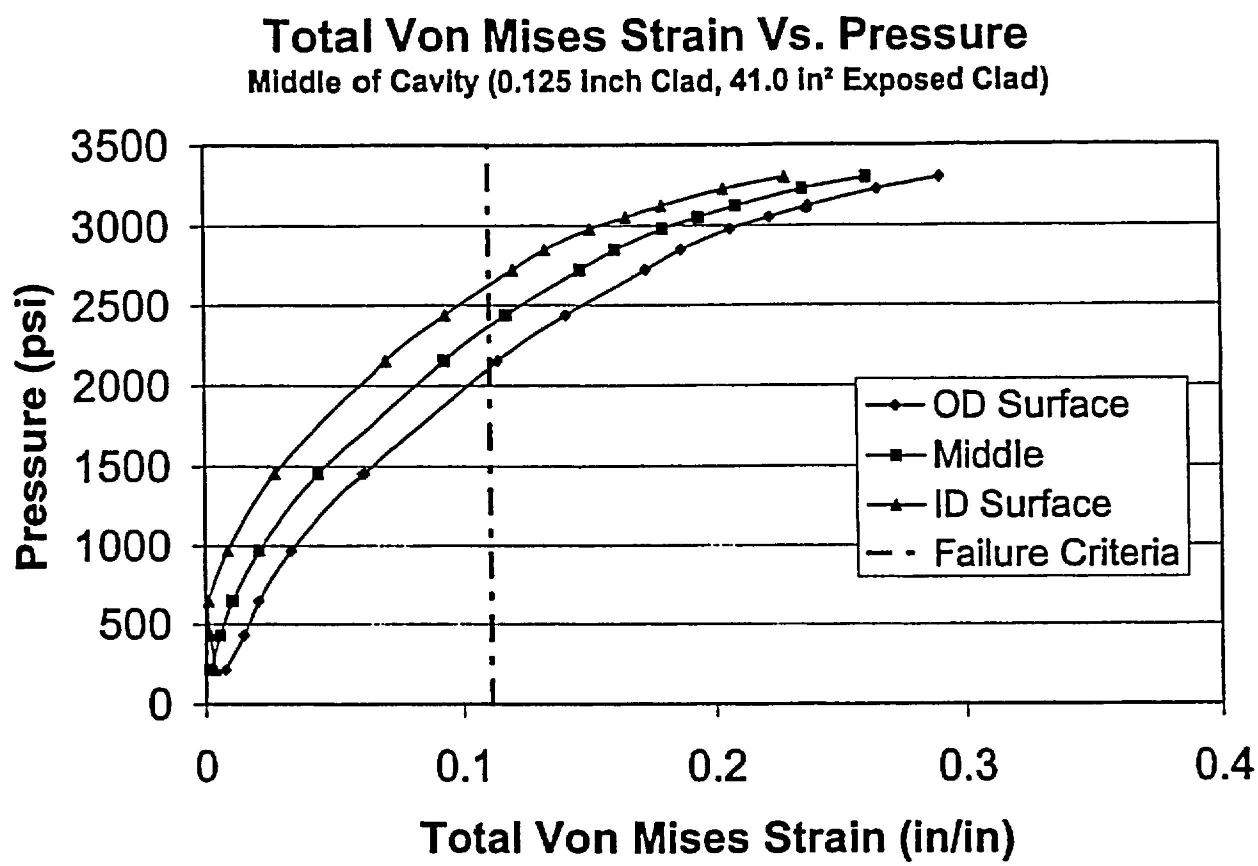


Figure 11 – Total Von Mises Strain Versus Pressure, Middle of Exposed Clad Region (0.125 Inch Clad, 41.0 in² Exposed Area)

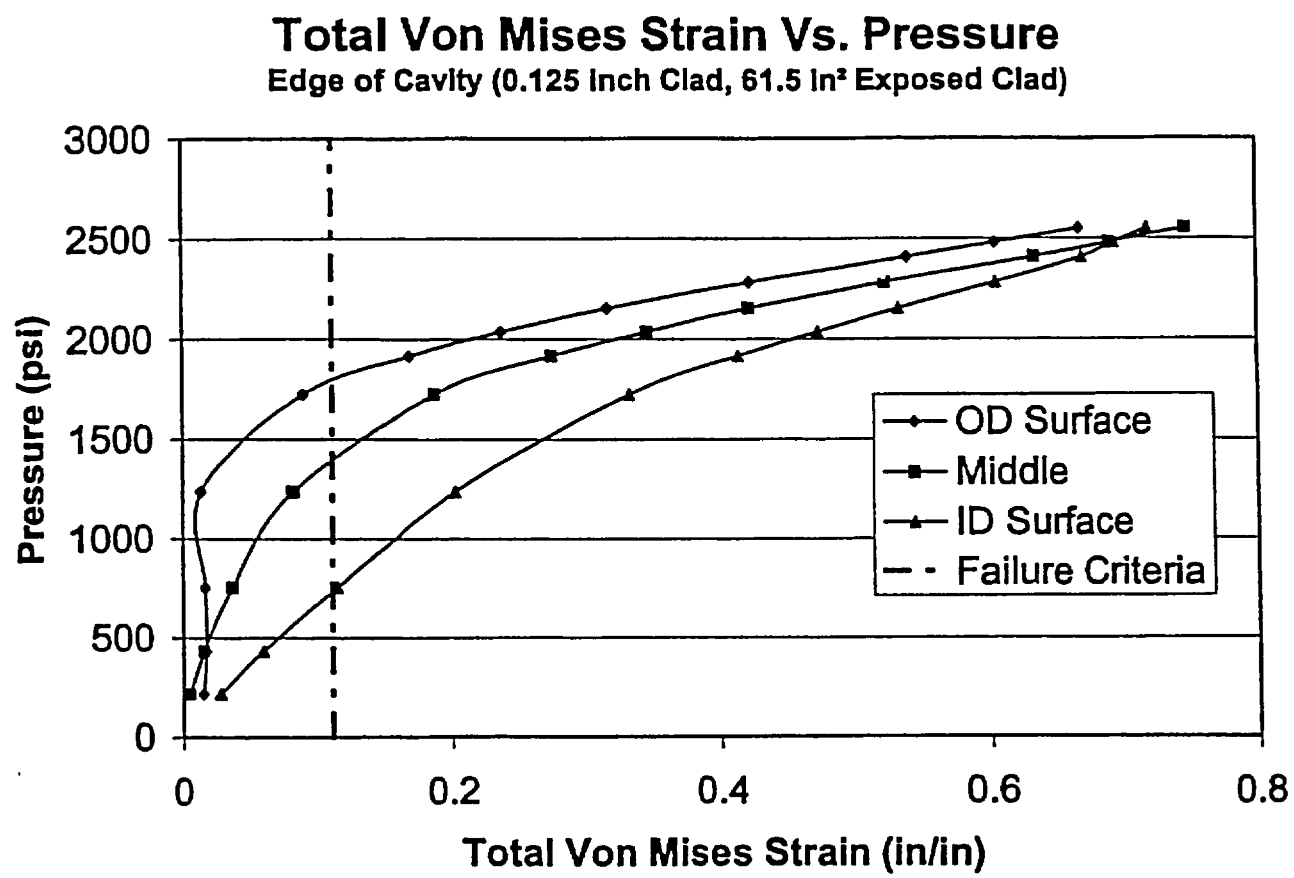


Figure 12 – Total Von Mises Strain Versus Pressure, Location at 11.15% Criterion Failure (0.125 Inch Clad, 61.5 in² Exposed Area)

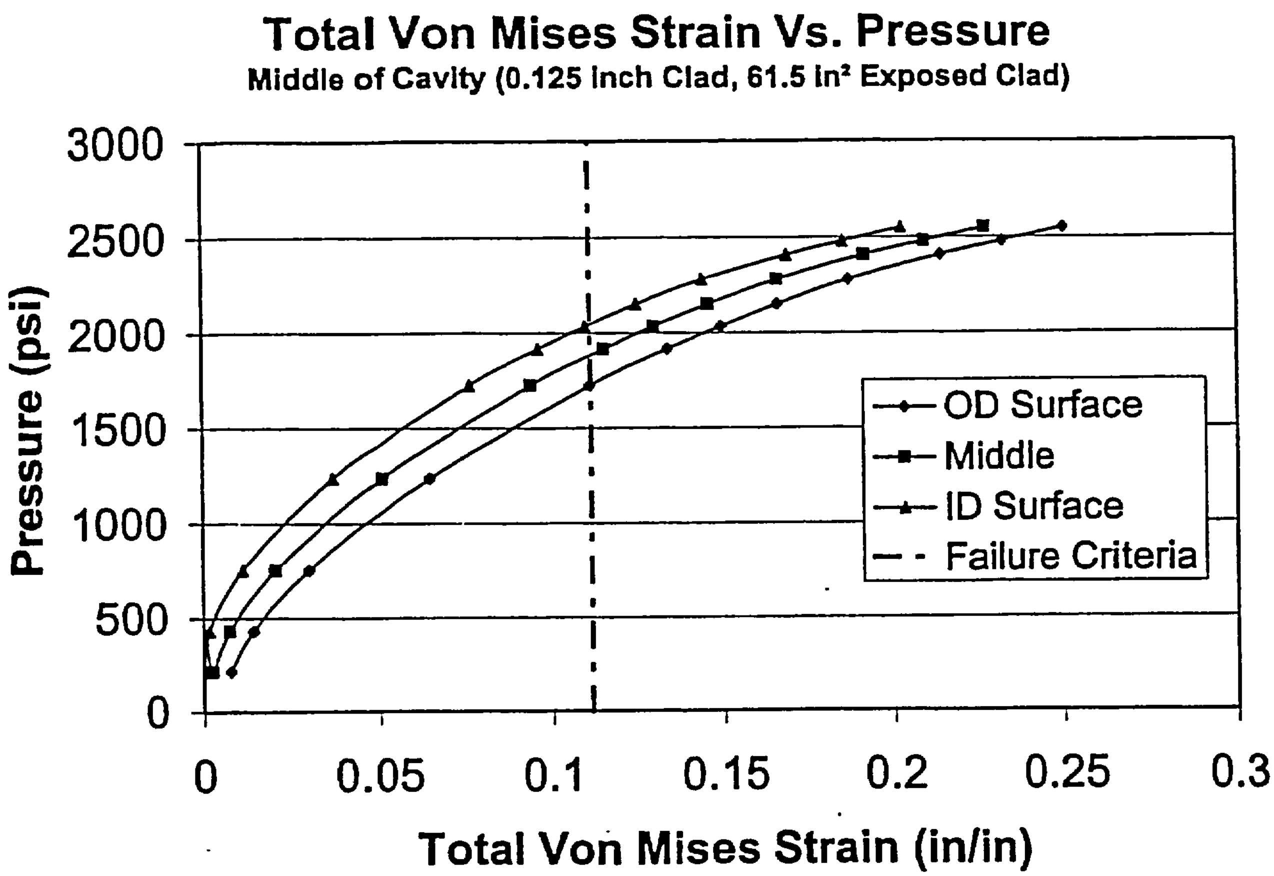


Figure 13 – Total Von Mises Strain Versus Pressure, Middle of Exposed Clad Region (0.125 Inch Clad, 61.5 in² Exposed Area)

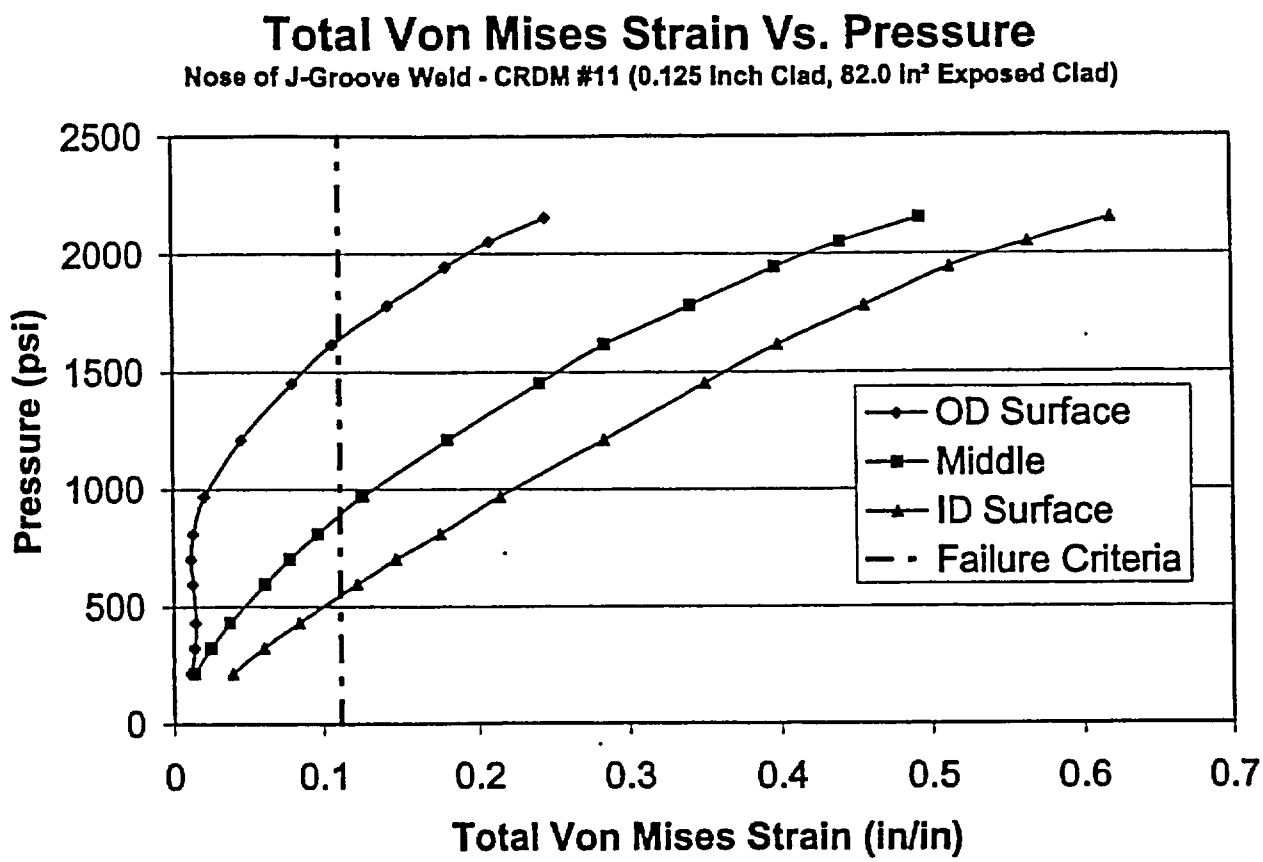


Figure 14 – Total Von Mises Strain Versus Pressure, Location at 11.15% Criterion Failure (0.125 Inch Clad, 82.0 in² Exposed Area)

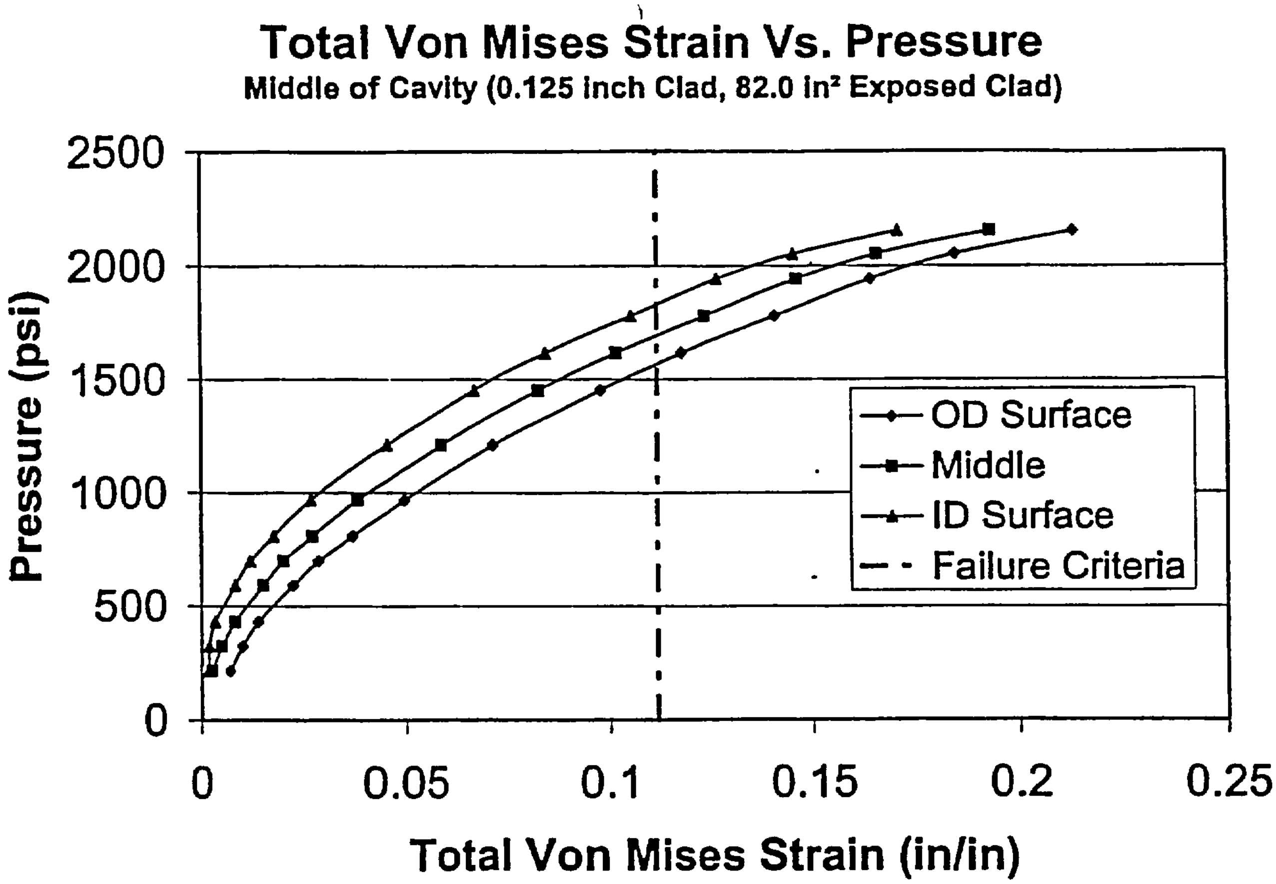


Figure 15 – Total Von Mises Strain Versus Pressure, Middle of Exposed Clad Region (0.125 Inch Clad, 82.0 in² Exposed Area)

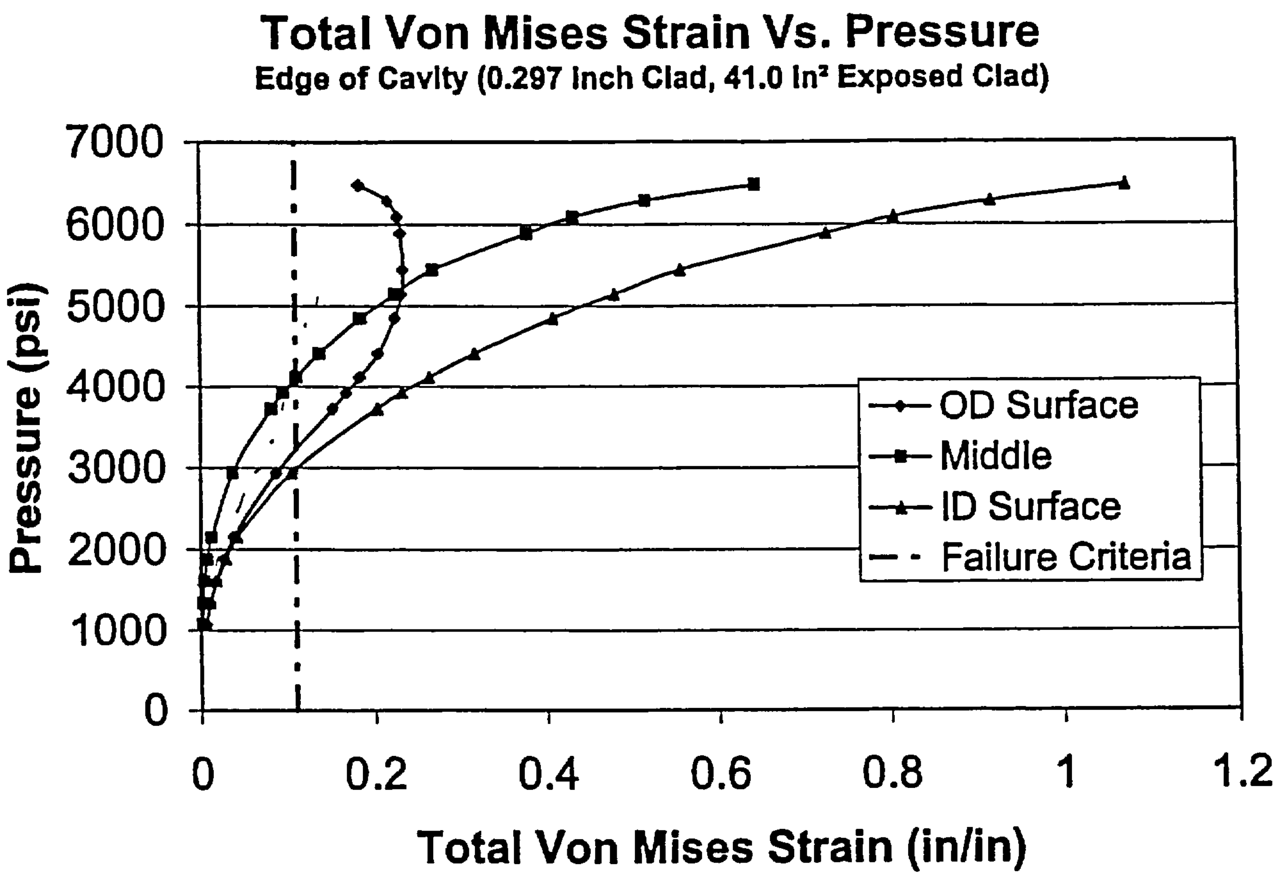


Figure 16 – Total Von Mises Strain Versus Pressure, Location at 11.15% Criterion Failure (0.297 Inch Clad, 41.0 in² Exposed Area)

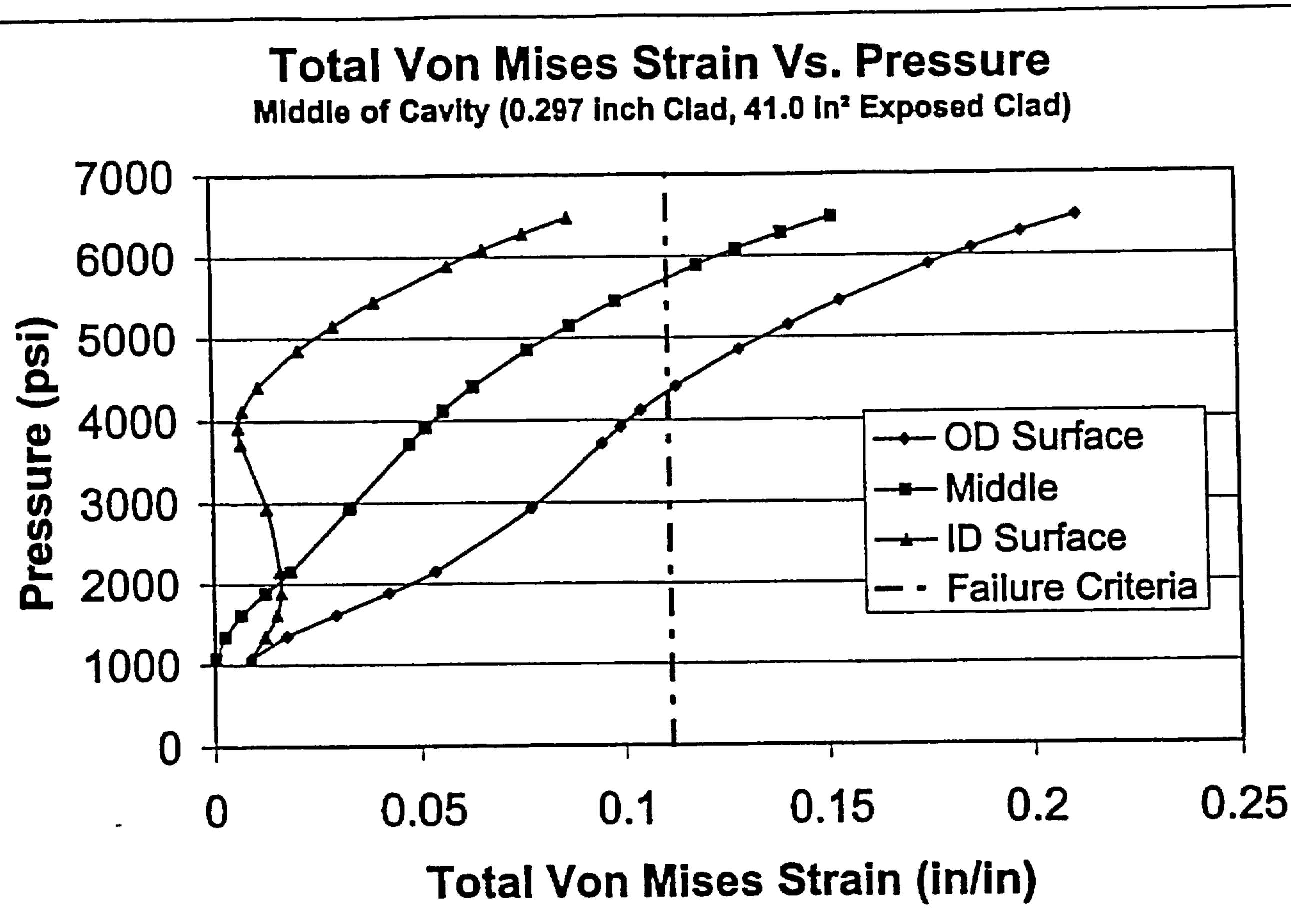


Figure 17 – Total Von Mises Strain Versus Pressure, Middle of Exposed Clad Region
(0.297 Inch Clad, 41.0 in² Exposed Area)

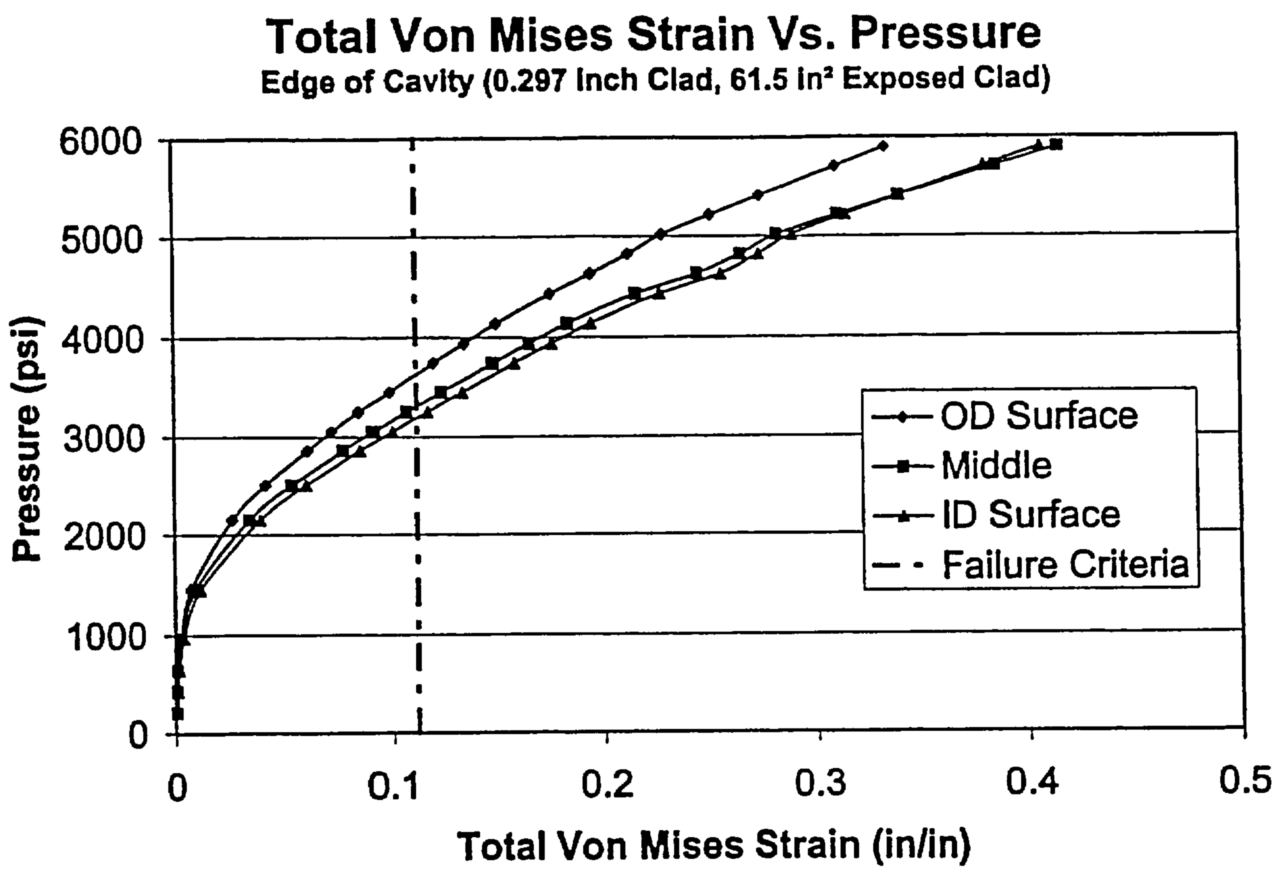


Figure 18 – Total Von Mises Strain Versus Pressure, Location at 11.15% Criterion Failure (0.297 Inch Clad, 61.5 in² Exposed Area)

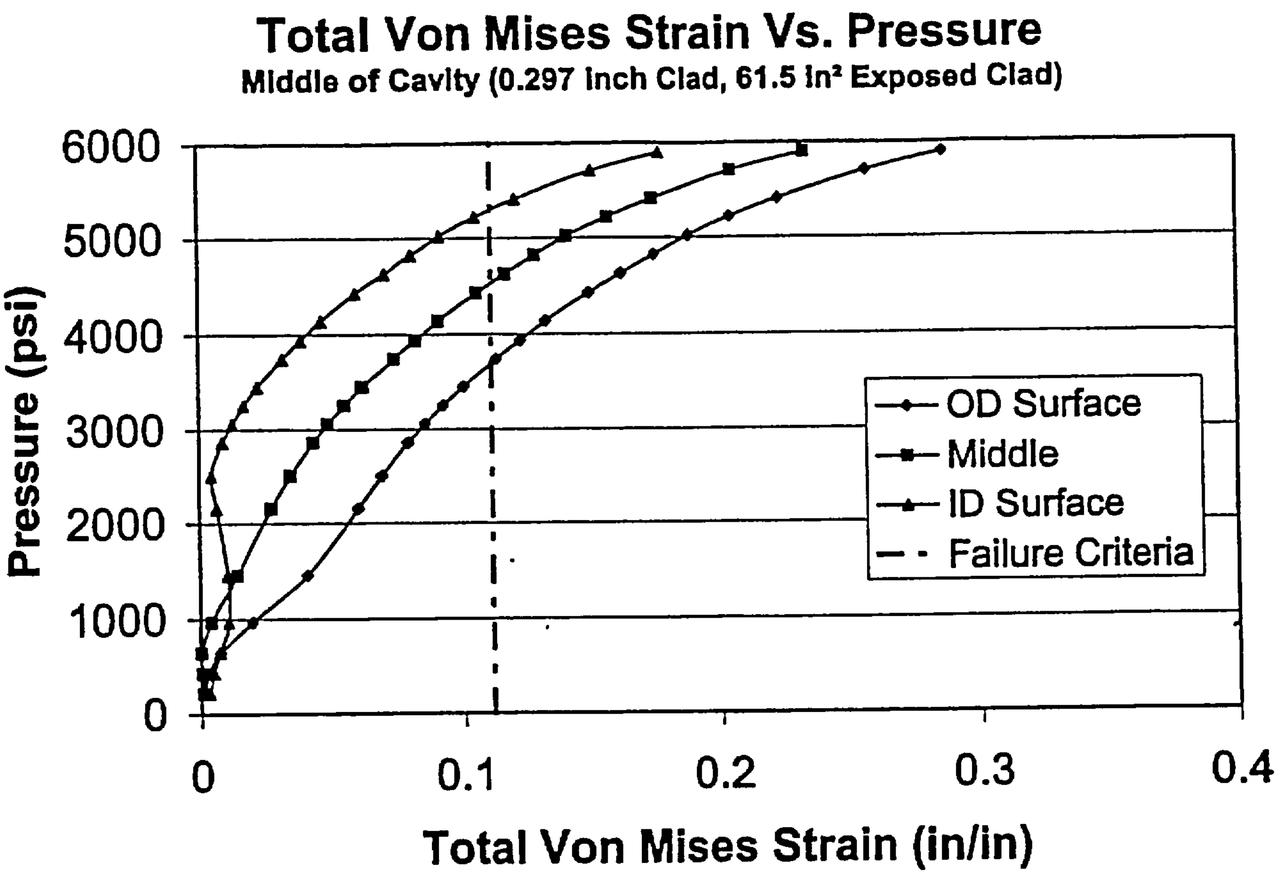


Figure 19 – Total Von Mises Strain Versus Pressure, Middle of Exposed Clad Region (0.297 Inch Clad, 61.5 in² Exposed Area)

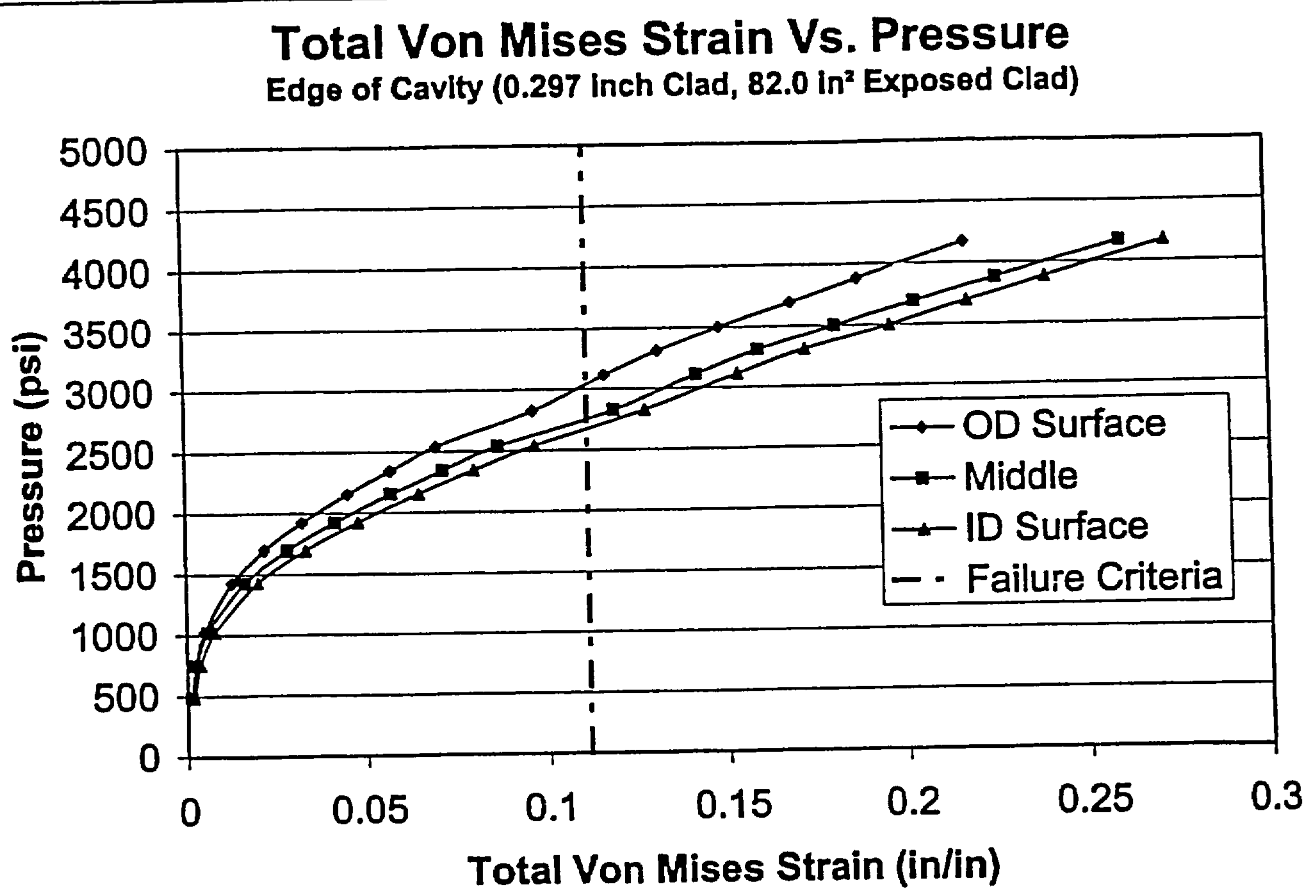


Figure 20 – Total Von Mises Strain Versus Pressure, Location at 11.15% Criterion Failure (0.297 Inch Clad, 82.0 in² Exposed Area)

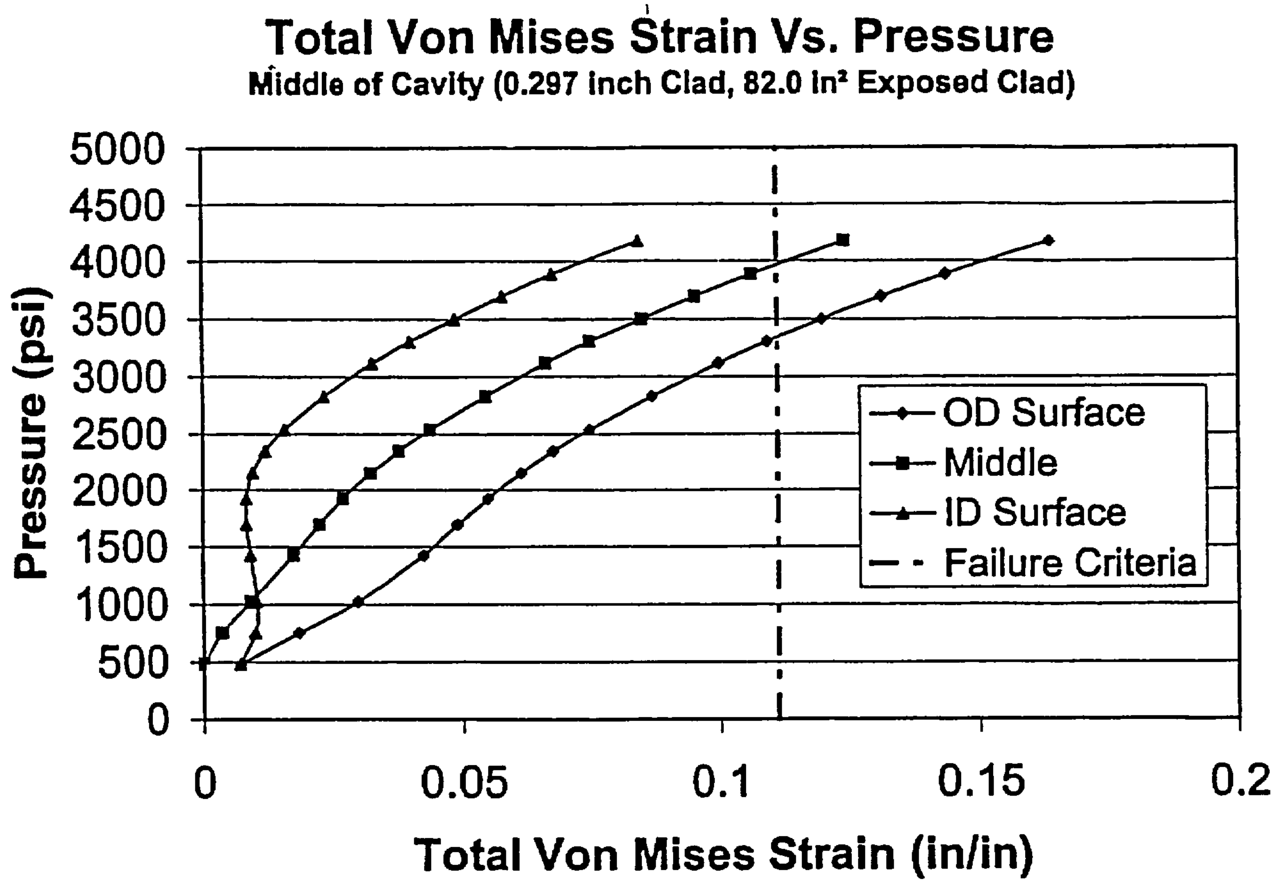


Figure 21 – Total Von Mises Strain Versus Pressure, Middle of Exposed Clad Region (0.297 Inch Clad, 82.0 in² Exposed Area)

Docket Number 50-346
License Number NPF-3
Serial Number 1-1282
Attachment 1

Structural Integrity Associates, Inc.
File Number W-DB-01Q-305
"Elastic-Plastic Finite Element Stress Analyses of Davis-Besse RPV Head Wastage Cavity with Different Enlarged Areas and Thicknesses"

(29 Pages Follow)

The Following Document Contains Proprietary Information

STRUCTURAL INTEGRITY Associates, Inc.	CALCULATION PACKAGE	FILE No: W-DB-01Q-305 PROJECT No: W-DB-01Q

PROJECT NAME: Operability and Root Cause Evaluation of the Damage of the Reactor Pressure Vessel Head at Davis-Besse

CLIENT: First Energy Corporation

CALCULATION TITLE: Elastic-Plastic Finite Element Stress Analyses of Davis-Besse RPV Head Wastage Cavity With Different Enlarged Areas and Thicknesses

PROBLEM STATEMENT OR OBJECTIVE OF THE CALCULATION:

Develop a finite element models to evaluate the effects of wastage cavity growth for clad thicknesses of 0.125 inches and 0.297 inches.

Document Revision	Affected Pages	Revision Description	Project Mgr. Approval Signature & Date	Preparer(s) & Checker(s) Signatures & Date
0	1 – 29 Project CD-Rom	Original Issue	[signature] 7/8/02	[signature] 7-8-02 [signature] 7-8-02

1.0 INTRODUCTION

During recent in-service inspections of the reactor pressure vessel (RPV) head and penetrations at Davis-Besse, significant wastage was observed in the vicinity of control rod drive mechanism (CRDM) No. 3. An initial investigation of the cavity was performed in order to understand the existing structural margin given different clad thickness values [1]. In the Reference 1 evaluation, the average measured clad thickness of 0.297 inches and the minimum measured thickness of 0.24 inches were considered. Subsequently, concerns were raised about the possibility of growth of the wastage cavity and how this growth will affect the structural margins. There was also a concern of the possibility of the cladding reaching the minimum specified thickness of 0.125 inches.

Initial investigations of the enlarged cavities were performed in a second calculation, which evaluated the effects of a cavity twice the original size of the cavity using the minimum measured thickness clad thickness of 0.24 inches [2].

This calculation is a follow up to the analyses performed in References 1 and 2 by evaluating clad thicknesses of 0.297 inches and 0.125 inches for cavities up to four times the original cavity.

2.0 TECHNICAL APPROACH

The evaluations will be performed using a three-dimensional finite element model (similar to those used in References 1 and 2), which accurately models the reactor pressure vessel head, the penetrations in the vicinity of the wastage, those CRDM attachment welds that are directly affected by the cavity and enlarged wastage areas. Similar to the References 1 and 2 evaluations, elastic-plastic material properties of the materials of the various components will be used to determine the limiting pressure.

2.1 Finite Element Model

The finite element model was constructed using the ANSYS finite element software package [3] and are based on the 3-D models developed in References 1 and 2. As such, the basic dimensions, material properties and assumption used in the original model development in References 1 and 2 remain valid. Any variations from Reference 1 and 2 modeling will be documented in the following sections. An example of the model can be seen in Figure 1. In summary, a series of full 360° model were created and includes the following:

- Closure head
- Closure head cladding
- Upper closure flange
- CRDM housing tubes 1, 3, 6, 7 and 11
- J-groove attachment weld and butter for CRDM tube No. 3 (All cavity sizes)
- J-groove attachment weld and butter for CRDM tube No. 11 (Most cavity sizes)
- Enlarged wastage cavity

A total of seven evaluations will be performed for various cavity sizes and clad thickness. The 0.125 inch clad was evaluated using the original cavity and cavities that were twice, three times and four times larger than the original cavity. The 0.297 inch clad was evaluated using cavities that were twice, three times and four times larger than the original cavity. The original cavity was previously evaluated for 0.297 inch clad thickness in Reference 1.

2.1.1 CRDM-to-Head Weld

For these evaluations, the J-groove attachment weld and butter were explicitly modeled only for Tubes 3 and 11. The one exception is in the case of the 0.125 inch clad evaluation for the original size cavity (20.5 in²). For that evaluation only, the J-groove weld for Tube 11 was also not explicitly modeled.

For all of the finite element models in this evaluation, the remaining modeled Tubes; 1, 6, and 7 (and Tube 11 for the original cavity 0.125 inch clad case) the CRDM tubes are attached only at the stainless clad.

The weld prep butter was assumed not to be part of the attachment between the vessel and the inconel tube. In addition, the cover fillet applied to the J-groove weld was not modeled.

2.1.2 Enlarged Wastage

References 1 provided a basic layout of the original modeled wastage. The exposed clad for this original cavity was approximately 20.5 in². Reference 2 expanded the wastage cavity to twice the original area, 41.0 in² for 0.24 inches of clad thickness. In addition, Reference 2 included expanded results for the 0.297 inch clad case for the original cavity (20.5 in²).

The self-similar enlarged cavity reproduced the same shape by scaling up the original cavity dimensions until the exposed clad area reaches the desired values. In this case the exposed clad areas investigated are 20.5 in² (A), 41.0 in² (2A), 61.5 in² (3A) and 82 in² (4A). See Figures 2 through 5 for the resulting exposed clad area and transition region. The decision to limit the cavity growth value to 4A for this evaluation is to ensure that Tube 11 is not fully exposed. As will be shown later in this calculation package, for the 0.297 inch cladding thickness, significantly more area of the cavity can be exposed before failure is predicted at the operating pressure of 2185 psig.

3.0 MATERIALS

The materials of the various components are as follows [1, 2]

Component	Material
Upper Head	SA-533 Grade B Class 1
Closure Flange	SA-508 Class 2
CRDM Housing Tube	SB-167 (Alloy 600)
J-Groove Weld	Alloy 82/182
Weld Butter	Alloy 82/182
Clad	308/308L Stainless Steel

It should be noted that Alloy 600 material properties were conservatively assumed for the J-groove Alloy 82/182 weld metal since the stress-strain properties for the weld metal are more favorable than the base metal.

Basic material properties, as well as detailed descriptions of the elastic-plastic material properties are included in Reference 2.

4.0 LOADING

A uniform temperature of 605°F [4] was applied over all models with the stress free temperature being 70°F.

A pressure load is applied incrementally to the inside surface of the hemispherical head, the external surfaces of the CRDM tube sections inside the vessel, the inside surfaces of the CRDM tubes and to the closure flange face out to a radius of 84.8115 inches [5] until instability is reached.

In addition, a cap pressure was applied to the outside free end of the CRDM tubes to simulate line load in each tube. Note that the applied cap load was actually applied in the negative direction in ANSYS, thus providing a traction load.

No other operating loads were applied since previous preliminary evaluations have shown that these loads do not have any significant effect on the limiting pressure. This includes closure loads such as bolt pre-load, gasket squash loads and ledge/spring loads.

5.0 FAILURE CRITERIA

In this elastic-plastic analysis, the failure criterion is set such that the maximum strain cannot exceed the ultimate tensile strain. Hence for the stainless steel cladding where the maximum strain is expected to occur, the maximum equivalent total strain is limited to the maximum strain of 11.15% (corresponding to the ultimate strain for the stainless steel cladding in Reference 6) through the thickness of the component.

It was concluded from the analyses performed in Reference 7 that a better prediction of actual failure pressure is the pressure at which numeric instability is reached in the ANSYS program. Hence, the pressure at which numeric instability occurred for each of the cases considered in this evaluation is also presented.

6.0 RESULTS

The resulting failure pressures for the 0.125 inch and 0.297 inch clad thickness are shown in Table 1. Also included are the pressures at which instability occurred. Figures 6 and 7 present the same data graphically. Also plotted on Figures 6 and 7 for comparison is the normal operating pressure of 2185 psig.

Table 1
Failure Pressure for Enlarged Wastage

Clad Thickness (in)	Exposed Clad Area (in²)	Failure Pressure (psi)	
		11.15% Criteria	Instability
0.125	20.5	~3480[2]	3667.7
	41.0	~2443[2]	3298.9
	61.5	~1775[2]	2551.6
	82.0	~1638[2]	2281.1
0.297	20.5	~5649[3] 1.623	7000[1] 1.909
	41.0	~4657[3] 1.906	6481.7 1.964
	61.5	~3627[3] 2.043	5899.9 2.712
	82.0	~3041[3] 1.857	4172.0 1.829

125.5 ~2185

[1] Results from Reference 1.
[2] Interpolated from Analysis Results. See Table 2 on the following page.
[3] Interpolated from Analysis Results. See Table 3 on the following page.

Tables 2 and 3 present the through-wall strain distribution for the location that first exceeds the 11.15% failure criterion. Note that for each cavity size, two sets of strains are listed, which bound the 11.15% criteria. Between these two sets of strains is a linearly interpolated set of results to approximate the 11.15% criteria.

Figures 8 through 21 present total Von Mises strain versus the applied pressure at outside surface, middle and inside surface of the clad at a given location. The locations of interest include the point where the through-wall strain first exceeds the 11.15% failure criteria, the location of the maximum Von Mises strain and at the approximate center of the exposed clad region. The failure location in each of these cases is not the same due to the wastage configuration.

Table 2
Through Wall Total Von Mises Strain at Failure of 11.15% Strain Criteria Location
0.125 inch Clad Case

Clad Thickness (in)	0.125											
Cavity Size (in²)	20.5	20.5	20.5	41.0	41.0	41.0	61.5	61.5	61.5	82.0	82.0	82.0
Pressure (psi)	3365	3480[1]	3547	2438	2443[1]	2722	1722	1775[1]	1916	1617	1638[1]	1780
Clad OD	8.9	11.15[1]	12.4	11.0	11.15[1]	18.0	9.1	11.15[1]	16.8	10.7	11.15[1]	14.2
	13.7	16.2[1]	17.6	11.9	12.0[1]	18.9	10.7	12.8[1]	18.6	16.7	17.2[1]	21.0
	18.7	21.3[1]	22.8	13.6	13.7[1]	20.9	14.2	16.4[1]	22.5	23.5	24.1[1]	28.7
Mid-Plane	23.0	25.7[1]	27.2	15.7	15.9[1]	23.3	18.6	21.0[1]	27.4	28.5	29.2[1]	34.2
	27.2	29.9[1]	31.4	18.3	18.5[1]	26.1	23.8	26.2[1]	32.7	32.8	33.6[1]	38.7
	31.4	34.1[1]	35.6	20.7	20.8[1]	28.2	29.3	31.6[1]	37.8	37.1	37.8[1]	42.9
Clad ID	34.7	37.3[1]	38.8	27.3	27.4[1]	29.6	33.1	35.3[1]	41.3	39.9	40.6[1]	45.7

[1] Linearly Interpolated Results to Approximate 11.15% Failure Criteria

Table 3
Through Wall Total Von Mises Strain at Failure of 11.15% Strain Criteria Location
0.297 inch Clad Case

Clad Thickness (in)	0.297											
Cavity Size (in²)	20.5	20.5	20.5	41.0	41.0	41.0	61.5	61.5	61.5	82.0	82.0	82.0
Pressure (psi)	5600[2]	5649[1]	5800	4409	4657[1]	4850	3448	3627[1]	3742	2826	3041[1]	3115
Clad OD	26.8[2]	27.1[1]	28.0[2]	20.5	21.6[1]	22.5	9.9	11.15[1]	12.0	9.7	11.15[1]	11.7
	14.0[2]	14.3[1]	15.2[2]	10 8	11.6[1]	12.2	11.8	13.3[1]	14 2	11.5	13.2[1]	13.8
	10.8[2]	11.15[1]	12.3[2]	9.1	11.15[1]	12.8	12.4	13.9[1]	14.9	12.0	13.7[1]	14.3
Mid-Plane	15.0[2]	15.4[1]	16.9[2]	13.9	16.5[1]	18.6	12.3	13.8[1]	14.8	11.9	13.6[1]	14.2
	22.3[2]	22.9[1]	24.9[2]	19.6	23.2[1]	26.0	12.3	13.8[1]	14.7	11.9	13.6[1]	14.2
	33.9[2]	34.8[1]	37.6[2]	26.6	31.1[1]	34.6	12.6	14.0[1]	15.0	12.2	14.0[1]	14.6
Clad ID	44.6[2]	45.6[1]	49.0[2]	31.7	36.9[1]	40.9	13.3	14.8[1]	15.8	12.8	14.7[1]	15.4

[1] Linearly Interpolated Results to Approximate 11.15% Failure Criteria
[2] Results from Reference 2.

7.0 CONCLUSIONS

The analyses presented in this evaluation have shown that for the 0.125 inch cladding thickness, considering the criterion based on the uniform elongation of 11.15%, failure is predicted to occur when the wastage cavity is over 47.5 in² (as shown in Figure 6) for an operating pressure of 2185 psig, which is over two times the original cavity size. If the failure criterion is based on when numeric instability occurred, up to four times the area of the original cavity can be tolerated before failure is predicted.

For the 0.297 inch cladding thickness, both the 11.15% uniform elongation criteria and that based on numeric instability predicted that up to four times the area of the original cavity can be tolerated without predicting failure (as shown in Figure 7). Linearly fitting the 11.15% criteria data indicates that failure will occur at exposed clad area of approximately 102.5 in², which is five times the original cavity area.

[redacted]

Ex 5

8.0 REFERENCES

1) Structural Integrity Associates Calculation W-DB-01Q-301, Rev. 1, "Elastic-Plastic Finite Element Stress Analysis of Davis-Besse RPV Head Wastage Cavity."

2) Structural Integrity Associates Calculation W-DB-01Q-302, Rev. 0, "Elastic-Plastic Finite Element Stress Analysis of Enlarged Davis-Besse RPV Head Wastage Cavity."

3) ANSYS/Mechanical, Revision 5.7, ANSYS Inc., December 2000

4) Letter DBE-01-000133, Dated September 13, 2001 from Prasoon Goyal (First Energy) to Dick Mattson (SI), SI File W-ENTP-11Q-219P.

5) Framatome Technologies Technical Document 33-1201205-02, Rev. 2, "Stress Report Summary for Reactor Vessel, Toledo Edison Company, Davis-Besse Unit No. 1," SI File W-ENTP-11Q-219P

6) Email of from B.R. Grambau (Framatome ANP) to N. Cofie (SI), "308 Stress –Strain Curve," March 15, 2002, SI File W-DB-01Q-202.

7) Structural Integrity Associates Calculation W-DB-01Q-304, Rev. 0, "Evaluation of Failure Criterion Used in Elastic-Plastic Analysis of Davis-Besse RPV Head Wastage."

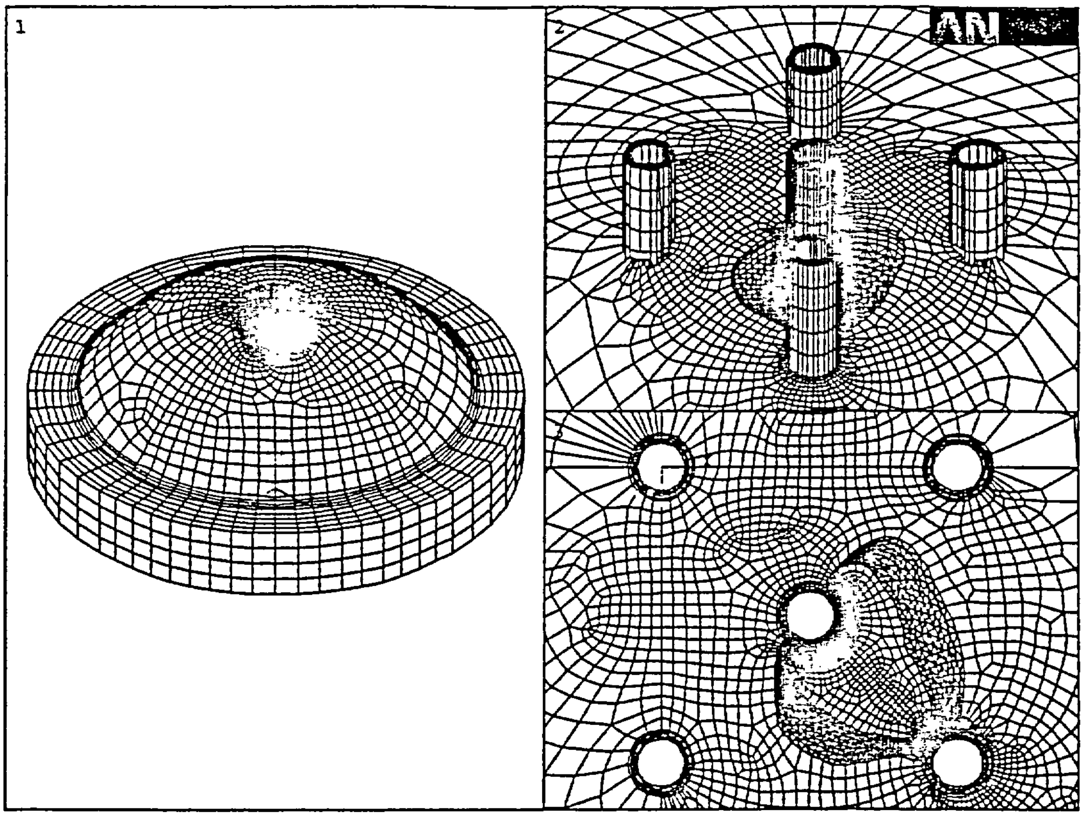


Figure 1 – Typical Finite Element Model

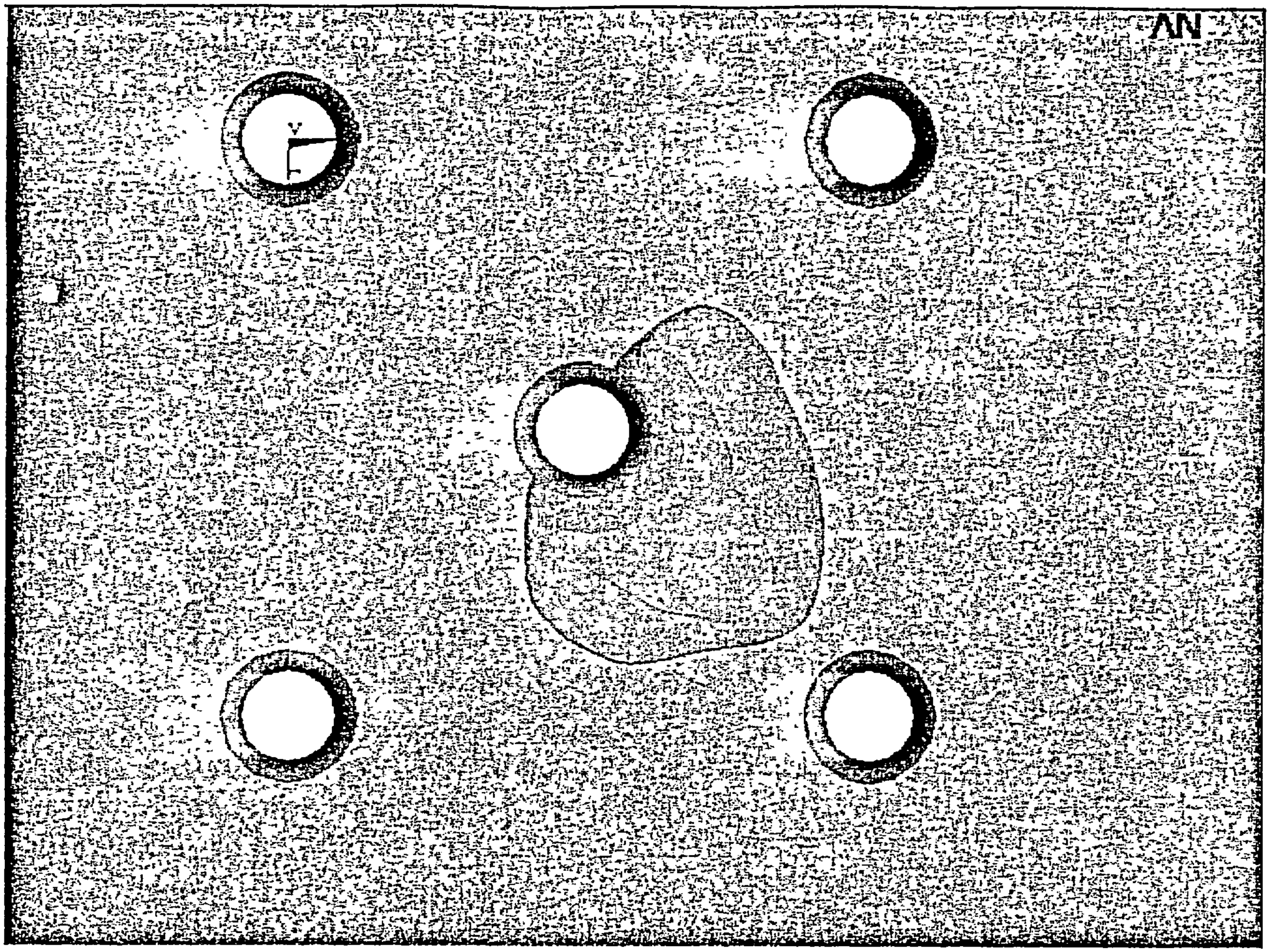


Figure 2 – Original Cavity Layout (per Reference 1 and 2)
Exposed Clad Area = 20.5 in² (A)

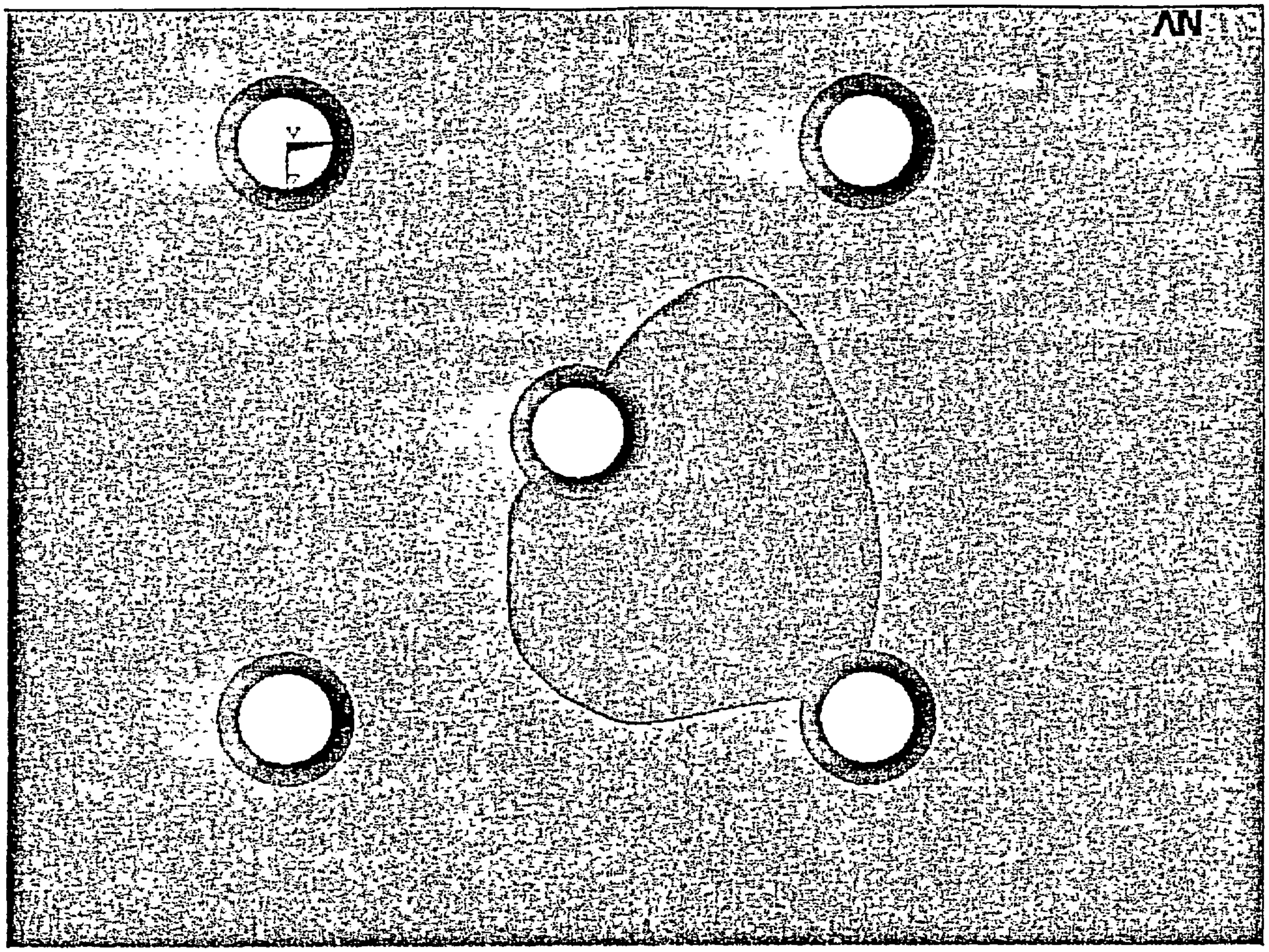


Figure 3 – Enlarged Self-Similar Cavity Layout
Exposed Clad Area = 41.0 in² (2A)

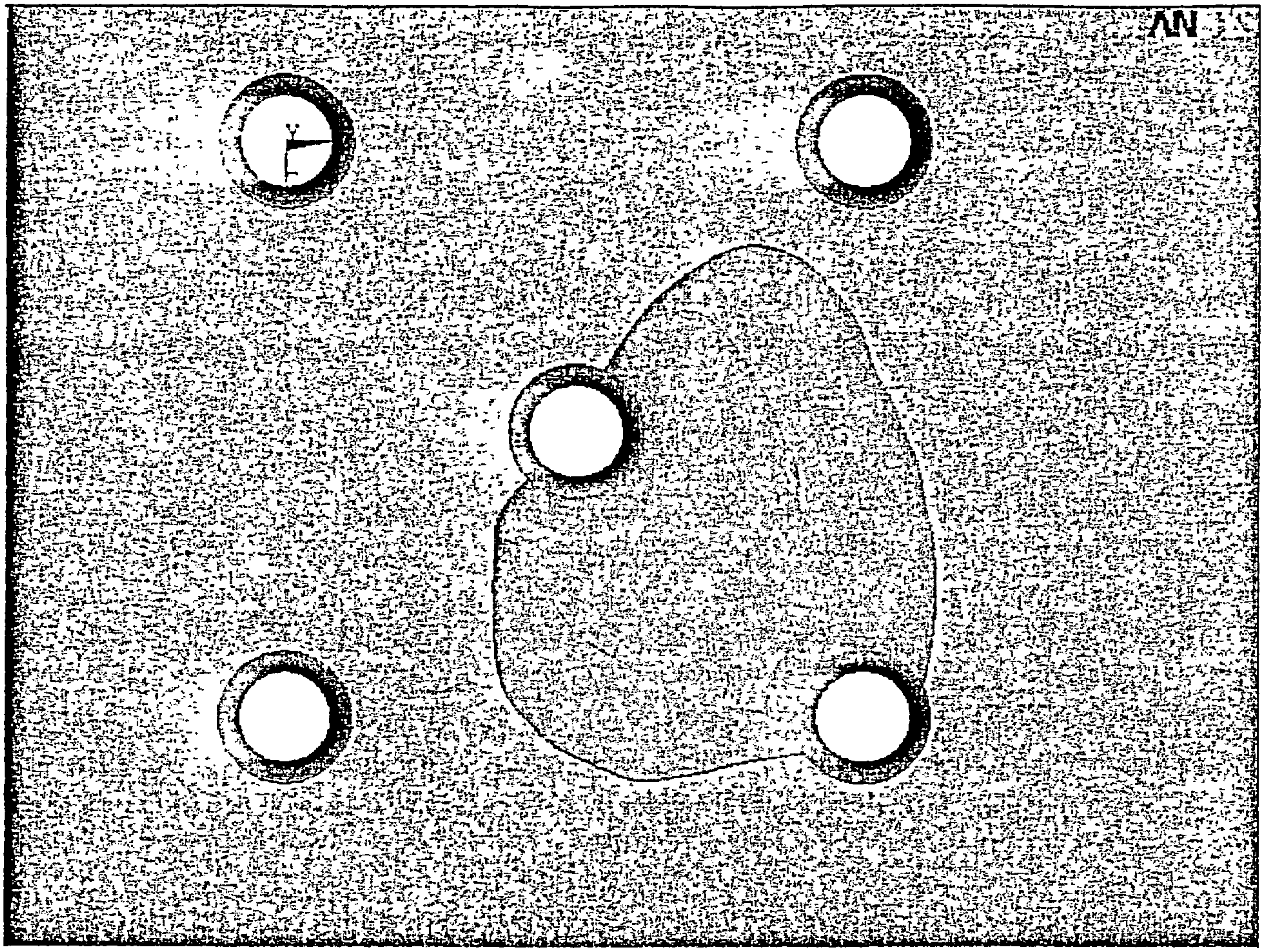


Figure 4 – Enlarged Self-Similar Cavity Layout
Exposed Clad Area = 61.5 in² (3A)

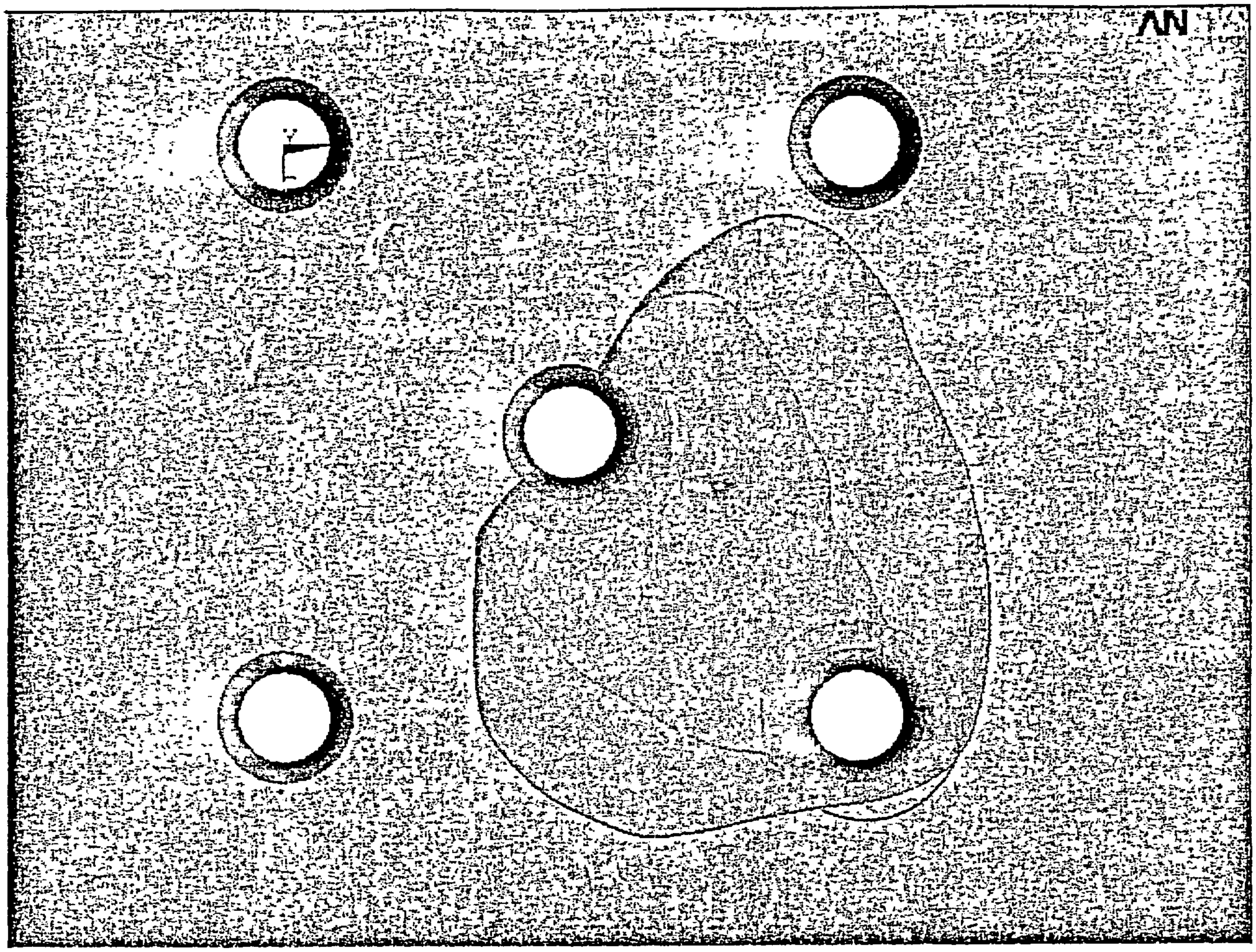


Figure 5 – Enlarged Self-Similar Cavity Layout
Exposed Clad Area = 82.0 in² (4A)

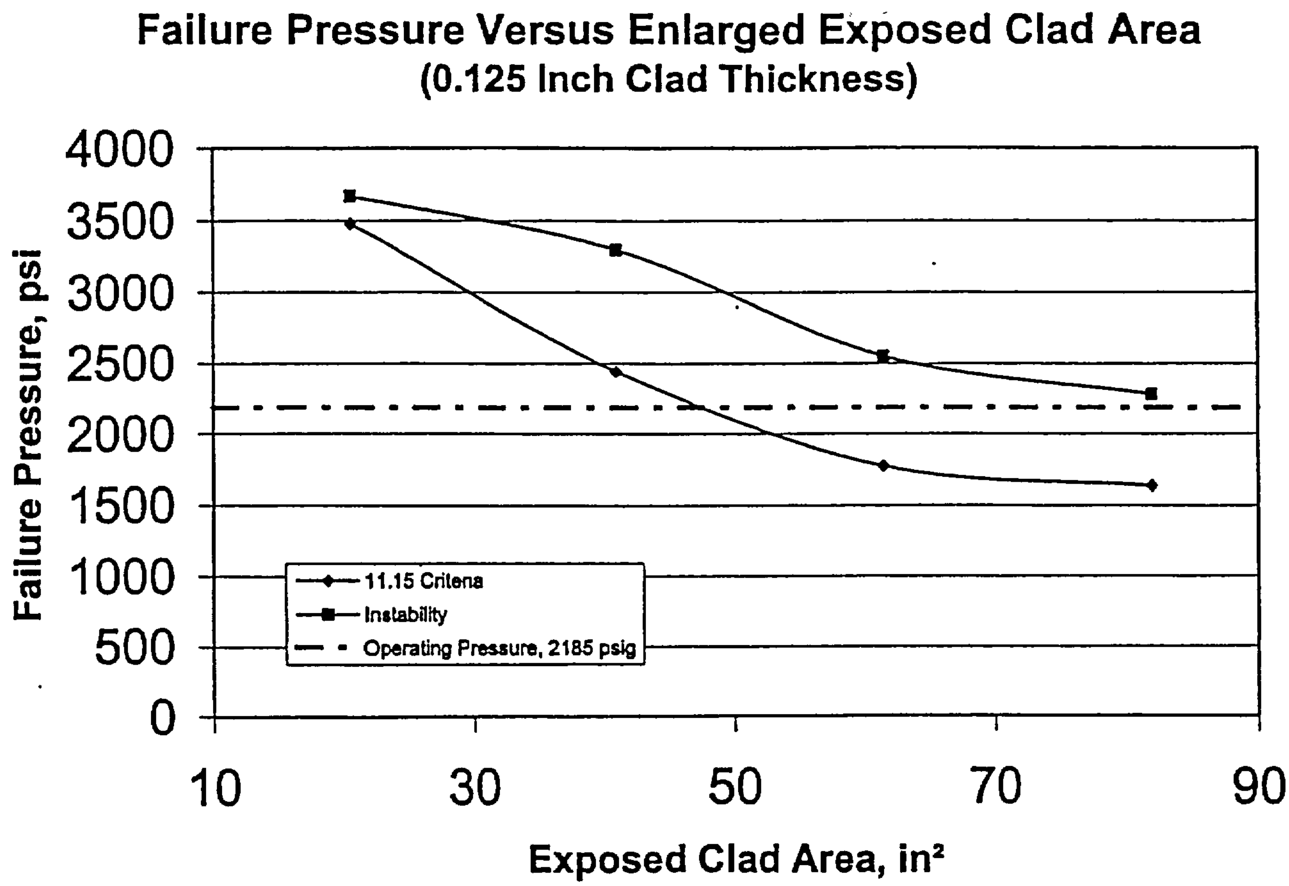


Figure 6 – Failure Pressure Versus Cavity Exposed Area, Clad = 0.125 inches

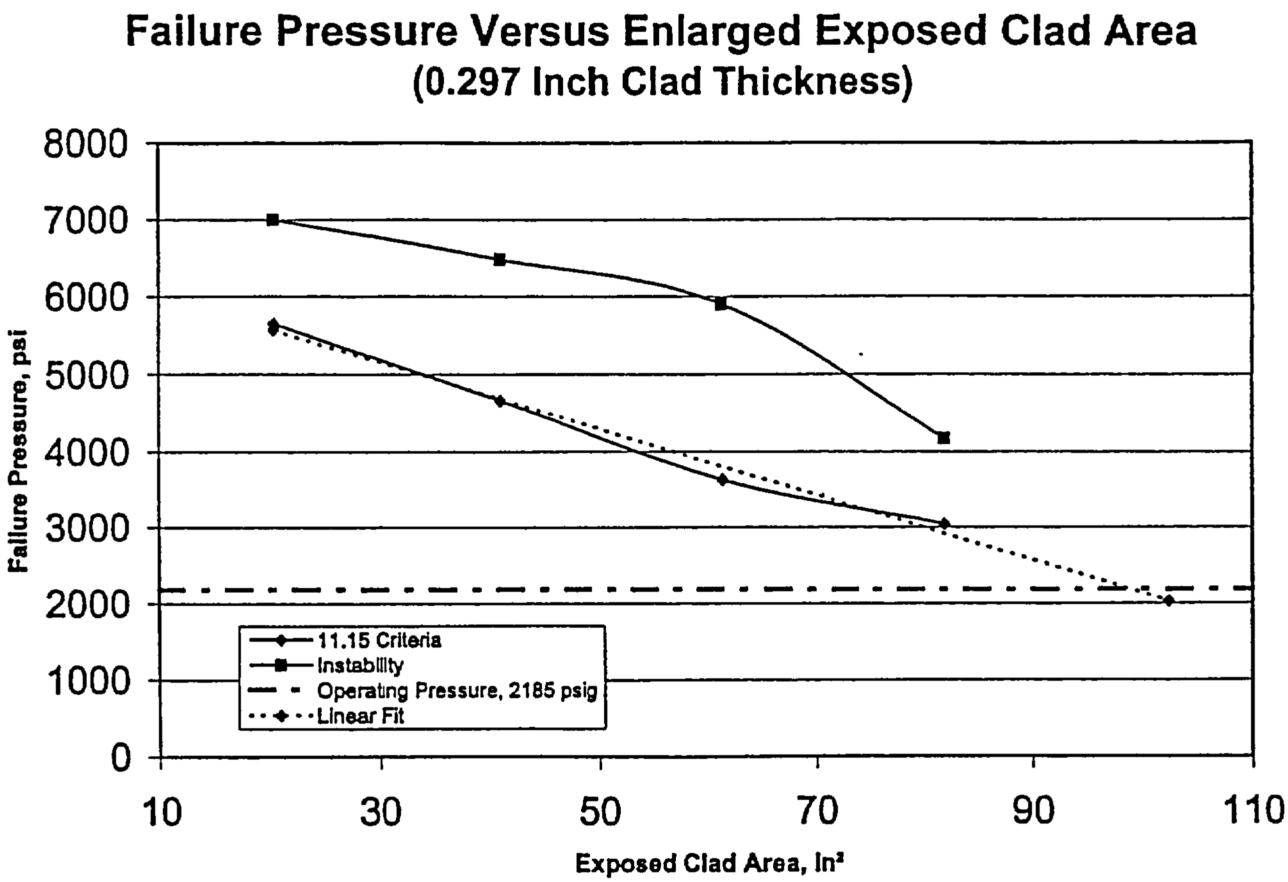


Figure 7 – Failure Pressure Versus Cavity Exposed Area, Clad = 0.297 inches

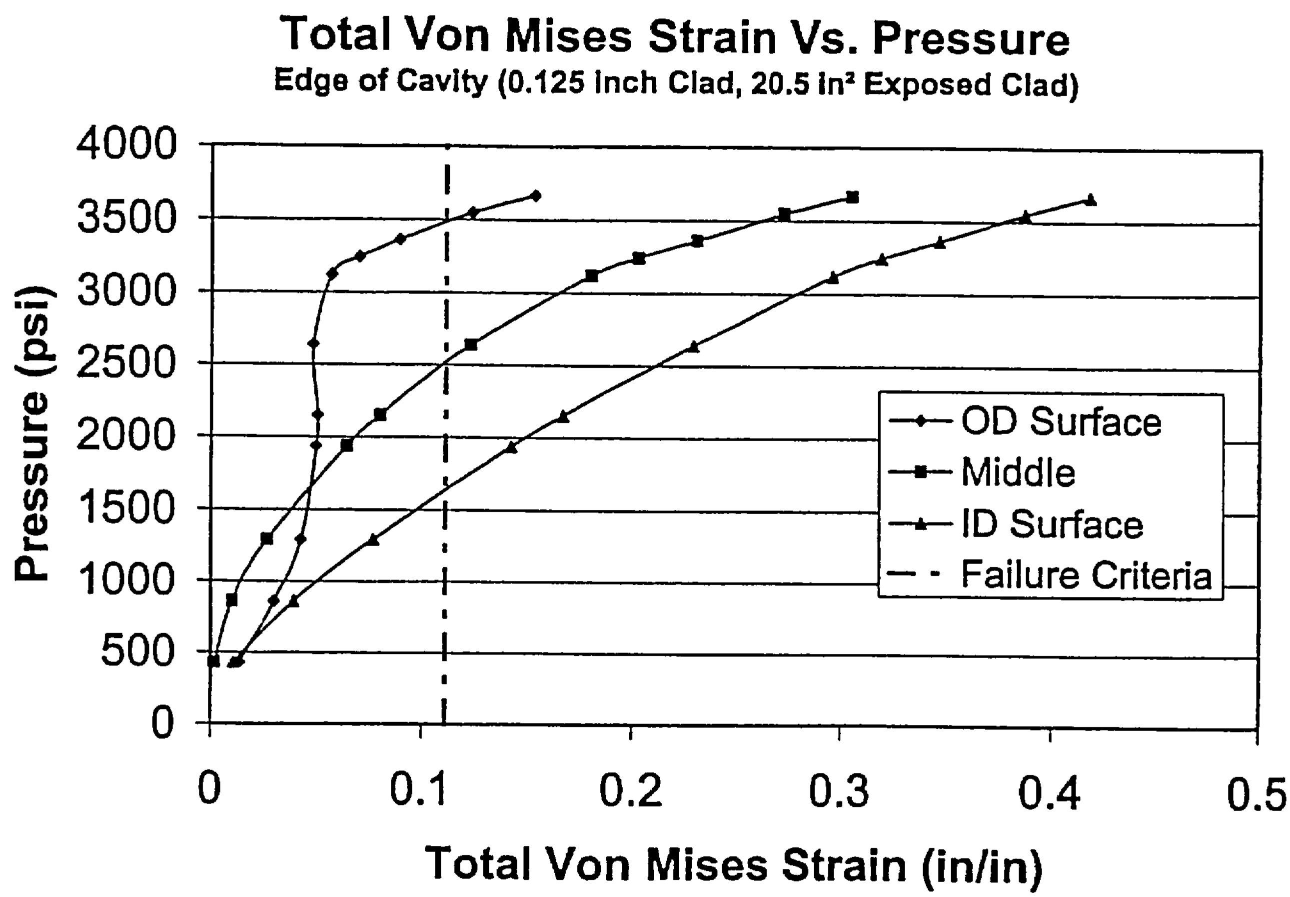


Figure 8 – Total Von Mises Strain Versus Pressure, Location at 11.15% Criterion Failure (0.125 Inch Clad, 20.5 in² Exposed Area)

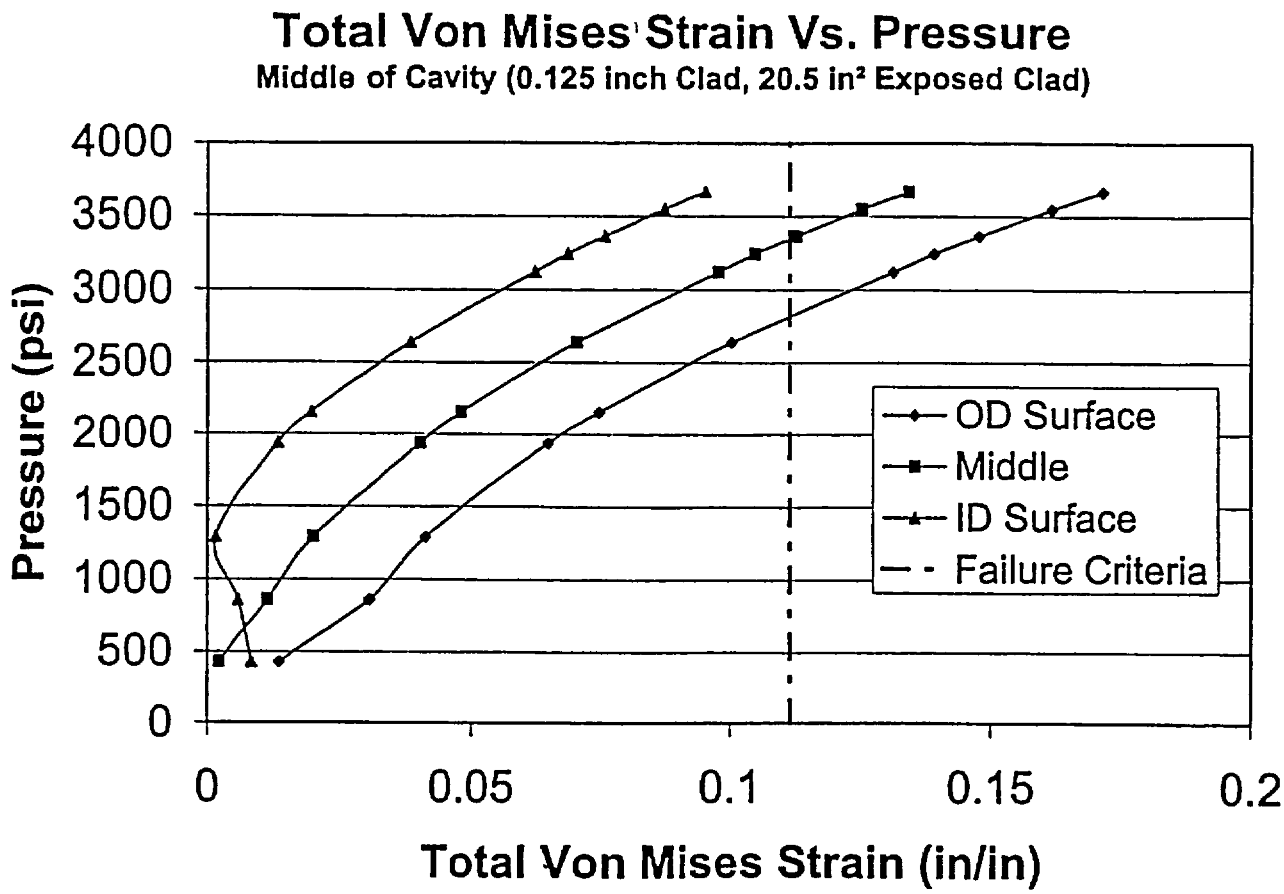


Figure 9 – Total Von Mises Strain Versus Pressure, Middle of Exposed Clad Region (0.125 Inch Clad, 20.5 in² Exposed Area)

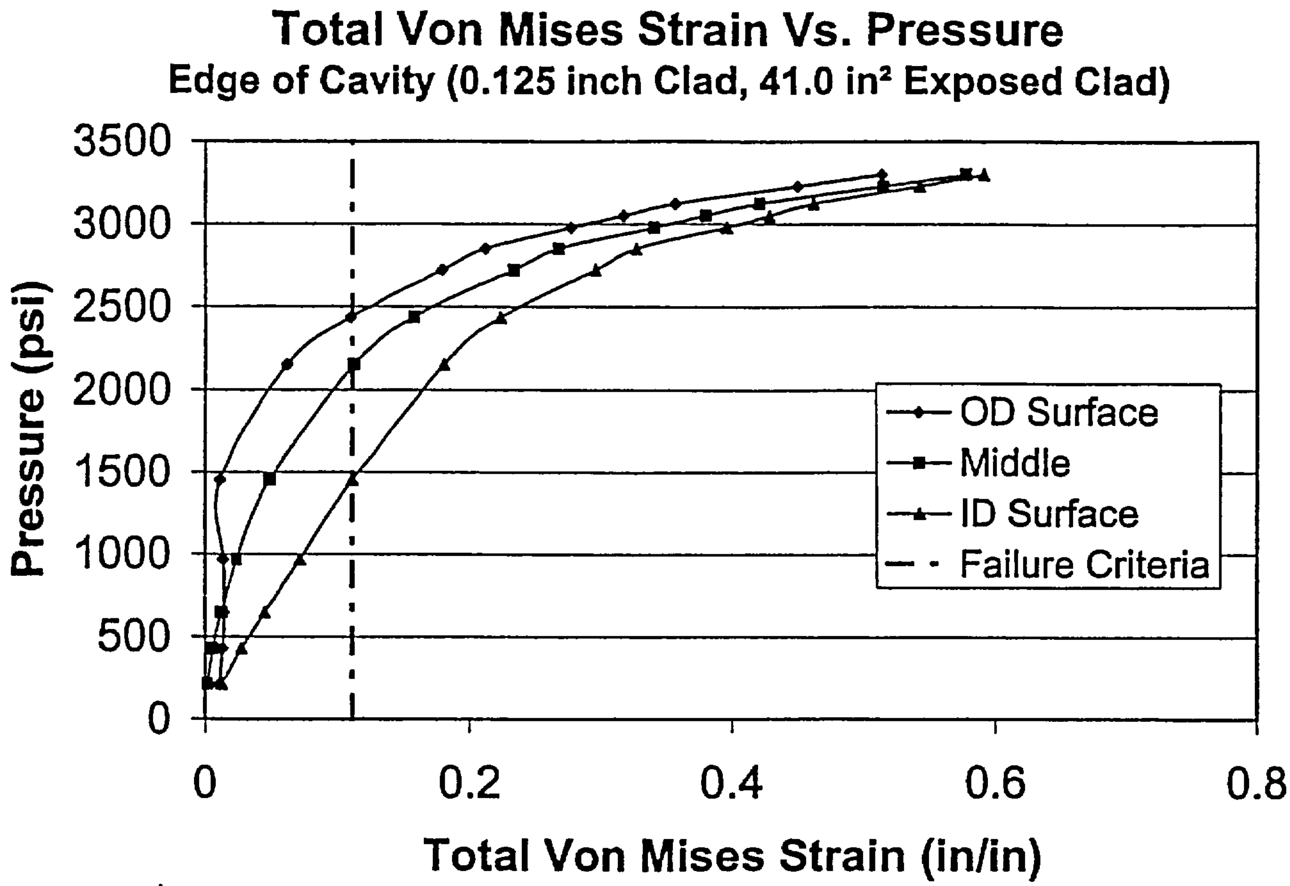


Figure 10 – Total Von Mises Strain Versus Pressure, Location at 11.15% Criterion Failure (0.125 Inch Clad, 41.0 in² Exposed Area)

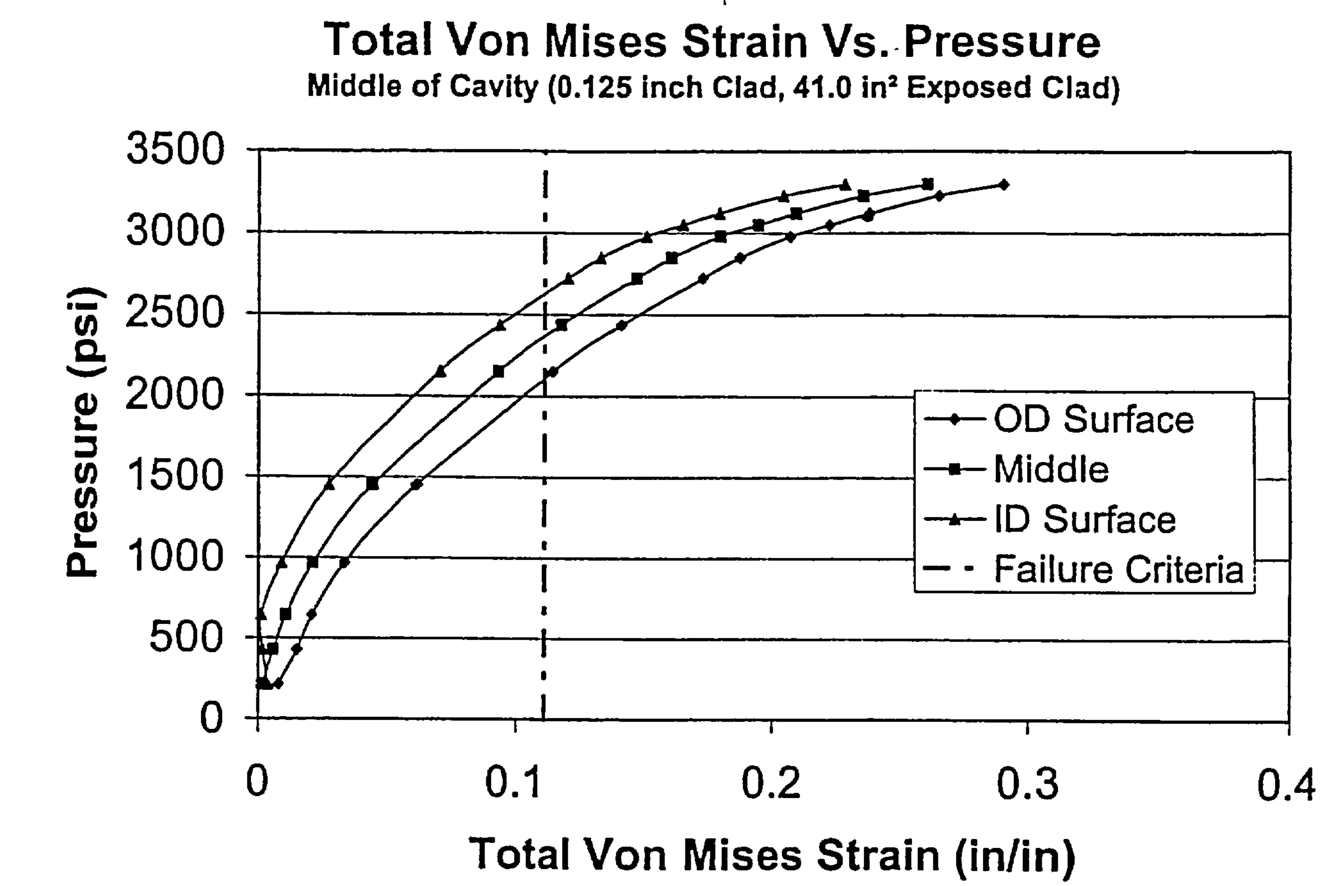


Figure 11 – Total Von Mises Strain Versus Pressure, Middle of Exposed Clad Region (0.125 Inch Clad, 41.0 in² Exposed Area)

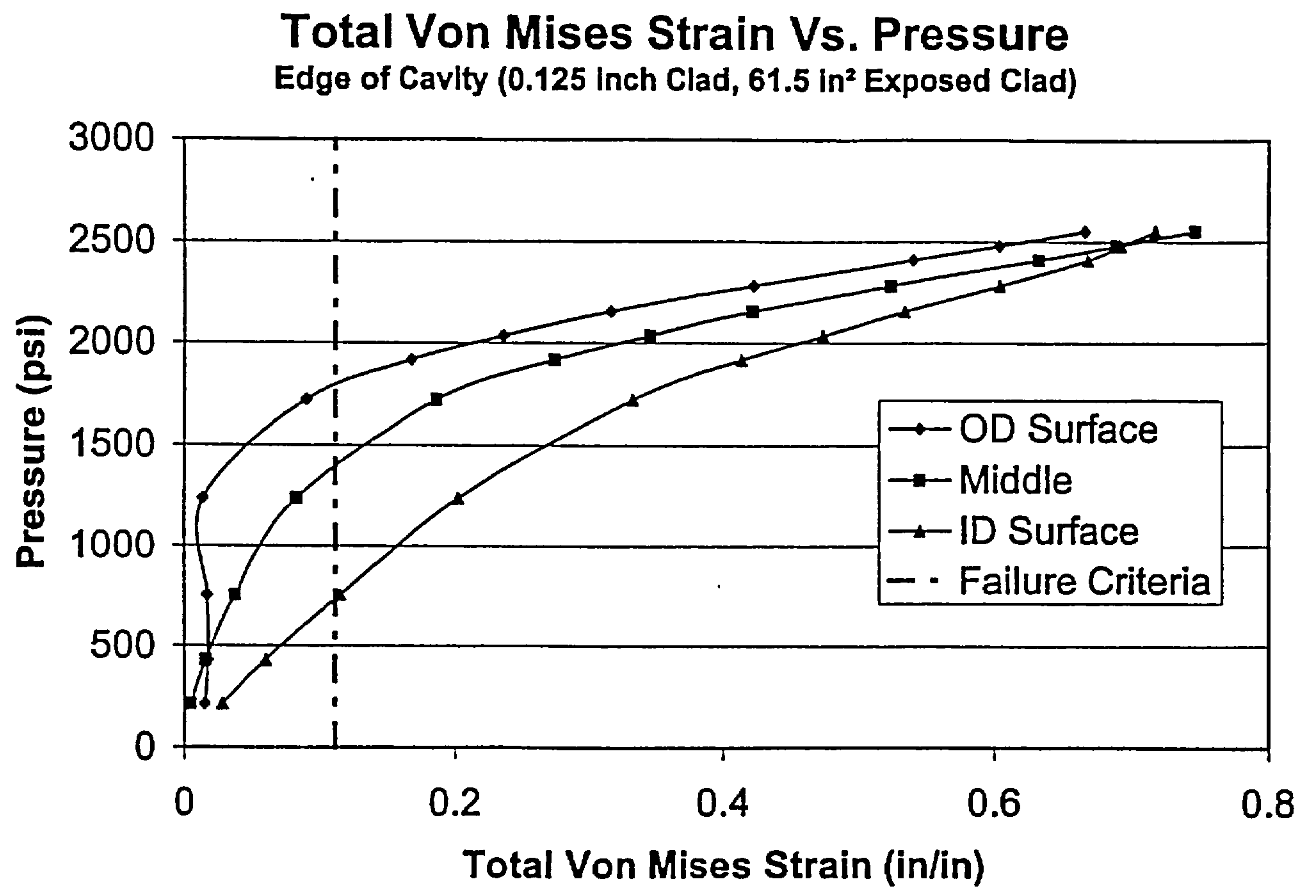


Figure 12 – Total Von Mises Strain Versus Pressure, Location at 11.15% Criterion Failure (0.125 Inch Clad, 61.5 in² Exposed Area)

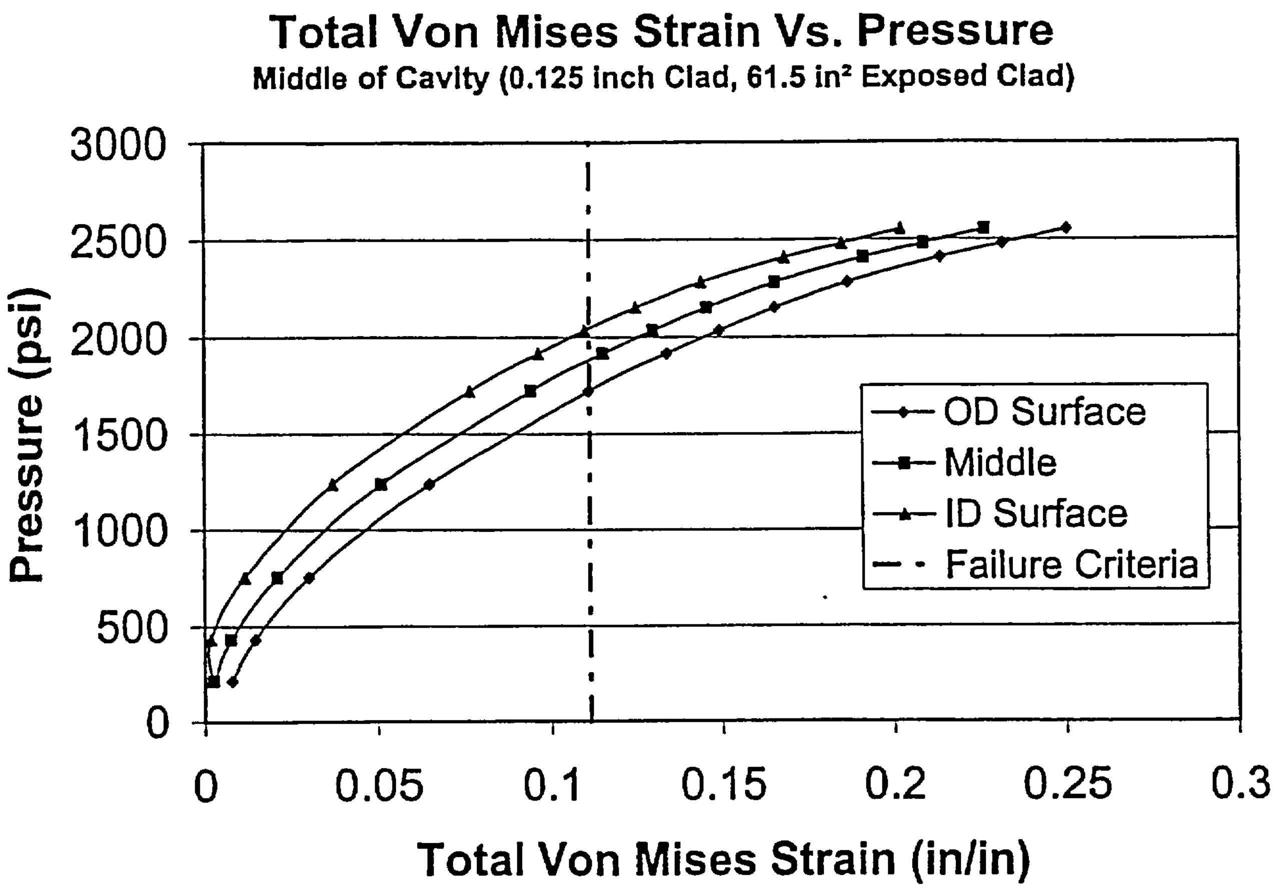


Figure 13 – Total Von Mises Strain Versus Pressure, Middle of Exposed Clad Region (0.125 Inch Clad, 61.5 in² Exposed Area)

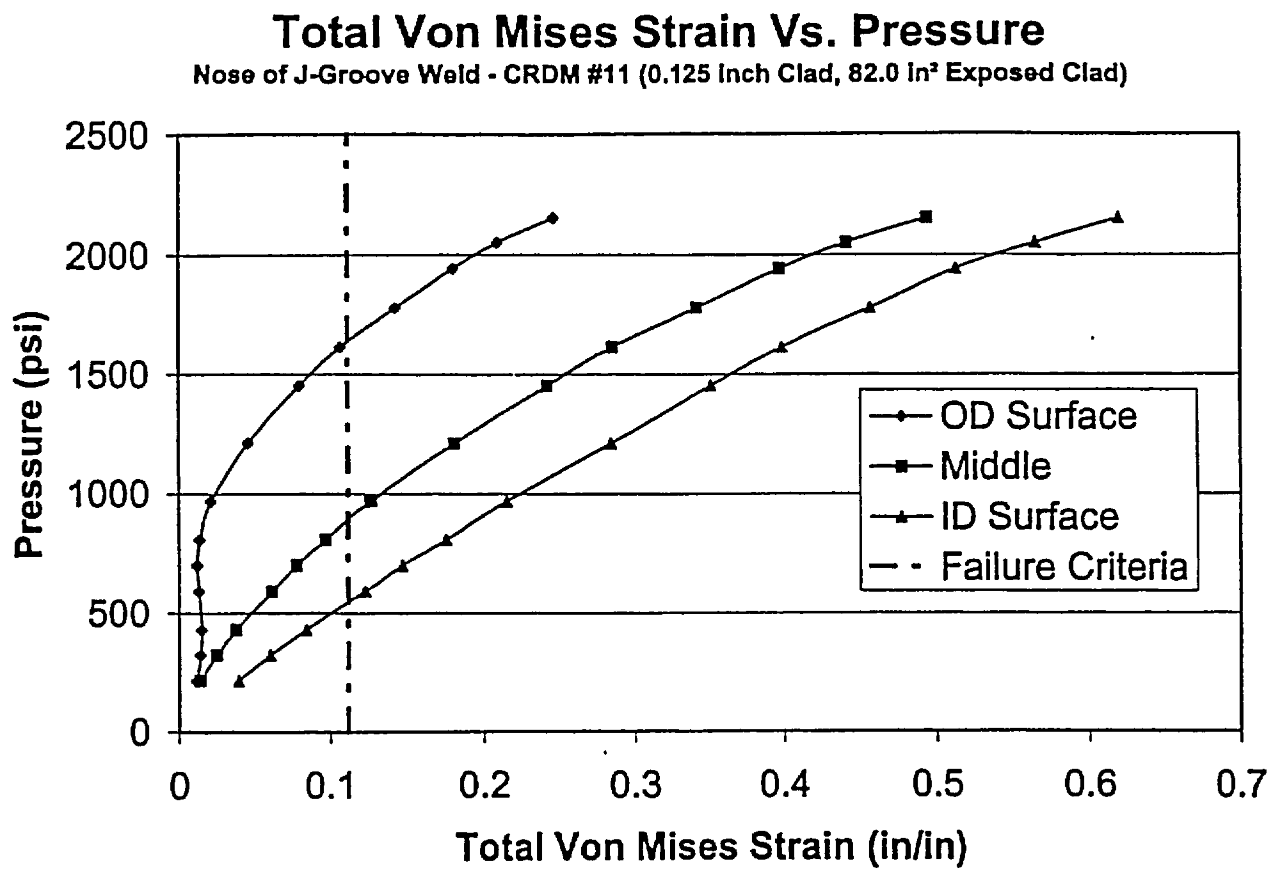


Figure 14 – Total Von Mises Strain Versus Pressure, Location at 11.15% Criterion Failure (0.125 Inch Clad, 82.0 in² Exposed Area)

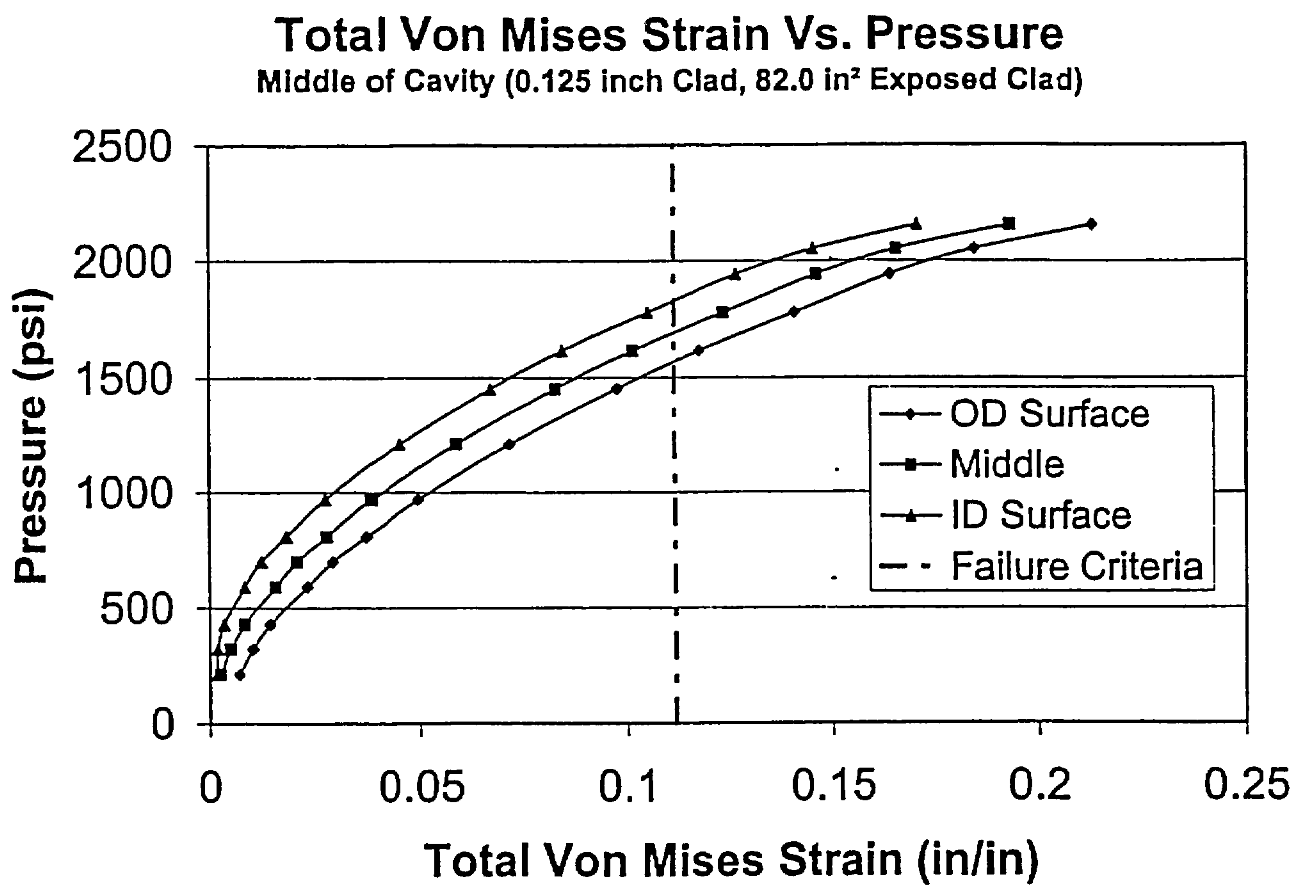


Figure 15 – Total Von Mises Strain Versus Pressure, Middle of Exposed Clad Region (0.125 Inch Clad, 82.0 in² Exposed Area)

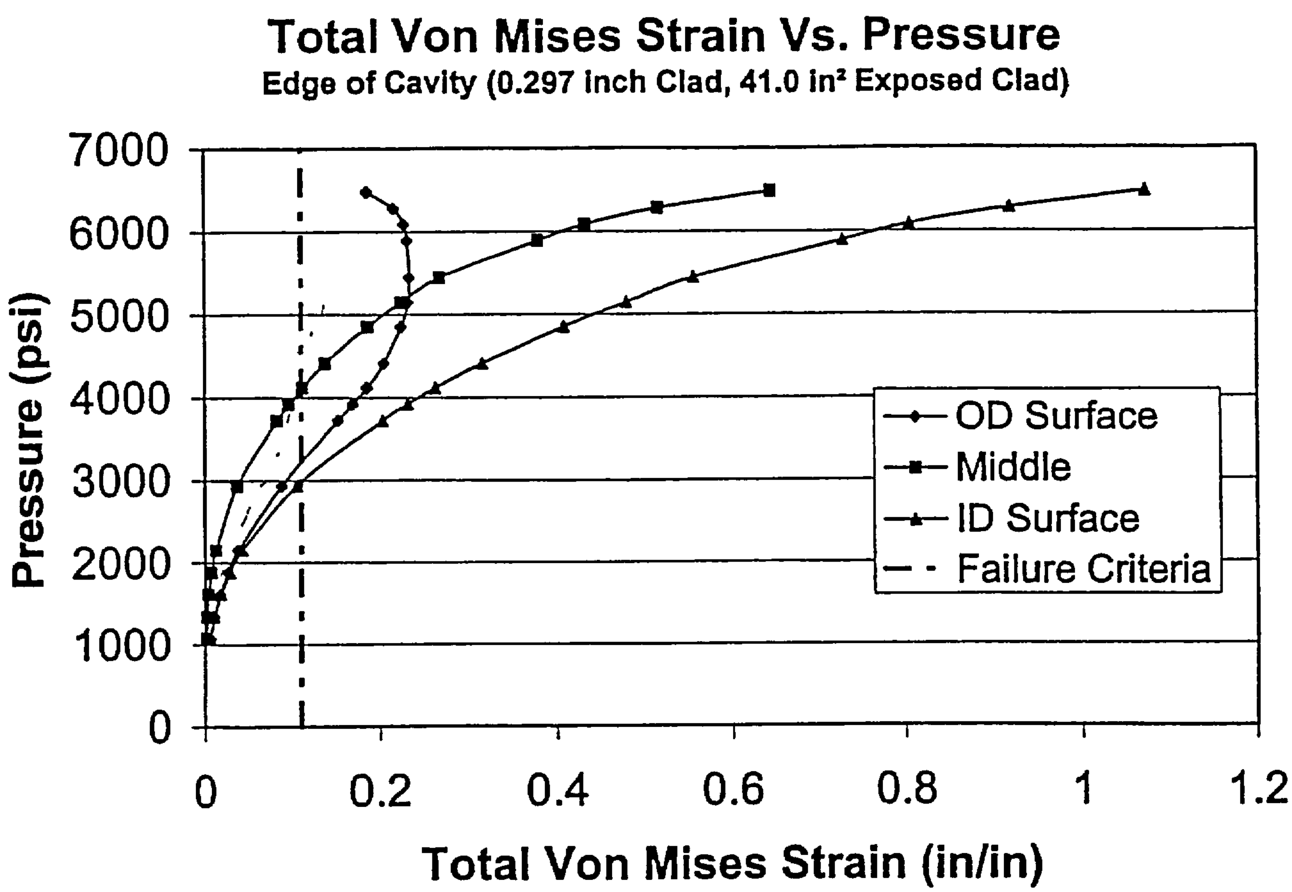
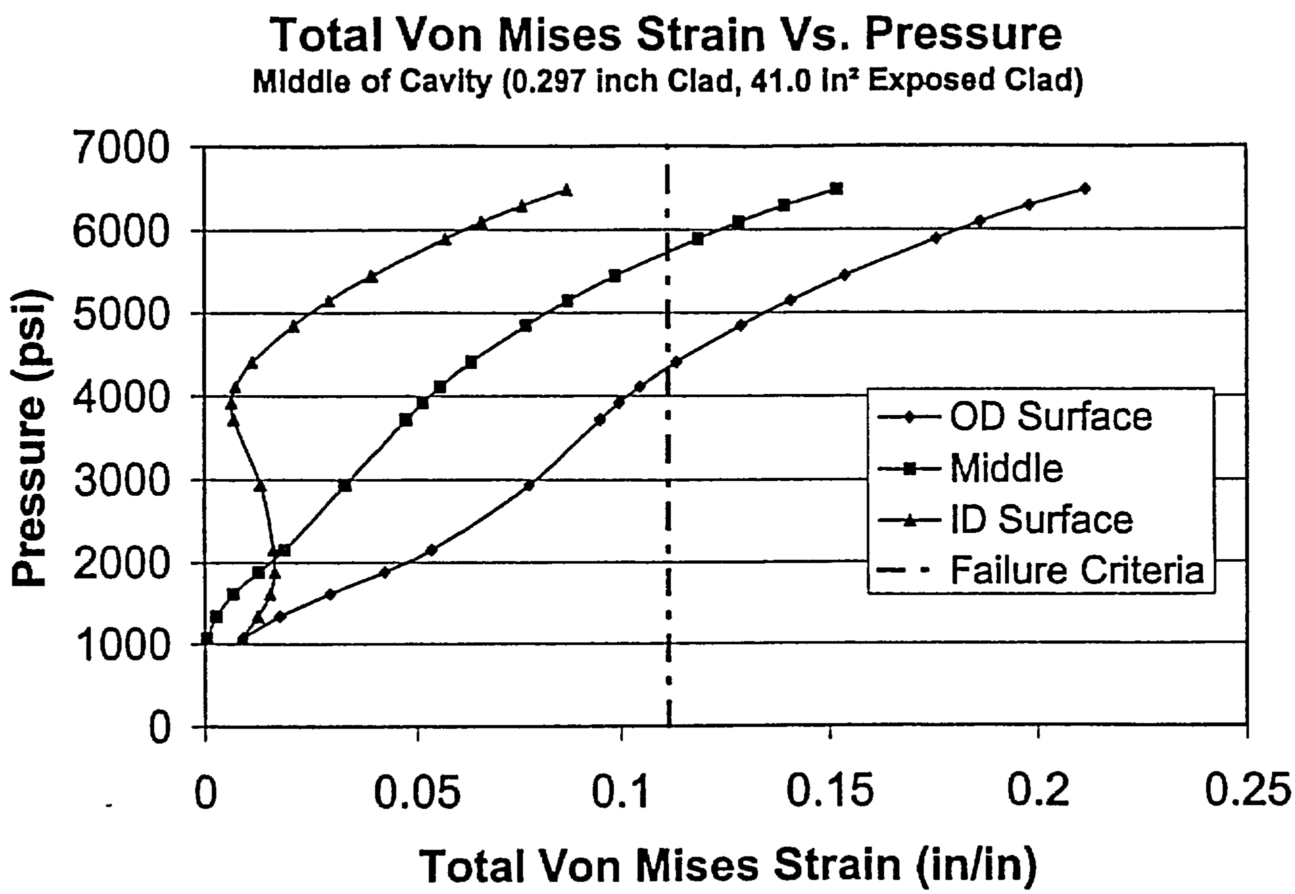


Figure 16 – Total Von Mises Strain Versus Pressure, Location at 11.15% Criterion Failure (0.297 Inch Clad, 41.0 in² Exposed Area)



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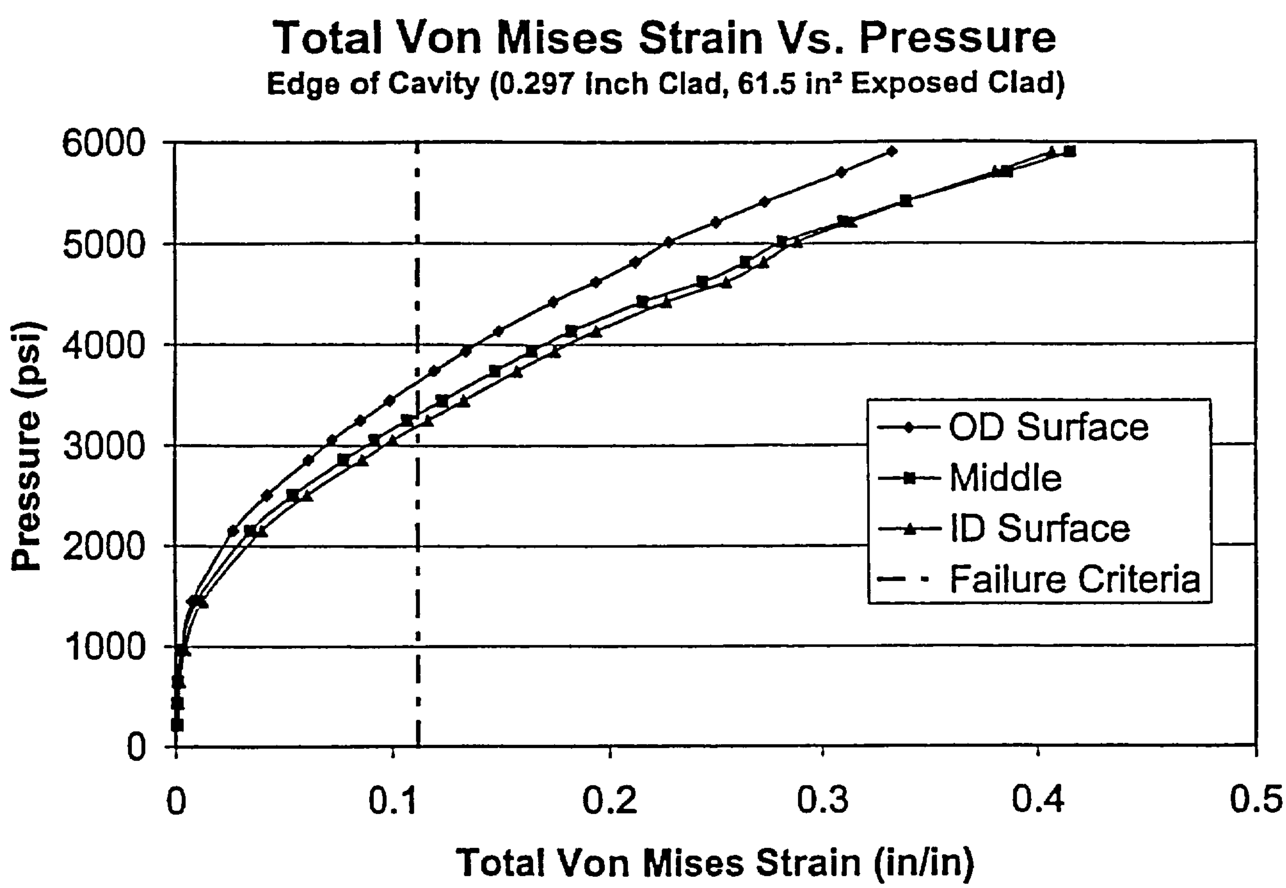

Figure 18 – Total Von Mises Strain Versus Pressure, Location at 11.15% Criterion Failure (0.297 Inch Clad, 61.5 in² Exposed Area)

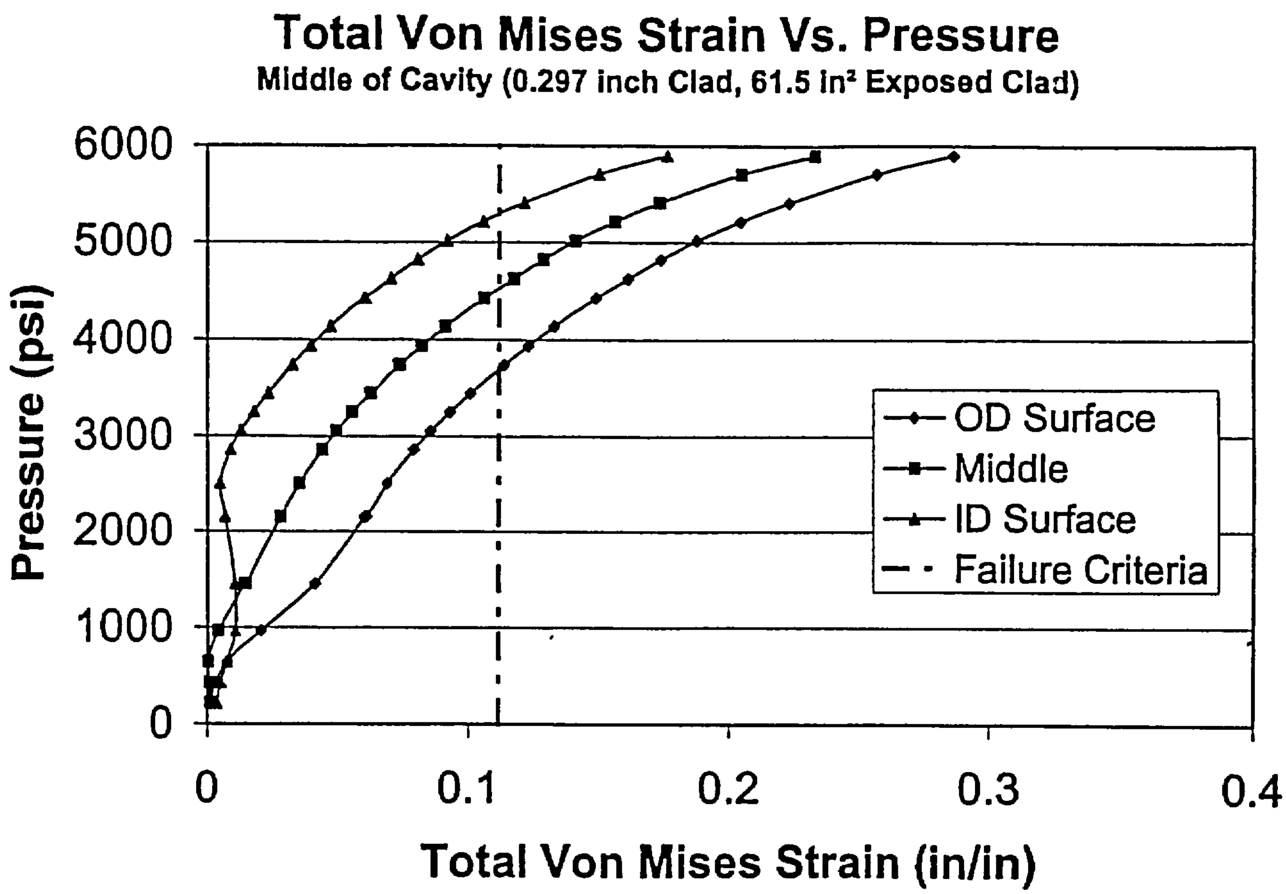

Figure 19 – Total Von Mises Strain Versus Pressure, Middle of Exposed Clad Region (0.297 Inch Clad, 61.5 in² Exposed Area)

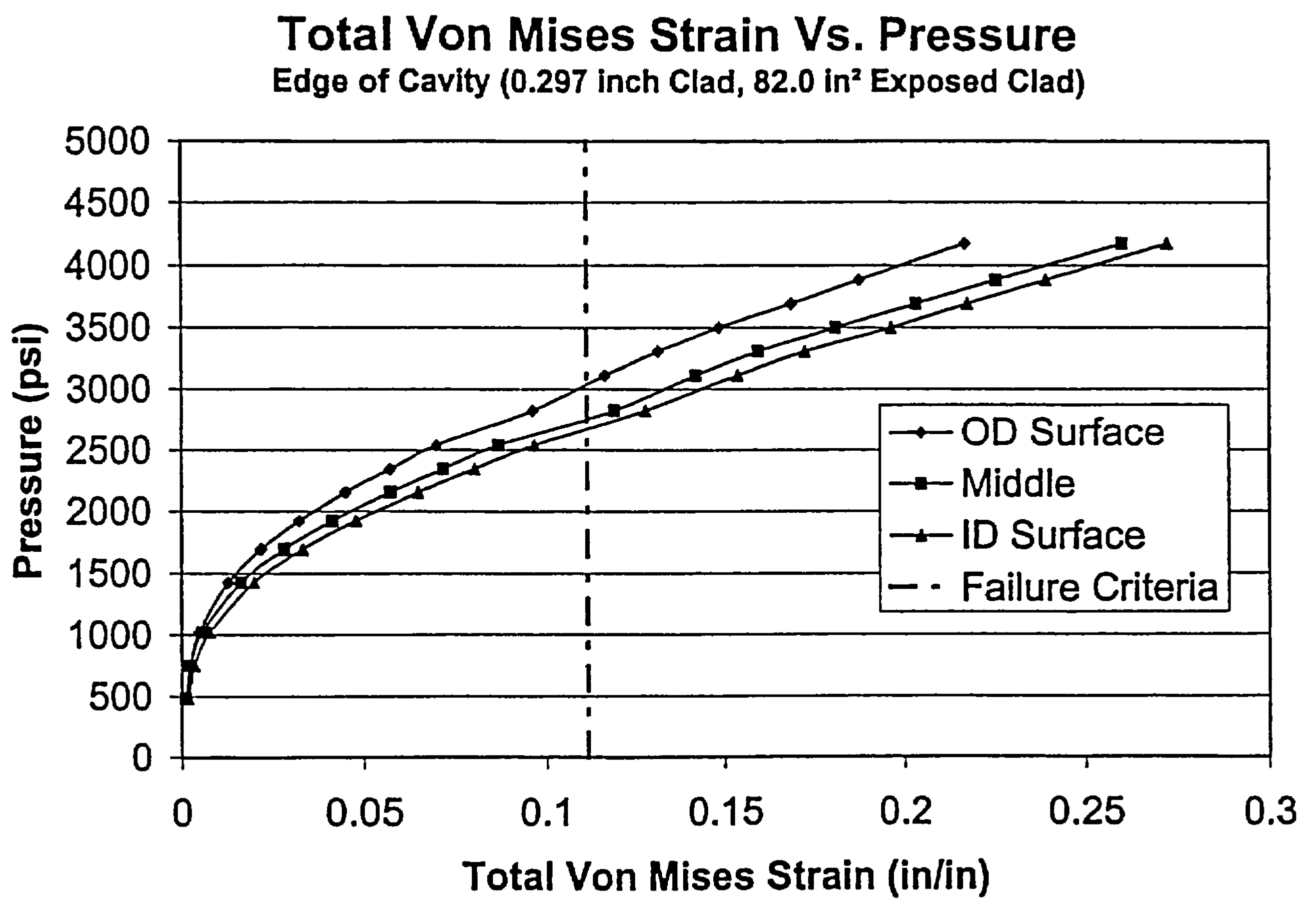

Figure 20 – Total Von Mises Strain Versus Pressure, Location at 11.15% Criterion Failure (0.297 Inch Clad, 82.0 in² Exposed Area)

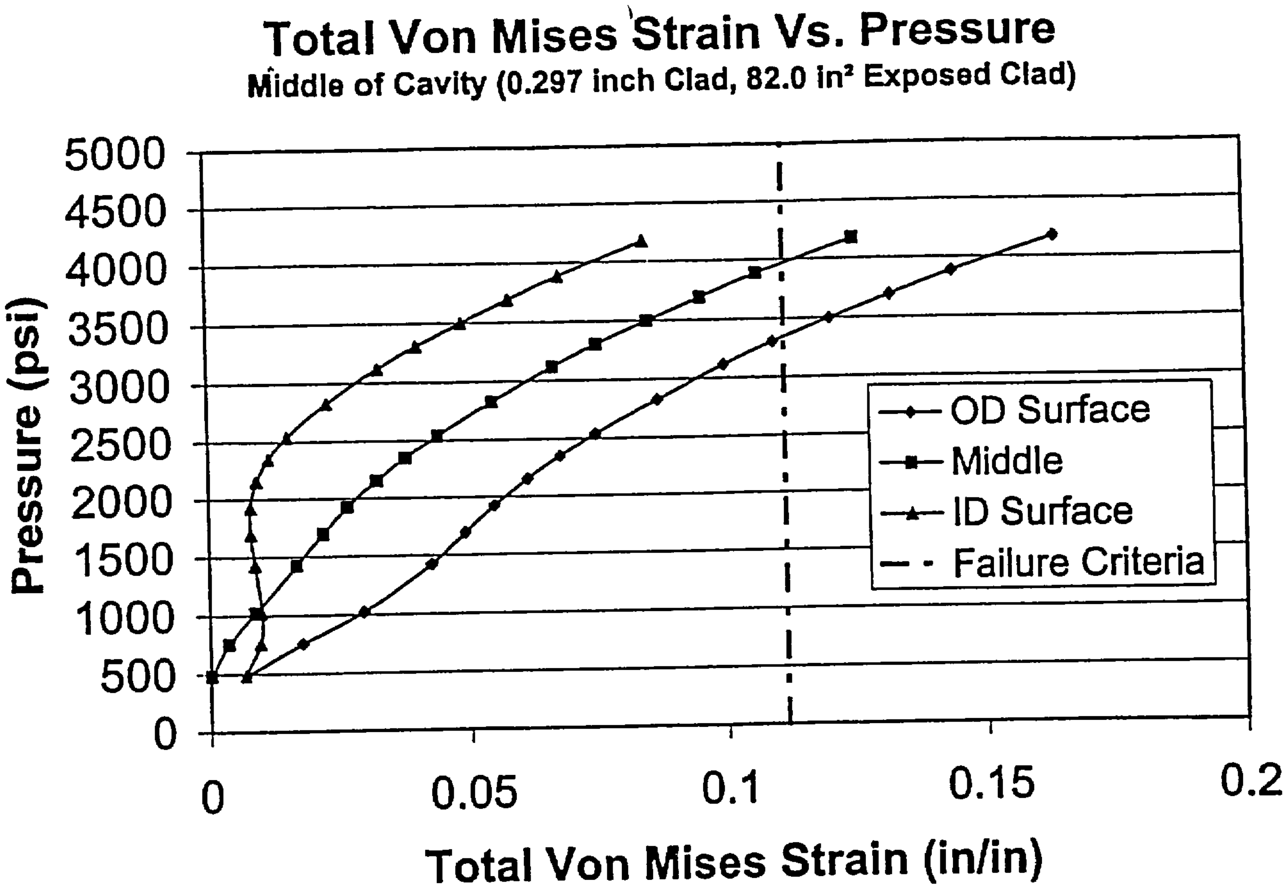

Figure 21 – Total Von Mises Strain Versus Pressure, Middle of Exposed Clad Region (0.297 Inch Clad, 82.0 in² Exposed Area)