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FRACTOGRAPHY OF GLASSES AND CERAMICS II

V.D. Fréchette • J.R. Varner

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Preface

The Second Conference on the Fractography of Glasses and Ceramics, held at Alfred University July 15–18, 1990, brought us the papers which constitute the chapters of this book. Together with the spirited discussions that ensued, they showed a growing appreciation among scientists and engineers for the power of fractography combined with fracture mechanics to shed light on materials problems. All of the attendees are to be congratulated on their contributions.

Because of overlapping concerns among the several papers, they were not segregated by field of interest, but were presented in random order and they are reproduced so here.

The yeoman labors of the International Convening Committee in encouraging authors and editing the submitted texts is gratefully acknowledged. Dean Richard Bradt, Professors John E. Bailey and John J. Mecholsky, Drs. Steve Freiman, Martin Schinker, John Kepple, and George Quinn, and Messrs. Roy Rice and John Lonergan all served unstintingly.

We appreciate the financial support of the Institute for Glass Science and Engineering, the Center for Advanced Ceramic Technology, and the Office of the Dean, all of the New York State College of Ceramics.

Mrs. Marlene Wightman, Mr. W.T. Emrick, Mrs. Coral Link, and many of our colleagues and graduate students in the New York State College of Ceramics assisted greatly with the Conference arrangements.

J.R. Varner
V.D. Fréchette

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Your comments, questions, and suggestions for future ***Ceramic Transactions*** *volumes are welcomed and should be addressed to the Director of Publications, The American Ceramic Society, Inc.*

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FINITE ELEMENT STRESS ANALYSIS AND CRACK PATH PREDICTION OF IMPLODING CRT

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ABSTRACT

The fracture pattern of cathode ray tubes (CRT) was predicted on the basis of the stress distribution analysed by finite element method. The stress state of a CRT was determined after evacuation and after the application of an implosion protection band. Calculated stresses are compared with stress data available in the literature. Actual fracture patterns are observed to agree with those predicted on a maximum principal stress criterion.

The maximum principal stress for a 68 cms (27 inch) diagonal CRT was determined to be 7.3 MPa at the end of the minor axis of the tube. Upon application of the implosion protection band the maximum principal stress reduced to 5.9 MPa.

INTRODUCTION

The safety of cathode ray tubes (CRT) during transportation, handling, manufacturing and during operation is of primary concern to every CRT manufacturer. This safety is dependent on the mechanical integrity of the CRT system. However, the material properties cannot readily be changed, although, the dimensions of the glass envelope can be increased for improving the mechanical strength. In addition, precautions in terms of laminations or implosion protection bands can be applied to the cathode ray tube to change the overall state of stress. This stress state can be changed not only in magnitude to improve the strength, but also in its orientation, which will govern the direction of crack propagation upon impact.

Implosion protection systems currently employed are either a machine tensioned band or a prestressed metal band. An adhesive tape is wrapped between the metal band and the glass panel. This tape prevents thermal shock of the panel during the band application and also allows the glass to stick to the metal band at the periphery of the CRT. The tape also prevents glass pieces from falling from the tube on impact. The band is wrapped around the panel such that compressive stresses are applied at the neutral axis of the panel at the corners. The stresses superimposed by the band change the stresses within the panel to control the fracture pattern of the panel on impact.

The safety of CRT's can also be changed by altering the basic design of the glass envelope. However, to test the effect of this change on the mechanical integrity of the system is an expensive proposition both in financial terms and in terms of time. Similarly it is expensive to determine the effects of the changes in implosion protection system on the mechanical integrity of tubes if numerous physical samples must be made and tested. Although expensive, theoretical analysis using FEA is perhaps the most economical and least time consuming approach. Only several studies have been attempted on the stress state of evacuated glass envelopes and even less study has been completed on the stress pattern of CRT's[1-4].

Elst and Wielenga[1] reported that the stress pattern obtained by FEA corresponds well with those obtained using strain gage measurements and therefore can be used to speed up design procedure.

Stress in CRT's have been addressed by Elst and Wielenga[1] and Enstrom et al[2]. Enstrom et al[2] have reported that the stresses can be reduced by 1.1 to 2.1 MPa (150 TO 300 psi)when an implosion protection band is applied to the tube. The stresses can also be modified by changing the geometry of the tube design, whereby more wedging is introduced into the structure, giving higher strength. Wedging is defined as the ratio of the difference of thickness of glass between the periphery and the centre of the panel and the thickness of glass at the centre of the panel. The stresses decrease by 3.1 MPa (450 psi) when the wedge is increased from 0.0 to 0.1. The apparent stresses when a typical Underwriter's Laboratories (UL)[5] missile impact of 21 Joules (15 ft-lb) is simulated, was reported to increase to 84 MPa (12 ksi).

In these aforementioned studies there are no concerns about the change of stress within the CRT on impact, or the fracture pattern which develops as a result of the impact. That type of study will indicate the theoretical prediction of the safety of the tubes as a result of the change in the stresses due to either design changes of the glass envelope or the design of the overall implosion protection system. Since the UL[5] and Canadian Standards Association (CSA)[6] standards restrict the glass weight and the number of pieces which are thrown to the front of the tube upon impact, this type of study can also predict whether the tubes will pass those test requirements.

The stress level of 84 MPa (12 ksi) resulting due to an impact of 21 Joules (15 ft-lb) is an order of magnitude higher than the normal cooling stresses in the glass. As the residual stress on cooling is approximately 5.2 MPa (750 psi) the effect of the residual stress state of glass will be minimal in affecting the initiation of fracture of the glass CRT. The crack propagation will be governed in terms of the instantaneous stress pattern which develops during impact consideration over and above the cooling stresses in glass.

EXPERIMENTAL PROCEDURES

The geometry of the CRT was taken per the commercial design drawings. The dimension of the cathode ray tube is given by the diagonal measurements. The aspect ratio of the front face is 3 by 4 with the longer dimension referred to as the major axis and the shorter dimension known as the minor axis.

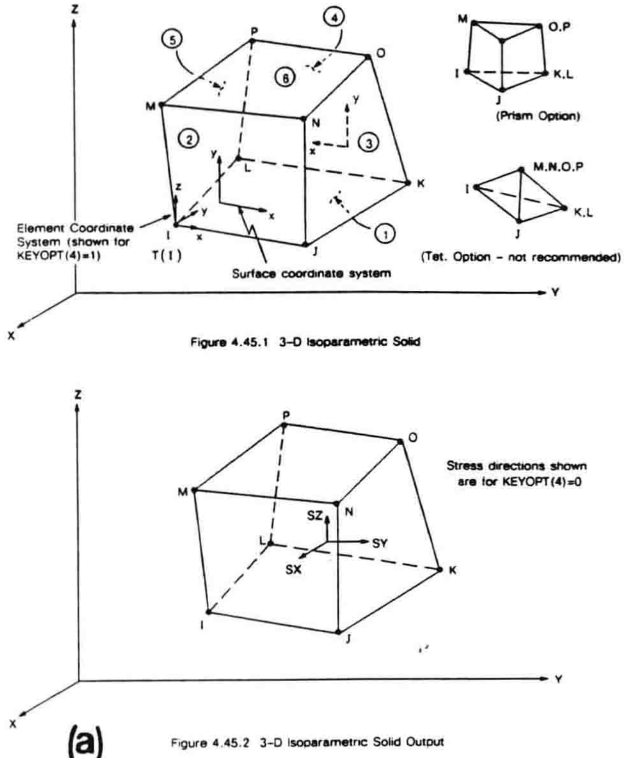
Schematic of the basic tube geometry and element geometry is shown in Figure 1. ANSYS 4.4 was used as the FEM program for the calculations of stresses. Table 1 summarizes the parameters used for the finite element analysis. The boundary condition was zero displacement of the tip of the neck in all three cartesian directions. Quarter symmetry was used and the elements were STIF 45 which is a 8 node 3-D isoparametric solid element.

TABLE 1: SUMMARY OF FEA PARAMETERS

CODE	MAX. PRINCIPAL STRESSES	CENTROID STRESSES
Element Type	Stif 45	Stif 45
No. of Elements Thru Thickness	2	1
Total No. of Elements	3968	1344
Boundary Conditions	0 Displacement At Neck in all three directions	0 Displacement At Neck in all three directions

For calculations of the maximum principal stresses on the outside and inside surfaces of the CRT two elements were used through the thickness of the tube. The seal between the panel and the funnel (frit sealing) is assumed to be a continuum of the panel and funnel glass and therefore its effect on the stress state is not considered.

To obtain an unified picture of the stress pattern single element was taken through the thickness. The stresses obtained were at the centroid of the elements and therefore at the centre of the glass panel. The centroid stresses are calculated by computing the average component stresses for each element from the component stresses of its nodes. The principal stresses are calculated from these averaged stresses and the vectors appear as arrows at the element centroid.



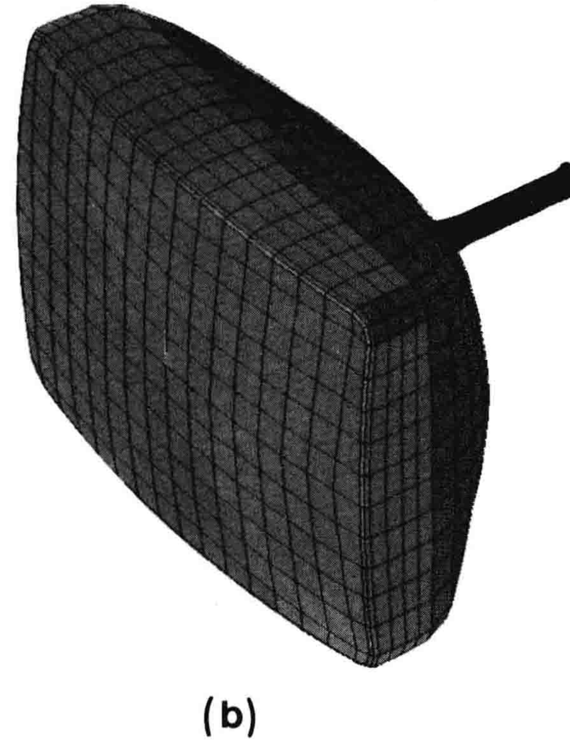


FIGURE 1: Schematic of (a) Stif 45 Element (b) Element Distribution on a 68 cm (27 inch) CRT.

Evacuation was simulated by applying stresses of 0.1 MPa (14.7 psi) on all the nodes on the outer surface, but no stresses on the inside surface.

Application of the implosion protection band was simulated by applying loads of 10675.2 N (2400 lbf) at the corners of the CRT. Impact was simulated by a point load at a location stipulated by UL[5] and CSA[6]. The point load for a 7 Joules (5 ft-lb) impact force of the ball was converted to 11529.7 N (2592.1 lbf) and 21 Joules (15 ft-lb) impact force for missile converted to an impact load of 34589 N (7776.3 lbf). Actual impact behavior was observed by subjecting a tube with a 5 cms (2 inch) diameter steel ball weighing 0.5 Kg (1 pound). The missile impact was obtained by using a missile shaped steel object which had a 5 cms (2 inch) diameter at the tip and weighed 2.4 kgs (5 pounds).

RESULTS AND DISCUSSION

The stress pattern of a CRT after evacuation is shown in Figure 2. Table 2 summarizes the stresses for the

TABLE 2: SUMMARY OF PRINCIPAL STRESSES (MPa)

CODE	VACUUM CASE	WITH IMPLOSION PROTECTION
Maximum Stress	7.3	5.9
Location	End of Minor Axis 1 inch into Skirt	End of Minor Axis 1 inch into Skirt
End of Major Axis		
Outside Surface	2.5	2.0
Inside Surface	0.5	-2.1
End of Minor Axis		
Outside Surface	3.1	2.6
Inside Surface	0.9	-1.5
End of Diagonals		
Outside Surface	1.6	1.7
Inside Surface	2.2	-3.4
Center of Panel		
Outside Surface	-0.06	-0.06
Inside Surface	3.1	1.5

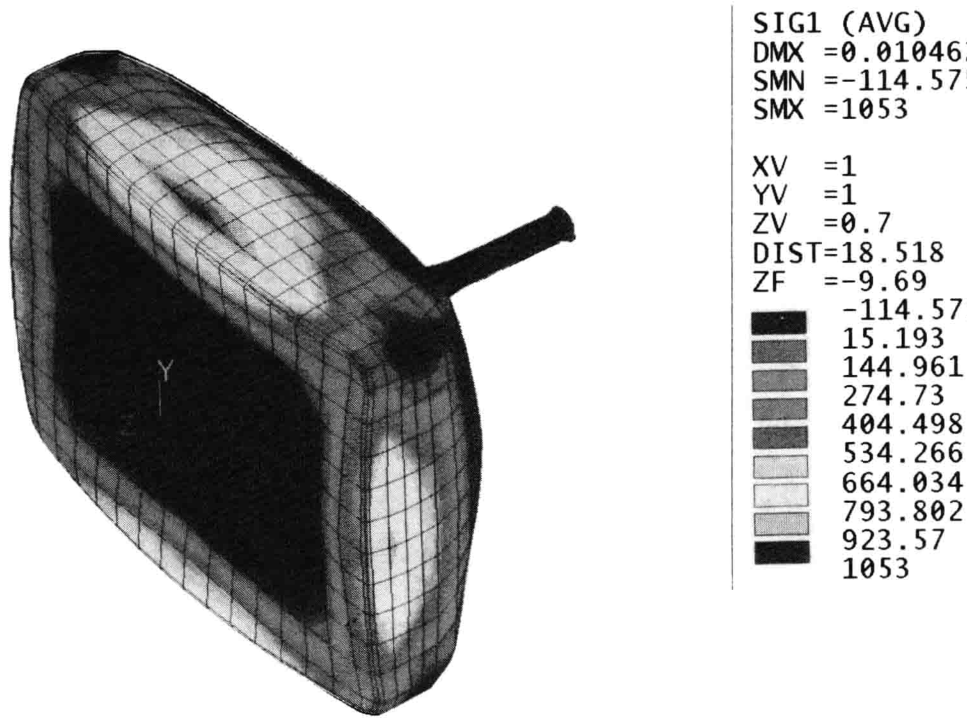


FIGURE 2: Stress Distribution in an Evacuated Tube.

different analyses done in this study. The maximum principal stress for the CRT is at the end of the minor axes around the skirt of the front panel. It is only 7.3 MPa (1053 psi) in magnitude. This agrees with the observations made earlier by Elst and Wielenga[1] and Enstrom et al.[2]. Experimentally measured values are also highest at these locations as confirmed by the glass manufacturers. Since there is no other documented work in the literature, the values obtained for the stresses were compared with theoretical analysis done by glass manufacturers namely Corning Asahi Videos and Owens Illinois-Nippon Electric Glass. For the same geometry of CRT, the stresses obtained by the glass manufacturers were similar to this analysis.

The stress distribution on the outside surface of the front of the panel is shown in Figure 3, only 1/4 of the geometry is shown because of the symmetry. On the outer surface of the front panel the stresses are compressive around the centre and has a value of -0.06 MPa (-9 psi) at the the center. At the end of the major axis the stresses are tensile and the nominal value is 2.5 MPa (357 psi) aligned parallel to the axis. The stress at the diagonal is 1.6 MPa (232 psi), perpendicular to the diagonal. At the end of the minor axis the stress is tensile and the nominal value is 3.1 MPa (446.2 psi) aligned parallel to the axis. High stresses exist in a circular orientation, about the center, at the peripheral points of the CRT.

The stress distribution on the inside surface is shown in Figure 4. The tensile stress is the highest at the center of the panel and its value is 3.1 MPa (446.3 psi) aligned perpendicular to the major axis. An important observation is that the the inside surface of the panel center is in tension while the outside surface at the center is in compression. From Table 2 and Figures 3 and 4 it is seen that the stresses at the ends of both the axes is lower on the inside surface by 2.0 MPa (290.1 psi). The inside surface at the diagonals has 37% higher tensile stresses than the outside. This is expected because the corners flex during evacuation and have a tendency to move away from the center of the tube with the inside face having a greater tendency to move out. The overall stress distribution on the

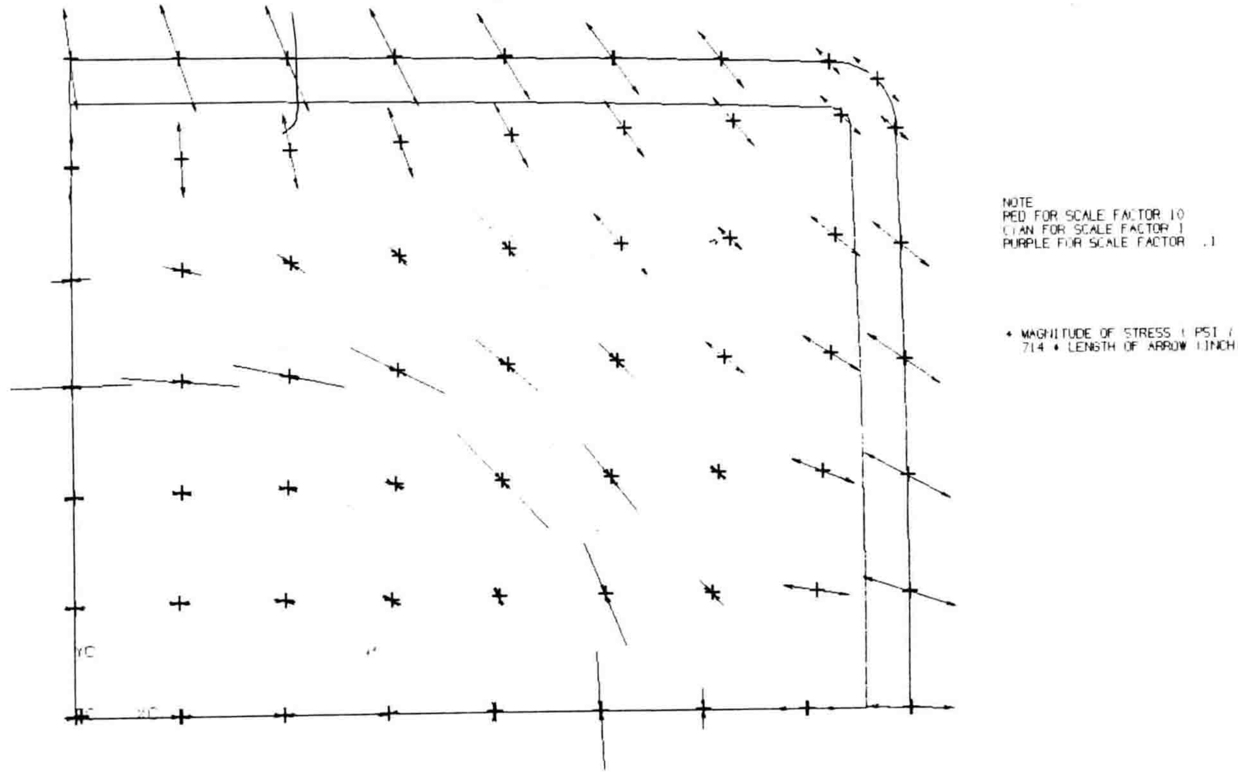


FIGURE 3: Maximum Principal Stress Directions and Magnitude in Panels on Outside Surface, Vacuum Case. (1/4 Model)