THERMAL STRESSES IN PYROTECHNIC INITIATORS USED IN AUTOMOTIVE SUPPLEMENTAL RESTRAINT STYSTEMS

FINAL REPORT

JANUARY 2006

KLK349

NIATT Report Number N06-05

Prepared for

OFFICE OF UNIVERSITY RESEARCH AND EDUCATION

U.S. DEPARTMENT OF TRANSPORTATION

Prepared by

NATIONAL INSTITUTE FOR ADVANCED TRANSPORTATION TECHNOLOGY

UNIVERSITY OF IDAHO

Karl Rink

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the information presented herein. This document is disseminated under the sponsorship of the Department of Transportation, University Transportation Centers Program, in the interest of information exchange. The U.S. Government assumes no liability for the contents or use thereof.

1. Report No.

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle

Thermal Stresses in Pyrotechnic Initiators Used in Automotive Supplemental Restraint Systems

5. Report Date
December 2005

6. Performing Organization Code
KLK349

Author(s)
Karl Rink

8. Performing Organization Report No.
N06-05

9. Performing Organization Name and Address
National Institute for Advanced Transportation Technology
University of Idaho
PO Box 440901; 115 Engineering Physics Building
Moscow, ID 838440901

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
DTRS98-G-0027

12. Sponsoring Agency Name and Address
US Department of Transportation
Research and Special Programs Administration
400 7th Street SW
Washington, DC 20509-0001

13. Type of Report and Period Covered
Final Report: August 2004- December 2005

14. Sponsoring Agency Code
USDOT/RSPA/DIR-1

Supplementary Notes:

16. Abstract

Airbags were responsible for saving 14,772 lives in the US between 1975 and 2003. Currently, over 146 million vehicles are equipped with airbags that are expected to function properly during a long vehicle life span. The airbag's pyrotechnic initiator is responsible for its deployment in crash situations. Cracks have been observed in the insulating glass that potentially can allow moisture to penetrate the initiator and degrade the pyrotechnic and bridgewire; degradation of the pyrotechnic or bridgewire can result in the initiator not functioning. The goal of this work was to determine the cause of the cracks with respect to the manufacturing process and to compare the results of this model to cracks observed in actual initiators returned from field service. Closed form solutions were used to determine basic stress magnitudes. A three-dimensional, finite element analysis was used to determine more exact stresses including the effects of transient cooling. The analysis showed that if the manufacturing process involves pouring molten glass into the initiator, the likelihood of cracking is high. Further, if the surface of the initiator cools faster than the center, cracking could result.

17. Key Words
Pyrotechnics; initiators; seat belts; airbags

18. Distribution Statement
Unrestricted; Document is available to the public through the National Technical Information Service; Springfield, VT.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	22. 10	…

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Airbags were responsible for saving 14,772 lives between 1975 and 2003. Currently, over 146 million vehicles in the United States are equipped with airbags, and the airbags are expected to function properly during a long vehicle life span. The pyrotechnic initiator within the airbag is responsible for deploying the airbag in crash situations. The initiator is composed of pyrotechnic material; a bridgewire, for igniting the pyrotechnic material; and two metal pieces, connected by the bridgewire and separated by a region of insulating glass. Recently, cracks have been observed in the insulating glass that potentially can allow moisture to penetrate the initiator and degrade the pyrotechnic and bridgewire. Degradation of the pyrotechnic or the bridgewire can result in the initiator not functioning. It is suspected that thermal stresses during manufacture are the cause of the cracks.

The goal of this work was to determine the cause of the cracks with respect to the manufacturing process, and to compare the results of this model to cracks observed in actual initiators returned from field service. Closed form solutions were used to determine basic stress magnitudes. A three-dimensional, finite element analysis was used to determine more exact stresses including the effects of transient cooling. The finite element analysis showed that if the manufacturing process involves pouring molten glass into the initiator, the likelihood of cracking is high. Further, if the surface of the initiator cools faster than the center, cracking could result. A push-out test was performed on one type of initiator, to determine the strength of the glass.

APPROACH AND METHODOLOGY

DESCRIPTION OF PROBLEM

The reliability of automotive inflatable restraint systems depends to a large extent on small electro-explosive devices called bridgewire initiators. These devices use an electrical current to heat a fine wire, resulting in the ignition of a small quantity of energetic material. The energy released from this reaction then ignitesother gas-generating materials, heat stored gases, or actuate flow control mechanisms. Due to their critical role in airbag applications, bridge-wire initiators are intended to be hermetic and impervious to the surrounding environment. The integrity of the bridgewire itself and the surrounding pyrotechnic are of particular concern since moisture in the bridgewire region is known to lead its corrosion and may also result in degradation of certain pyrotechnic materials [2, 3, 4]. However, recent work at the University of Idaho has identified the presence of radial cracks in the glass portion of some initiators [5, 6].

Design and assembly of bridge-wire initiators is quite complex, and significant variations in component geometry, materials of construction, and assembly processes exist, depending on the manufacturer and specific application. The salient components of initiator construction for the purposes herein are represented in Fig. 1. The ends of the bridgewire are welded to two metal pieces, an electrical pin in the center and a surrounding ring or header, which are separated by a region of insulating glass. A photograph of a crack in an initiator is shown in Fig. 2. Because of the cracks, moisture could potentially diffuse through the radial cracks and penetrate the bridge-wire region.

It is suspected that cracking is caused by thermal differences experienced during the manufacturing process. The goal of this work was to develop models that could lead to determining the cause of the cracks.

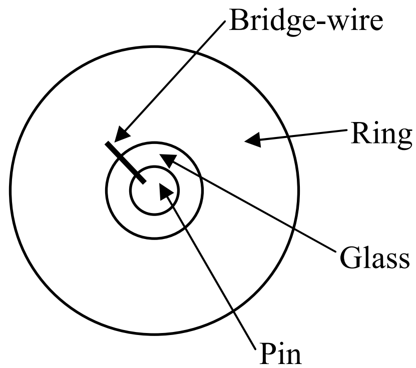

Figure 1: Simplified schematic of initiator

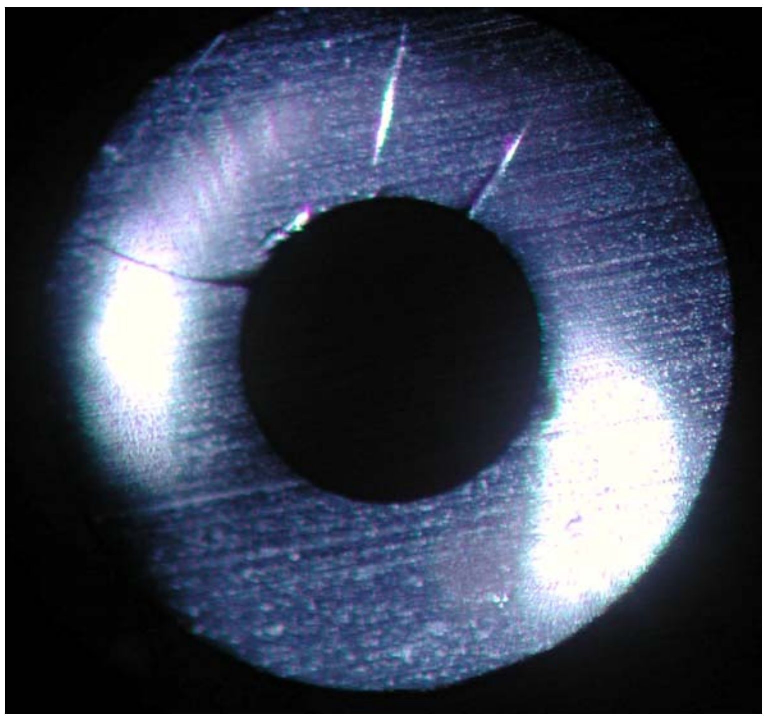

Figure 2: Initiator showing three cracks in the ring

Overview

The initiator selected for testing was an actual initiator from a passenger vehicle. The exact initiator model will not be provided for proprietary reasons. The materials and nominal dimensions of this initiator are shown in Table 1. The outer ring of the initiator was made of type 304L stainless steel; the glass-to-metal seal was composed of type 8061 glass, and the center pin of the initiator was composed of Alloy 52, which has a composition of 50.5 percent Ni-Fe. The material properties of these materials are shown in Table 2. This initiator was selected due to the simplicity of its design--the three elements are concentric--and its availability in quantities sufficient for testing.

Table 1: Materials and geometry of initiator

	Pin	Glass	Ring
Inner Diameter [mm]	-	1.00	2.00
Outer Diameter [mm]	1.00	2.00	6.17

Table 2: Material properties

	Alloy 52	8061 Glass	304L Stainless Steel
E [GPa]	165.5	70.0	196.5
ν	.29	.22	.29
α [μm/m/K]	10.0	9.30	18.0
ρ [kg/m^3]	8304	2600	8000
k [W/m/K]	14.0	1.00	18.0
c_p [J/kg/K]	502	737	500

Details of the exact manufacturing process used for these initiators were not available, but there are two common methods of producing initiators. In first method, the three components are assembled at room temperature, the initiator is heated in a furnace until the glass melts to produce a seal, and then the initiator is cooled to room temperature. In the second method, molten glass is poured between the center pin and the outer ring of the initiator. Both of these manufacturing processes were modeled.

Finite Element Analysis

A finite element analysis was used to investigate the three-dimensional and transient effects of the manufacturing process. Initially a model was built for comparison with the closed form mechanics of materials solution [7]. This model had similar geometry and conditions to the model used by Nattermann, et al. [8]--it applied temperatures to the nodes and specified the stress-free reference temperature of each material. A static stress analysis was then performed. Meshes of the airbag initiator were analyzed using ALGOR-FEMPRO. Initial temperatures were specified for the components for the two cases: when all parts begin at the glass transition temperature of the 8061 glass (467ºC), and when just the 8061 glass begins at 467ºC. A convection coefficient of 100 W/m/K was applied to the external surfaces of the initiator, simulating the flow of air over the part. A transient heat transfer analysis was performed, producing the temperatures at each node as the initiator cooled. The results of the transient heat transfer were then used to perform a transient stress analysis, which resulted in the state of stress for each node as the initiator cooled. The finite element analysis results were then compared to the glass strength.

Push-Out Tests

To obtain glass strength data, a series of push-out tests were conducted. The equipment available for this test was a Satec model T5000 Electromechanical Load Frame, with a 5000 lb. load cell. A fixture was manufactured that held an initiator, preventing side-to-side motion and supporting the ring of the initiator in the load frame, and a stylus was produced that mounted in the load cell. The stylus was designed so that it pressed on the pin and glass of the initiator during the test. The loading configuration is shown in Fig. 3.

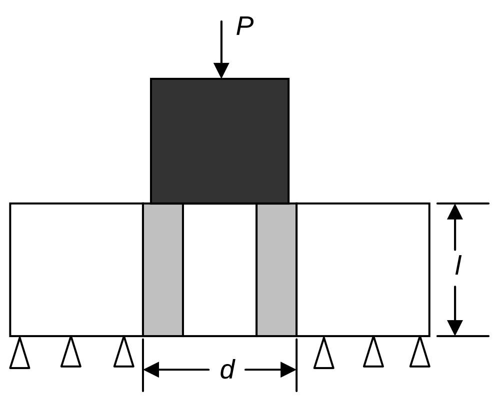

Figure 3: Loading of initiator in push-out test

When the test was performed, it was assumed that, due to the support on the ring, the entire surface of the glass was placed in a state of pure shear. Using Mohr's circle [9, 10], the maximum normal stress for this loading was determined to equal the shear stress. Assuming a uniform shear distribution on the glass, the normal stress is then given by Eq. 1.

$$\sigma = \frac{P}{\pi d l}. \tag{1}$$

The resulting strength data was analyzed using a Weibull analysis [11] to produce statistical data of the strength of the glass. The basis of the Weibull analysis is Eq. 2, which relates the probability of failure p_f to the characteristic strength, σ_θ, stress due to loading σ and the Weibull modulus *m*. This strength data was then used with the analytical and finite element models to determine the likelihood of failure of the various scenarios analyzed.

$$P_f = 1 - \exp\left(-\left(\frac{\sigma}{\sigma_\theta}\right)^m\right). \tag{2}$$

FINDINGS; CONCLUSIONS; RECOMMENDATIONS

Finite Element Analysis

The finite element analysis showed that if the entire initiator is uniformly cooled, only compressive stresses occur in the glass and therefore no cracks will occur. This agrees with the results of Nattermann, et al. [8] for the areas of geometric similarity. However, if molten glass is poured into the rest of the airbag initiator and the steel is at room temperature, high tensile tangential stresses occur (Fig.4).

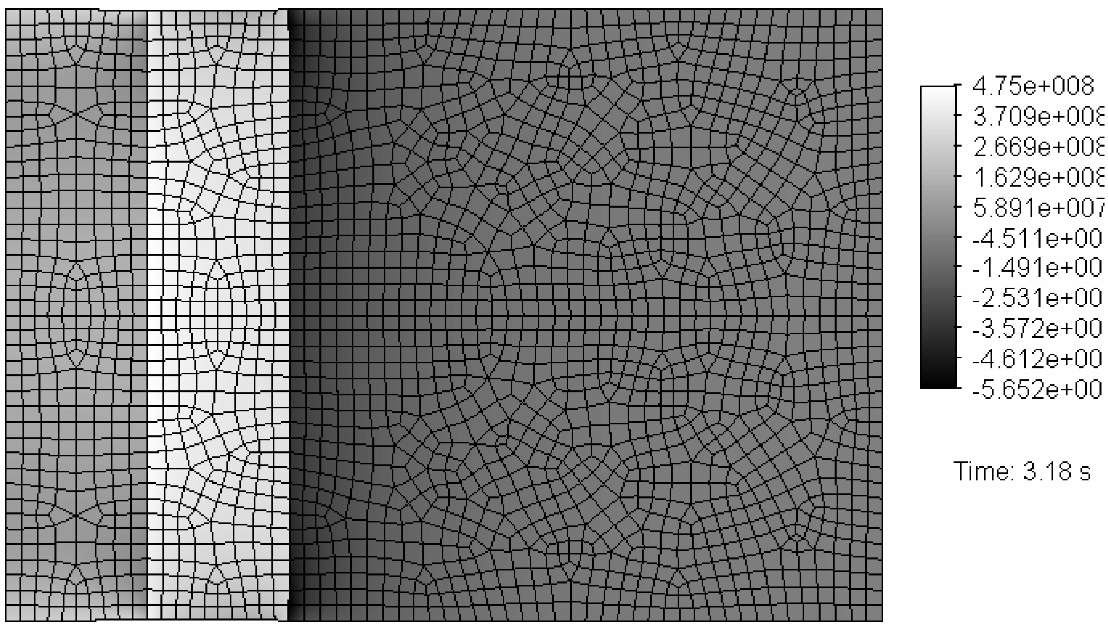

Figure 4: Tangential stress results of finite element analysis of pouring molten glass into initiator

Finite element analysis agreed with the mechanics of materials when examining uniform cooling of the initiator, and provided additional details of the stress; however, in actual manufacturing transient cooling will occur. When transient cooling was analyzed with finite element analysis, it was found that tensile stresses developed on the exterior surfaces when the whole initiator cooled from a high temperature and when glass at a high temperature was poured into the initiator.

When the entire initiator cooled from 467ºC with convective heat transfer applied, .two seconds into the cooling a tangential tensile stress of 5.88 MPa was observed at the center of the surface of the glass. Since cracks in surface of glass are most important with regards to the strength, according to Brückner [12], this result is significant.

The tangential stress results of the analysis of transient cooling of the initiator after molten glass is poured into the initiator is shown in Fig. 4. This figure shows the maximum tensile tangential stress that developed in the initiator, which is 475 MPa. Using Eq. (2) with the results of the push-out test, the probability of failure for this scenario is 25.5 percent.

Push-Out Test

The push-out test was performed on fifteen specimens. Using the Weibull analysis, the characteristic strength of the glass was determined to be 554.5 MPa with an unbiased Weibull modulus of 7.94 (Fig. 5)

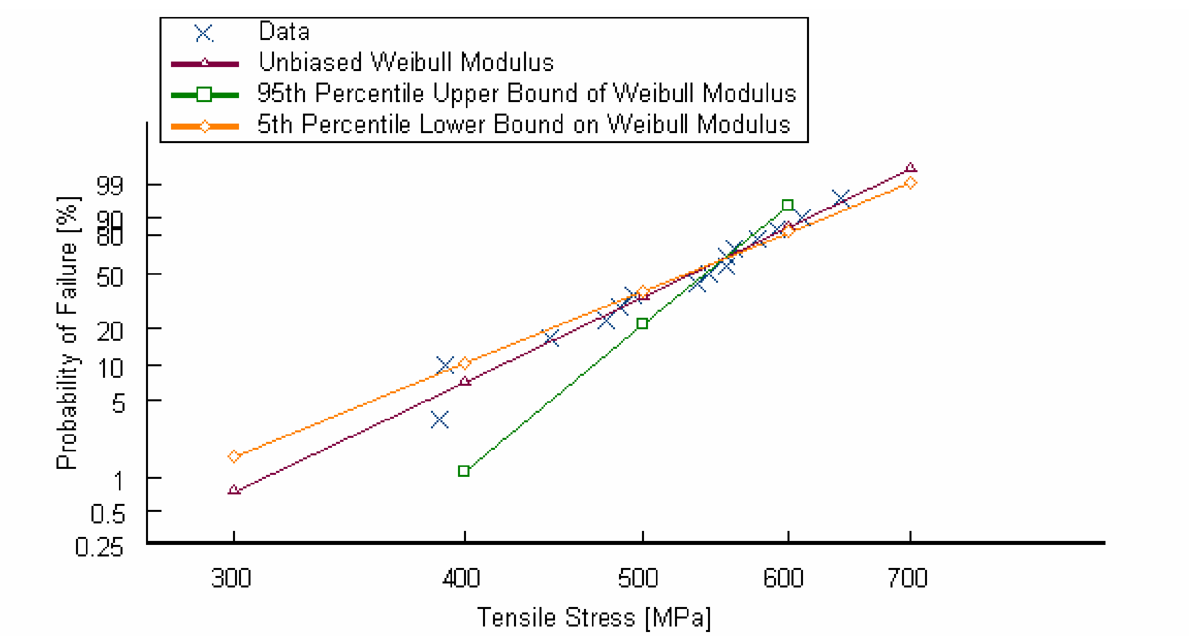

Figure 5: Results of push-out test

Conclusions

This research showed that during manufacture, it is possible for tensile stresses to occur in the glass of an initiator. The results of the models developed agree with photographic evidence of cracks in initiators. It is advised that manufacturers of airbag initiators use processes that will cool the surface and center of an airbag initiator as uniformly as possible and avoid large temperature differences between the materials of the initiator during manufacture.

REFERENCES

[1] National Center for Statistics & Analysis, *Traffic Safety Facts 2003: Occupant Protection,* DOT HS 809 765, 2004.

[2] Miyake, A., N. Nishiyama, Y. Oka, and T. Ogawa, "Moisture Effect on the Rate of Corrosion of Bridge Wire and its Lifetime Prediction," Twenty-Eighth International Pyrotechnics Seminar, Adelaide, South Australia, 2001, pp. 545-551.

[3] Tibbitts, E., and R.F. Salerno, "Nickel-Iron Alloy Corrosion in a Sealed Pyrotechnic System," Seventh International Pyrotechnics Seminar, 1980, pp. 629-649.

[4] Ballard, C. P., R. J. Eagan, and E. A. Kjeldgaard, "Glass Ceramics for Explosive Device Headers." Seventh International Pyrotechnics Seminar, 1980.

[5] Klein, M. K. and K. K. Rink, *Pyrotechnic Initiator Research at the University of Idaho,* Poster presented at 19th International Colloquium on the Dynamics of Explosions and Reactive Systems, Hakone, Japan, 2003.

[6] Rink, K. K., *Failure Mode Investigations Related to Non-Hermetic Behavior in Bridge-Wire Initiators*, proceedings of the 5th Cartridge-Propellant Actuated Device (CAD/PAD) Technical Exchange Workshop, Naval Surface Warfare Center, Indian Head, Maryland, 2004.

[7] Thompson, L. M., *Thermal Stresses in Airbag Initiators,* MS Thesis, University of Idaho, 2005.

[8] Nattermann, K., H. Krümmel, and L. Frank, "Strength Optimization of Airbag Initiators" in *Mathematical Simulation in Glass Technology,* Berlin and New York: Springer-Verlag, 2002, pp. 413-438.

[9] Boresi, A. P. and R. J. Schmidt. *Advanced Mechanics of Materials.* New York: John Wiley & Sons, 2003.

[10] Shigley, J. E., and C. R. Mischke. *Mechanical Engineering Design.* New York: McGraw-Hill, 2001.

[11] ASTM C 1239-00, *Standard Practice for Reporting Uniaxial Strength Data and Estimating Weibull Distribution Parameters for Advanced Ceramics,* ASTM International, 2000.

[12] Brückner, R., "Mechanical Properties of Glasses," *Materials Science and Technology,* VCH, New York, 1991.