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| 13. SUPPLEMENTARY NOTES<br>The views, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy or decision, unless so designated by other documentation.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                   |                                |                                                      |                                                           |                                                  |
| 14. ABSTRACT<br>Research focused on establishing processing capabilities with specific material systems in order to control properties and be able to design and perform the model studies. Analytical modeling was initiated to describe the crack tip stress field stresses, with a focus on how higher order terms in the crack tip stress field expansion alters the stress field. On the materials processing side, research continued in the area of microstructural development of transparent magnesium aluminate spinel; progress was made to understand the specific role of LiF in developing                                                                                                                                                                                                                                                                                                                          |                   |                                |                                                      |                                                           |                                                  |
| 15. SUBJECT TERMS<br>interfaces, cracks, transparent materials, processing, T-stresses                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                   |                                |                                                      |                                                           |                                                  |
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The technical description of accomplishments is divided as follows. After a summary on the goal of the project is given, progress on three areas is described. These include 1) the processing of transparent spinel, 2) glass-ceramic/polymer laminates, and 3) glass-ceramic processing and characterization.

### **Summary**

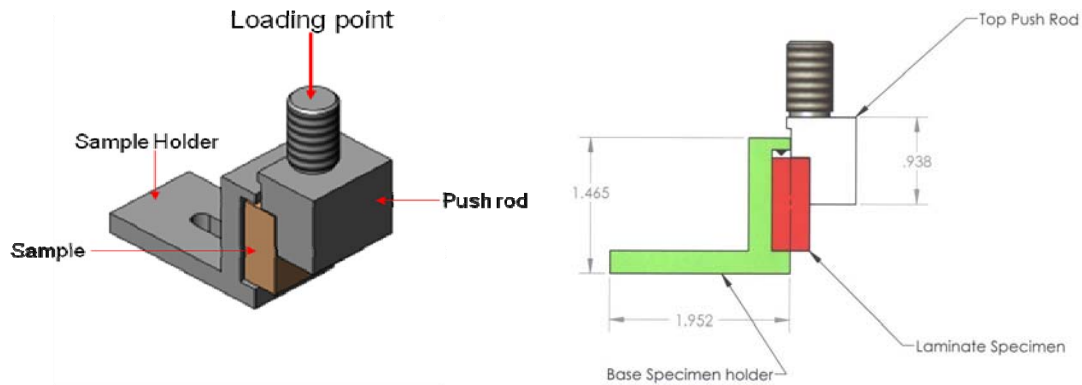
The ultimate goal of the research is to develop a fundamental understanding of crack growth near interfaces in optically transparent materials. Transparent magnesium aluminate spinel and a class of transparent glass ceramics were chosen because of their ability to allow systematic variation of the residual stress at interfaces. Once processing conditions are established, crack extension studies will be conducted to examine the crack path stability for cracks situated near interfaces and/or high residual stress gradients. Analytical modeling on the influence of higher order terms on the crack tip stress field has begun; results will be discussed at a later time.

### **Processing-Property Relations in Transparent Spinel**

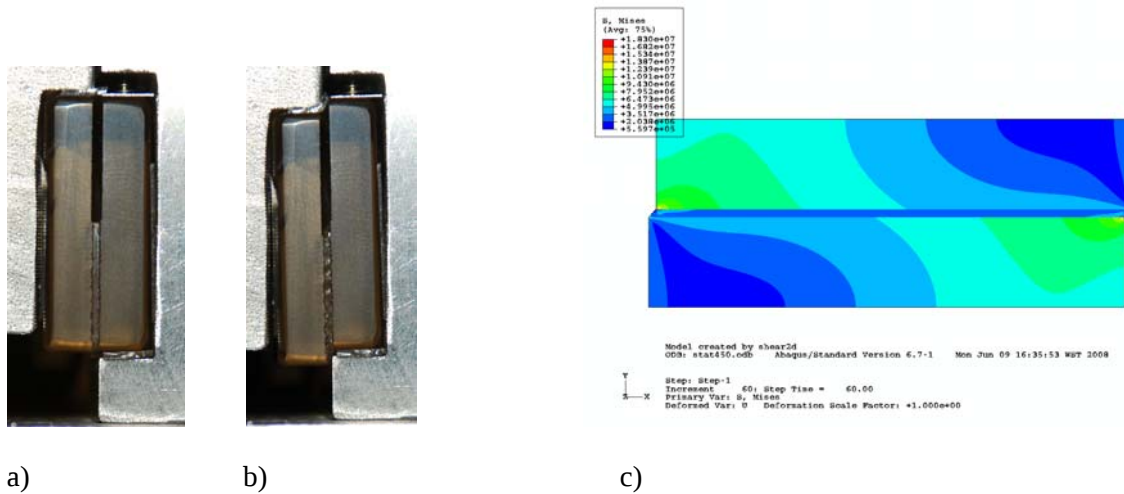
The key to be able to control the properties of transparent magnesium aluminate spinel (strength, transparency) is to understand the role of LiF in processing. The PIs continue to reveal the complex interactions between LiF and  $\text{MgAl}_2\text{O}_4$  which change with temperature, pressure and starting powder purity. The work is summarized in three papers [1-4]. Work continues in collaboration with scientists at Corning Incorporated who have developed their own spinel powder.

### **Glass-Ceramic Laminates**

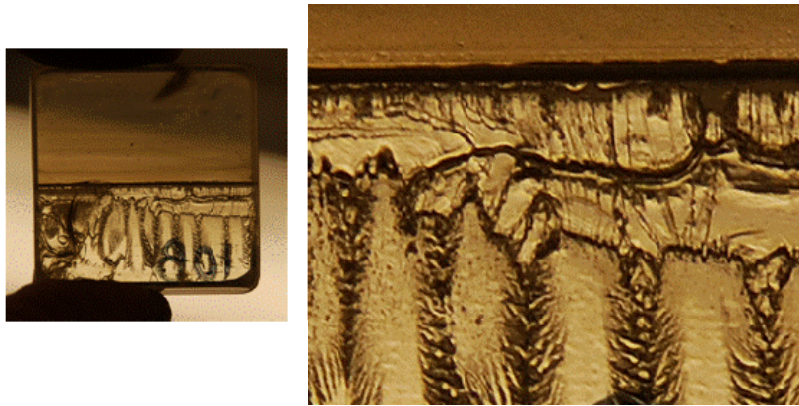
Approximately 100 mechanical tests have been performed on a modified shear-lap testing geometry to measure the strength in shear of glass-ceramic/polyurethane interfaces. To the knowledge of the PIs, this test has not previously been used. Collaborator Prof. Jeremy Leggoe at the University of Western Australia has performed finite element modeling of the test and examined the stress state for different layer thicknesses of polyurethane. Results were presented at the International Structural Integrity and Failure Conference in Perth July 9 – 11, 2008, some of which are shown below in Figure 1. The figure captions provide the relevant details.



**Figure 1** a) Schematic drawing of modified shear-lap fixture. b) Side view of fixture drawn to scale. Alignment is very challenging in this fixture.



**Figure 2** a) and b) show optical images of the specimen during testing. The specimen comprises two glass ceramic plates bonded by a polyurethane layer inbetween. A notch was sawed through the interface (upper section of the specimen) to promote delamination at the interface). Left photograph, a) is under no load, whereas the right photograph, b), is under load (note deformation at the surface of the polyurethane layer between the glass-ceramic plates). c) Finite element model result showing the von-mises stress variation throughout the specimen while under load (orientation of this is inverted and 90 degrees rotated compared with b).



**Figure 3.** Optical micrographs showing the deformation within the polyurethane layer (viewing through the glass-ceramic onto the interface) after shear testing. The size of the specimen shown in the photograph on the left is approximately 25.4 mm square. The featureless area on the top half is a notch that was sawed into the specimen to promote interface failure during the test. The deformation is primarily cohesive failure within the polymer, but also comprises some delamination at the interface. Further results are available in the presentation referenced in the above text.

### **Glass-Ceramic Processing and Characterization**

The Ph.D. student funded by this project, Ms. Jaya Dorsey, spent the summer of 2008 at Corning Incorporated working with their glass-ceramic scientists on the processing and property measurement of a spinel-based glass ceramic. The objectives of the research are 1) to achieve control over the distribution of nano-size crystallites within the glass matrix, 2) to correlate mechanical, optical, and thermal properties with that nano-structure, 3) to conduct fracture studies in which the T-stress is varied and crack behavior studied, and 4) to bond different composition plates together to produce model interface specimens for fracture/T-stress studies. 11 compositions have been fabricated, with about half having a high transparency<sup>1</sup>. The grain size, toughness, elastic modulus, Poisson's ratio, and the coefficient of thermal expansion have been measured for all specimens. The PIs are preparing a manuscript for publication of these results.

### **Future Work**

Efforts are underway to perform fracture mechanics experiments and modeling that examine the role of higher order crack stress field terms on crack path and driving force. An opposite roller loading (ORL) geometry has been designed and specimens will be tested; this ORL geometry enables a systematic variation of the T-stress term during fracture experiments. Glass-ceramics produced above will be examined.

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<sup>1</sup> These materials are of interest for transparent armor. The distribution of nano-sized crystallites not only alters the transparency, but the mechanical behavior, including ballistic performance.

## References

1. K. Rozenburg, I. E. Reimanis, H.-J. Kleebe and R. L. Cook, "Chemical Interaction between LiF and  $\text{MgAl}_2\text{O}_4$  Spinel During Sintering", *Journal of the American Ceramic Society* 90[7], 2038-2042 (2007).
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