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AMBIENT TEMPERATURE TESTING OF METALLIC MATERIALS EXPOSED TO PROPELLANT COMBUSTION ENVIRONMENTS CONTAINING HYDROGEN

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MARCH 1997

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Combustion gases containing hydrogen can cause severe environmental degradation and cracking in the high strength steels used in gun tubes. Although the hydrogen is evolved at the elevated temperatures of combustion, the deleterious effects of hydrogen on steel are most severe near ambient temperature.

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BACKGROUND

Combustion gases containing hydrogen can cause severe environmental degradation and cracking in the high strength steels used in gun tubes. Although the hydrogen is evolved at the elevated temperatures of combustion, the deleterious effects of hydrogen on steel are most severe near ambient temperature. As a general rule, hydrogen-induced cracking failures and stress corrosion cracking failures are easily distinguishable from each other; the former is most severe at ambient temperature, while the latter typically increases in severity with increasing temperature (ref 1). It is, therefore, a conservative and sound engineering approach to test armament materials exposed to hydrogen under ambient temperature conditions.

Hydrogen-induced cracking is a persistent problem. Although much work has been conducted in this area in the past three decades, there are still failures in armament attributed to hydrogen (refs 2-5) . Furthermore, hydrogen-related failures can be expected to increase as propellant environments become more severe and as component strength levels increase.

DISCUSSION

It is well known that hydrogen-induced cracking presents the greatest problem near room temperature. The classic crack growth rate curves produced by Williams and Nelson (ref 6) on 4130 steel in the presence of a gaseous hydrogen environment show that the fastest crack growth rates are produced at room temperature. A schematic of their results is shown in Figure 1. It is easy to fathom that crack growth rates below room temperature will be lower because of the limited diffusion of the hydrogen into the material. However, the reason for lower crack growth rates above room temperature may not be as obvious. As temperature increases, the diffusivity increases exponentially and greatly increases the likelihood of desorption of the hydrogen. This is the theory behind "baking-out" steels. The phenomenon of maximum hydrogen crack growth rates at room temperature occurs not only with 4130 steel but also with various steels, stainless steels, nickel, titanium, and aluminum alloys.

It seems appropriate, using this information, to test the room temperature behavior of hydrogen-induced cracking of gun tube materials in order to determine the effects of propellant environments. Of course, the ideal test would be the actual firing environment from full-scale tests or from a test chamber; however, these tests are technically challenging, extremely labor intensive, and expensive to conduct. How the hydrogen is produced is irrelevant as long as there are no significant chemical reactions taking place that will bias the test and as long as the amount of hydrogen available is representative of the actual propellant environment. For example, an acid environment can be used to produce hydrogen. However, if the pH of the acid changes over the test duration, so does the amount of hydrogen available to cause cracking. As another option, an electrochemical cell can be used to create hydrogen at the cathode (test material) surface. However, the experimentalist must decide if a "poison" should be used to limit the amount of hydrogen gas formed and must determine the rate at which hydrogen is evolved (varying the current density).

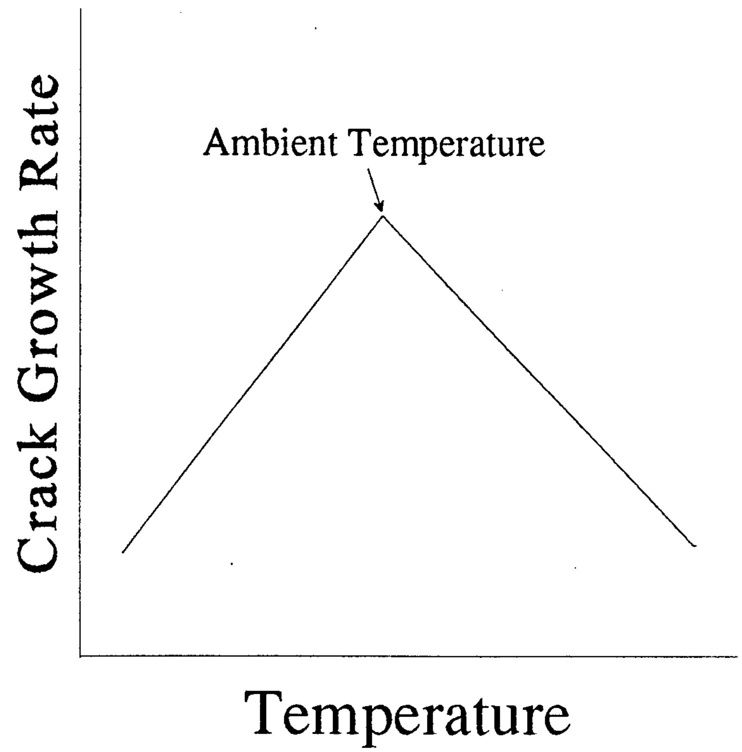

Figure 1. Schematic of hydrogen embrittlement crack growth rate tests conducted by Williams and Nelson.

SUMMARY/CONCLUSIONS

- Maximum hydrogen-induced crack growth rates occur at or near room temperature for a wide range of materials, including gun steels.

- Although the hydrogen may be produced from propellants at high temperatures, it is the hydrogen effects at room temperature that are of greatest concern and that cause cracking.

- Testing armament materials in hydrogen-containing environments at room temperature provides a proper measure of the susceptibility of these materials.

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