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STANDARDS FOR ORDNANCE MATERIALS; DYNAMIC FRACTURE AND ENVIRONMENTAL CRACKING APPLICATIONS

JOHN H. UNDERWOOD

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US ARMY ARMAMENT RESEARCH,
DEVELOPMENT AND ENGINEERING CENTER
CLOSE COMBAT ARMAMENTS CENTER
BENÉT LABORATORIES
WATERVLIET, N.Y. 12189-4050

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John H. Underwood

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Two difficult and very different service conditions for Army ordnance, dynamic fracture and environmentally-assisted cracking, result in surprisingly similar approaches for fracture testing standards.

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INTRODUCTION

It is easy to appreciate that dynamic fracture is important when dealing with ordnance components and materials. To many, ordnance means cannons and projectiles, and that of course means a rapid load applied to both the cannon and the projectile. Because of this the effects of dynamic loading on ordnance materials has been of concern for a long time, literally for centuries. Much more recently, it has been realized that the chemical environments associated with the firing of a cannon create problems of comparable difficulty to those caused by rapid loading. Environmentally-assisted crack growth is a particular problem in cannons, because it is often present in combination with other severe loading and service conditions that are typical of cannon firing.

At first thought, there is no obvious interrelation between these two problem areas in ordnance, dynamic fracture and environmentally-assisted crack growth. However, surprisingly similar approaches are being used in the ASTM fracture test methods developed to characterize these apparently different types of fracture. This leads to the objective here, which is to describe the ordnance applications and some general concepts of the fracture test methods related to dynamic and environmentally-assisted fracture in ordnance. In this description, the similar approach to the two different problems will be addressed, to show how each effort complements the other.

ORDNANCE APPLICATIONS - AND PROBLEMS

The sketch and captions of Figure 1 give a summary of some of the key physical and mechanical processes in cannons and projectiles, particularly those related to difficult problems in fracture testing. During cannon manufacture, chromium is often plated on the bore to provide protection against wear, erosion, and exposure to high temperature during firing of projectiles. The plating process includes significant exposure to aggressive electropolishing and plating solutions, including sulfuric acid, which in turn has led to environmentally-assisted cracking problems. Reference 1 describes such a problem and the fracture testing approach of Wei and Novak (ref 2) used to address it.

The cannon firing process can include dynamic and environmentally-assisted fracture problems for both cannon and projectile, but repeated use of the cannon makes it the likely focus of concern. The rapid increase in pressure that accelerates the projectile also produces a rapid increase in tensile stresses in the cannon wall which can, in the worst circumstances, cause a dynamic fracture. Also, if the conditions are just "right," the hot propellant products can contain acids or even hydrogen, both recognized as among the worst possible contributors to environmentally-assisted cracking in metals. The dynamic fracture concern with cannon firing led to a recent investigation of dynamic fracture behavior in the type of steels used for cannon (ref 3). The concepts and test methods used were those (ref 4) that are the basis of the recently published ASTM *Standard Test Method for Determining the Plane Strain Crack-Arrest Fracture Toughness, K_{Ia}, of Ferritic Steels* (E-1221).

Finally, another class of particularly difficult fracture problems arises from the terminal phase of a cannon firing, the impact of the projectile with the target. The loading of projectile and target is extremely fast, often so fast as to be beyond the scope of the methods of dynamic fracture testing being addressed here.

A FRACTURE TESTING CONCEPT - CRACK ARREST

An important concept of fracture testing, and the basic concept that was used to develop the two, quite different test methods under discussion, is the concept of crack arrest. The sketch in Figure 2 shows the concept as applied to both dynamic and environmentally-assisted fracture testing. In both cases, a wedge-loaded specimen of the so-called compact configuration is used, where an initial crack of length "a" grows deeper into the specimen and then arrests, as indicated by the dashed lines in Figure 2. The arrested crack depth is the critical test information; it gives a measure of the resistance of the material to crack growth under the conditions of the test. A high resistance to crack growth is indicated by a relatively small amount of growth prior to arrest.

This basic crack-arrest concept works equally well for the two, significantly different types of crack growth under discussion, that due to a rapidly running crack under mechanical loads only, and that due to a very slow moving crack under sustained mechanical load with assistance from a chemical environment.

One fundamental and practical requirement of a crack-arrest test is that the crack must stop before it grows completely through the test specimen. It must arrest! Arrest is favored for the wedge-loaded compact specimen, because the driving force for the crack, the stress intensity factor, K, decreases as the crack grows. This is shown in Figure 3 for a given wedge opening, 0.3 mm, and specimen width, W = 50 mm, for two types of test specimen. Although the two specimens have somewhat different loading arm depths, H, relative to specimen width, W, the K for each specimen constantly decreases. This allows the crack to arrest at the critical minimum value of K, which is the fracture toughness of the material for the particular test conditions. The basic arrest condition is that the applied K equal the critical K for the material, $K_{applied} = K_{material}$. For dynamic conditions a crack-arrest fracture toughness, K_{Ia}, is measured for the material following the procedures of ASTM Method E-1221. For environmental conditions, a wedge-loaded standard test for the threshold K value for environmentally-assisted cracking, K_{Ieac}, is now being considered by the new ASTM Committee E-8 on Fatigue and Fracture, the recent combination of the former committees E-9 on Fatigue and E-24 on Fracture Testing.

RESULTS - PROBLEMS DESCRIBED, IF NOT SOLVED

Perhaps the best way to further illustrate the crack-arrest concept as applied to K_{Ia} and K_{Ieac} tests, and to show the similarity of the tests, is with typical results. K_{Ia} results, addressing dynamic fracture, and K_{Ieac} results, addressing environmentally-assisted cracking, were taken from References 3 and 1, respectively, and are shown in Figures 4 and 5. Each set of results was obtained from wedge-loaded specimens with the features already discussed, the principal feature being a decreasing applied K with increasing crack growth. Because of this decreasing applied K, the general trend in each type of test is a high value of applied K to begin crack growth, followed by a much lower applied K after some crack growth and arrest have occurred.

Note first, in the dynamic fracture results of Figure 4, that the initial static K value applied to the specimen varies from about 90 to 150 MPa√m, and that following dynamic crack growth and arrest, the applied K is about 50 to 60 MPa√m shown by the line. This lower and much narrower range of K provides a useful measure of the resistance to dynamic fracture for this steel, the crack-arrest fracture toughness, K_{Ia}.

In Figure 5 a similar high-to-low progression of applied K is observed as the tests proceed, but note that K is plotted versus exposure time, as is usual for environmentally-assisted cracking tests. At the end of the test, after 1540 hours of exposure, the crack in both specimens had grown to a relative crack depth, a/W, of more than 0.9 and had apparently arrested. The values of applied K at arrest for the two samples, 16 and 19 MPa√m, are a measure of the threshold resistance of the material to environmentally-assisted cracking, K_{Ieac}.

SUMMARY

This brief description of ordnance fracture testing applications concentrated on dynamic and environmentally-assisted fracture testing and the key concept of crack arrest that is common to these two types of testing. Some general summary statements and conclusions can be noted, based on the work briefly described and supported by the research publications given as references.

1. Fracture problems of cannons and projectiles that are in need of attention are the potential dynamic fracture of cannon or projectile parts during cannon firing and the environmentally-assisted cracking of cannon components exposed to acid or hydrogen-bearing hot propellant products.

2. The wedge-loaded compact specimen has an inherent decrease in applied K as the crack grows, the basic requirement for the crack growth and arrest fracture tests discussed here - the crack-arrest fracture toughness test of ASTM Method E-1221 that addresses dynamic fracture, and the threshold for environmentally-assisted cracking test being considered by Committee E-8 on Fatigue and Fracture.

3. Wedge-loaded tests of dynamic cracking and arrest in a nickel-chromium-molybdenum steel gave a good measure of crack-arrest fracture toughness, K_{Ia}. Wedge-loaded tests of an A723 steel exposed to acid resulted in arrest after 1500 hours and provided a useful measure of the threshold for environmentally-assisted cracking, K_{Iscc}.

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2. R.P. Wei and S.R. Novak, "Interlaboratory Evaluation of K_{Iscc} and da/dt Determination Procedures for High-Strength Steels," *Journal of Testing and Evaluation*, Vol. 15, No. 1, January 1987, pp. 38-75.

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4. A.R. Rosenfield, P.N. Mincer, C.W. Marschall, and A.J. Markworth, "Recent Advances in Crack-Arrest Technology," *Fracture Mechanics: Fifteenth Symposium, ASTM STP 833*, R.J. Sanford, Ed., American Society for Testing and Materials, Philadelphia, 1984, pp. 149-164.

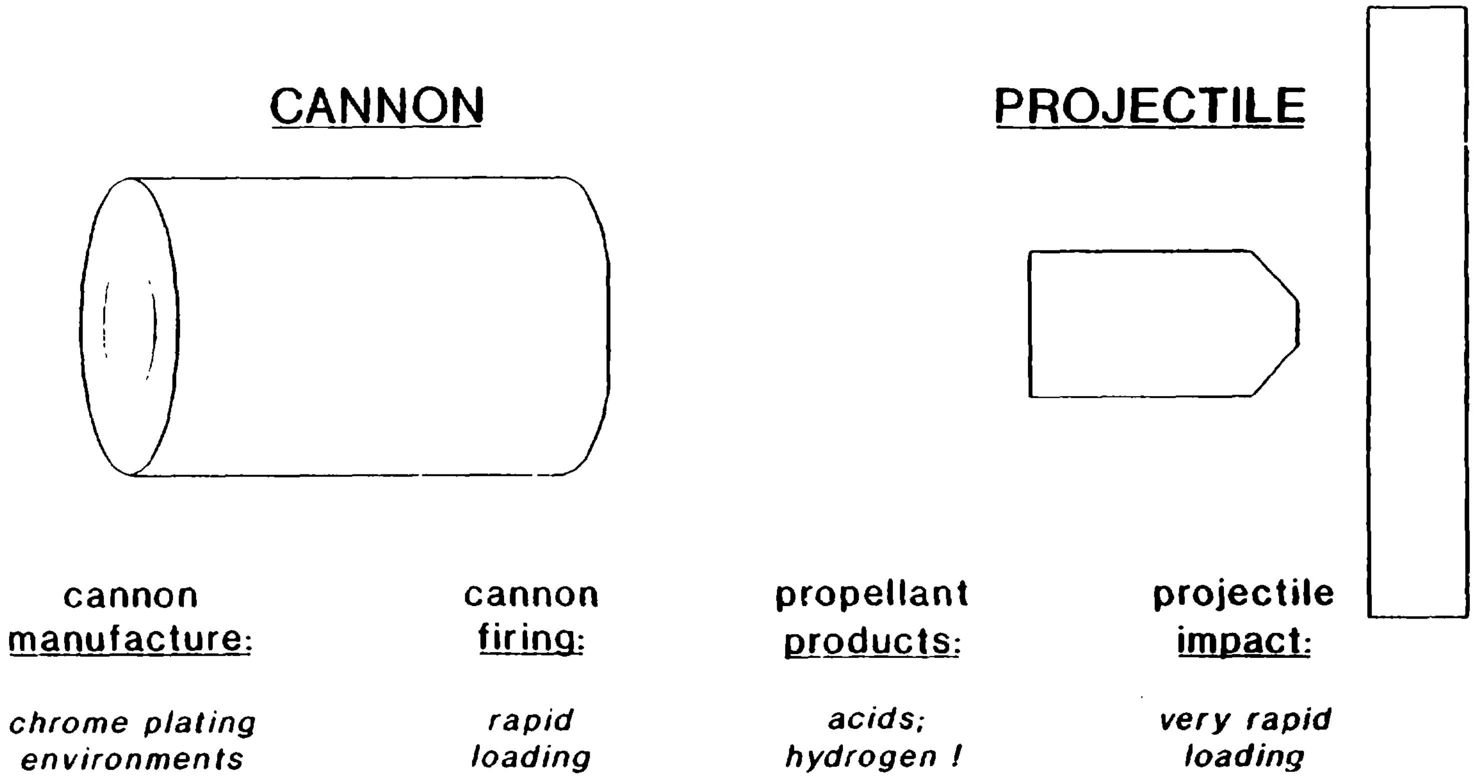

Figure 1. Diagram showing cannon and projectile components undergoing dynamic or environmentally-assisted fracture as a result of manufacturing processes or cannon firing conditions.

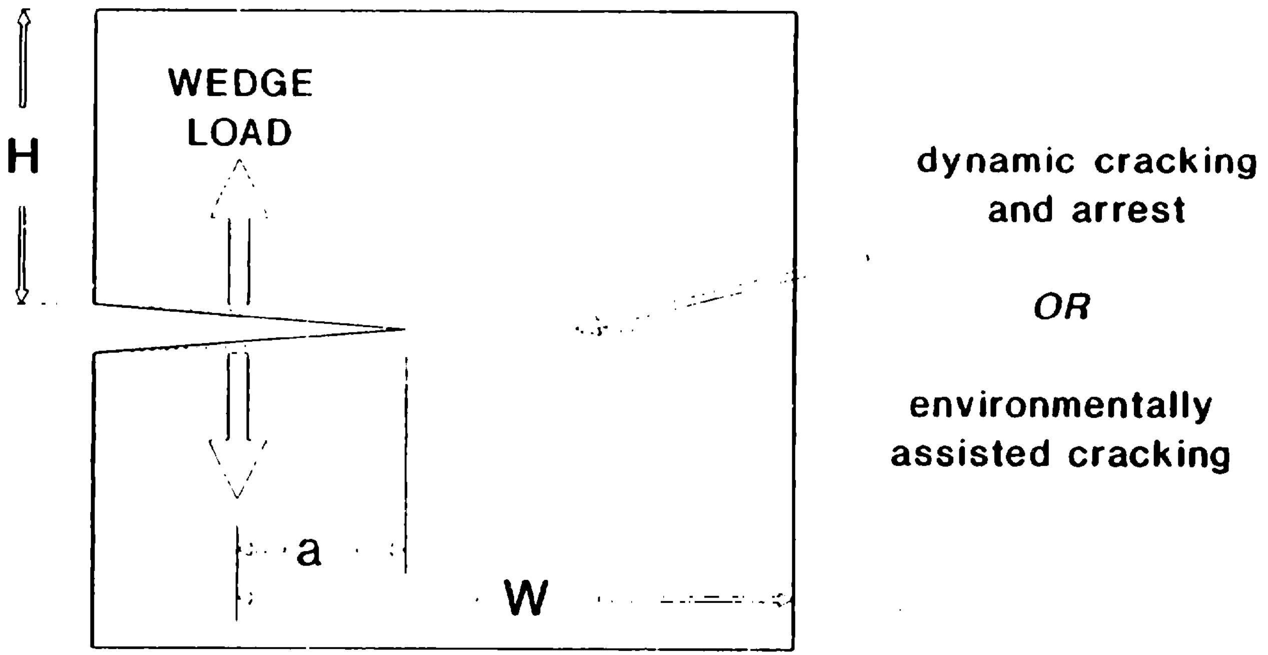

Figure 2. Diagram showing basic concept of crack growth and arrest in a wedge-loaded test specimen as applied to dynamic cracking and environmentally-assisted cracking test methods.

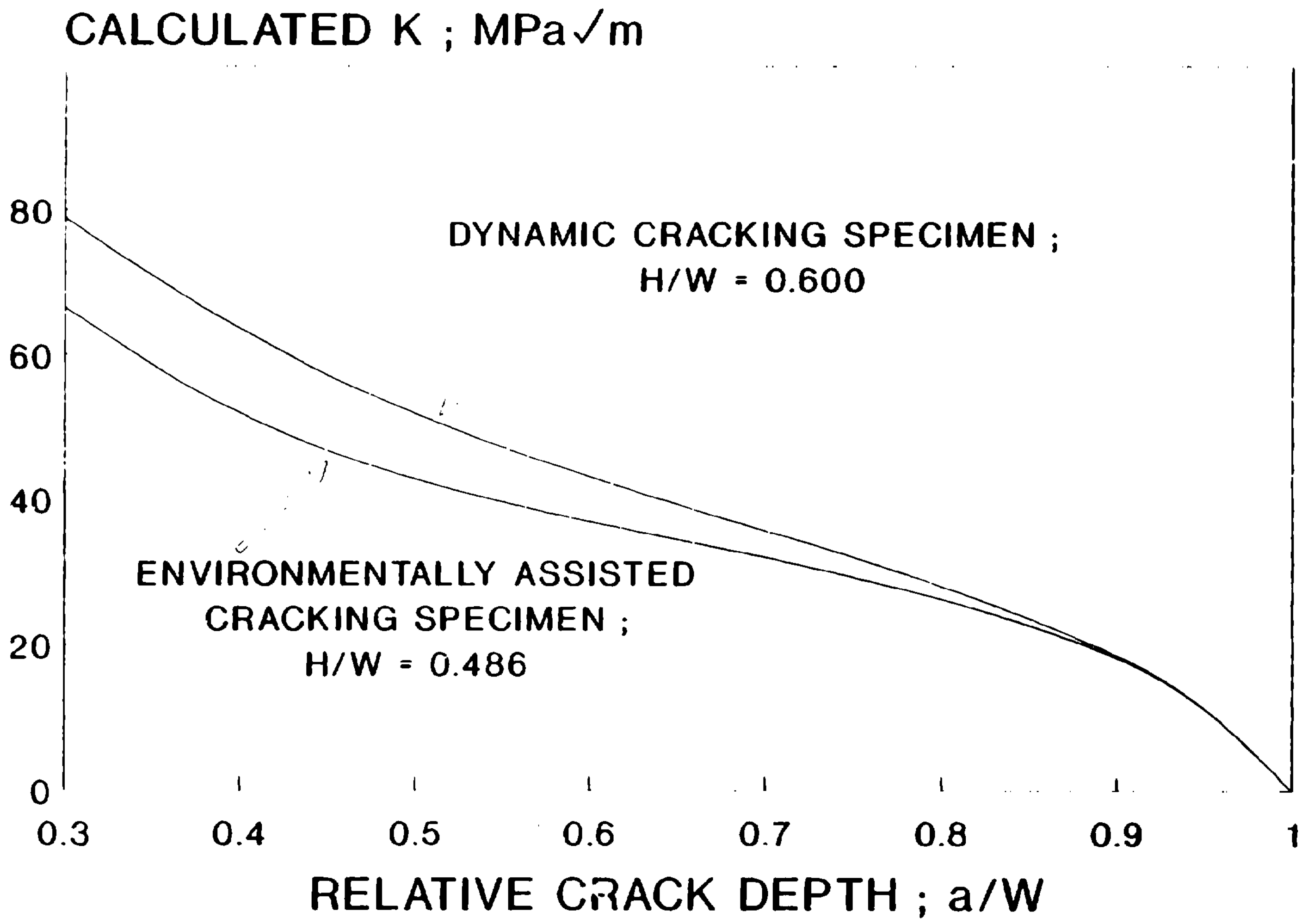

Figure 3. Profile of the decrease in applied stress intensity factor, K, as crack depth increases, allowing crack arrest to occur in the wedge-loaded specimen.

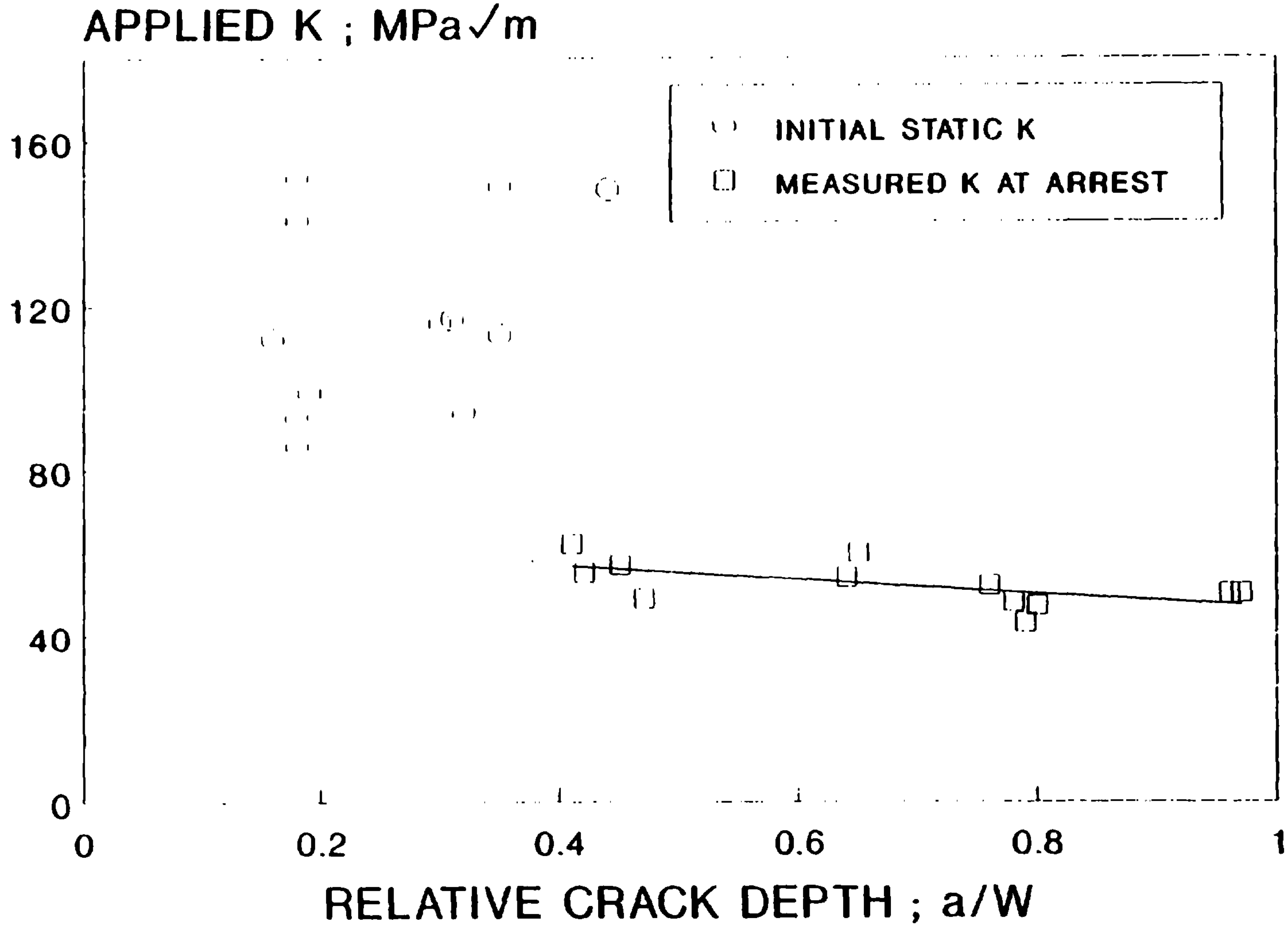

Figure 4. Profile of dynamic cracking and arrest in a nickel-chromium-molybdenum steel giving a crack-arrest fracture toughness, K_{Ia}, of about 55 MPa√m.

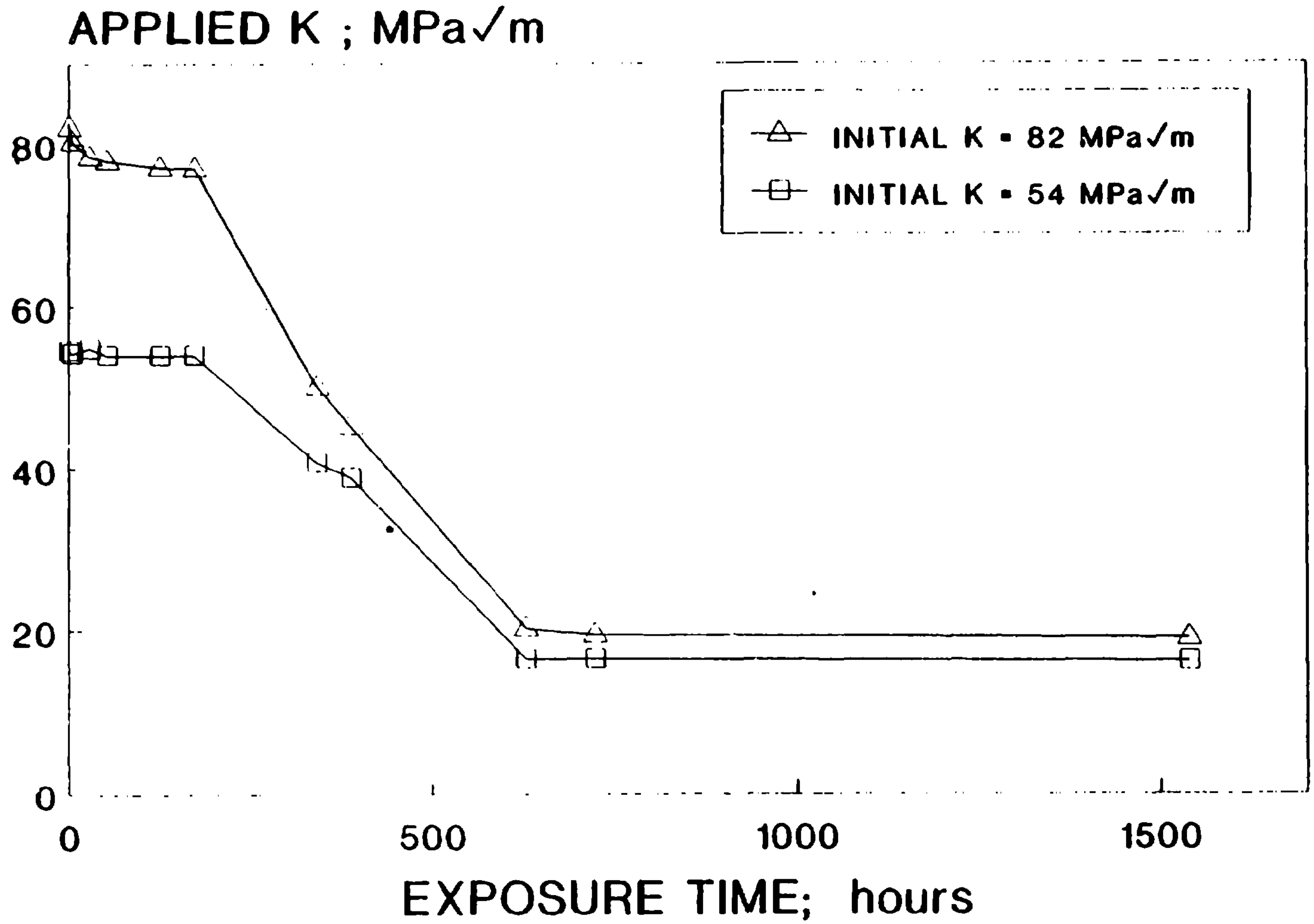

Figure 5. Profile of an A723 steel exposed to a sulfuric and phosphoric acid mixture showing an apparent arrest after 1540 hours and a threshold of environmentally-assisted cracking, K_{IEAC}, of about 16 MPa√m.

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