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impact testing of chains, 1952

E. H. Bareiss

W. J. Eney

F. P. Beer

INVESTIGATION OF METHODS FOR THE IMPACT TESTING OF CHAINS

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By E.H. Bareiss, W.J. Eney and F.P. Beer

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I. INTRODUCTION

The American Chain and Cable Company has asked the Institute of Research to develop a suitable method for the impact testing of chains. This work was placed in the hands of Dr. Erwin H. Bareiss, who has now completed a preliminary study of the problem under the direction of Professor F. P. Beer, and in consultation with Professor W. J. Eney.

Mr. R. J. Coffey, Chief Engineer, American Chain and Cable Company, had suggested the following device for the impact testing of chains. A given load would be dropped from a certain height and catch the lower end of a chain hanging vertically. The load and height of drop should be chosen large enough so that the chain would be certain to fail under the impact. The resistance offered by the chain to the impact could be measured in either of two ways: One suggested procedure called for hanging the chain from a support resting on a ball and plate similar to the ones used in Brinell's hardness test (Fig. 1a). The size of the indentation was supposed to give a measure of the resistance of the chain, the reasoning being that the larger the indentation, the bigger the resistance of the chain. An alternate method was based on measuring the remaining kinetic energy of the load after it has broken the chain, by letting it hit a ball and plate arrangement placed under the chain (Fig. 1b). Here, the smaller the indentation, the bigger the resistance of the chain.

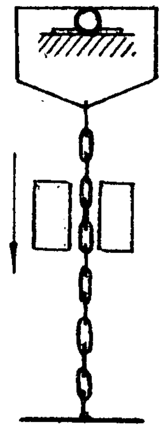

FIG. 1a.

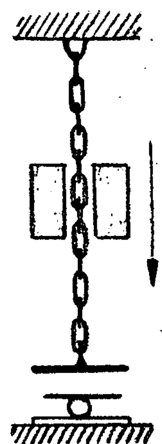

FIG. 1b.

SUGGESTED TESTS.

If the first arrangement is selected, the correlation between size of indentation and strength of chain is very complex. The propagation of elastic and plastic waves along the chain must be considered. Moreover, the time needed to break the chain, which is no criterion for the strength of the chain, will affect the size of indentation: A plastic chain might elongate and exert a pressure on the ball for a larger time than would an elastic chain failing under the same load and height of drop. It therefore does not seem advisable to engage at this time in the very lengthy analysis that the solution of this problem would require.

If the second arrangement is used, with the Brinell ball and plate located beneath the chain (Fig. 1b), or some variation thereof, involving a pendulum machine similar to the one used in the Sharpy test (Fig. 2a), the size of indentation may easily be correlated with the remaining kinetic energy of the load after impact and therefore with the energy spent to break the chain. This method of measuring the resistance of a chain to impact will not essentially differ from other methods based on the measurement of the same energy.* The main problem here is thus to determine whether or not the measurement of the energy needed to break a chain provides an adequate measure of the resistance of the chain to impact loading.

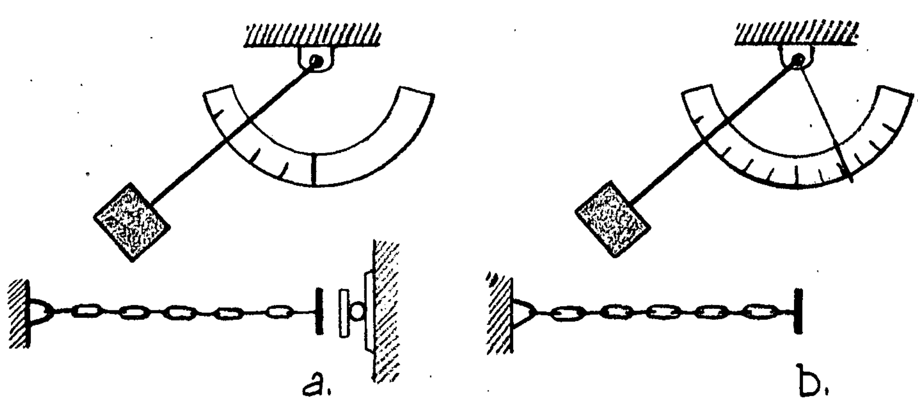

FIG. 2. MEASUREMENT OF FRACTURE ENERGY.

* One such method had been used with little success by the ACC. The energy remaining after impact was determined by measuring the angle through which the pendulum swings after breaking the chain (Fig. 2b).

II. ENERGY SPENT IN BREAKING A CHAIN

In view of the above, Dr. Bareiss found it advisable to begin his investigation by a thorough study of the energy absorbed by a chain under various conditions. His findings, together with a complete bibliography, will appear in the Final Report to be submitted at the close of the contract. We shall only, at this time, outline the more significant points covered.

Let us first consider the influence of impact on the stress-strain properties of a material. Take a chain which is progressively and very slowly loaded in a testing machine. Plotting each load against the corresponding elongation will yield a static force-elongation curve which is characteristic for the given chain. If the same chain had been suddenly loaded as a result of the impact, the curve obtained by plotting the force exerted on the chain at any instant during the impact against the corresponding elongation would have been quite different from the static force-elongation curve. Static and dynamic force-elongation curves corresponding to rods made of various kinds of steel are shown in Fig. 3.

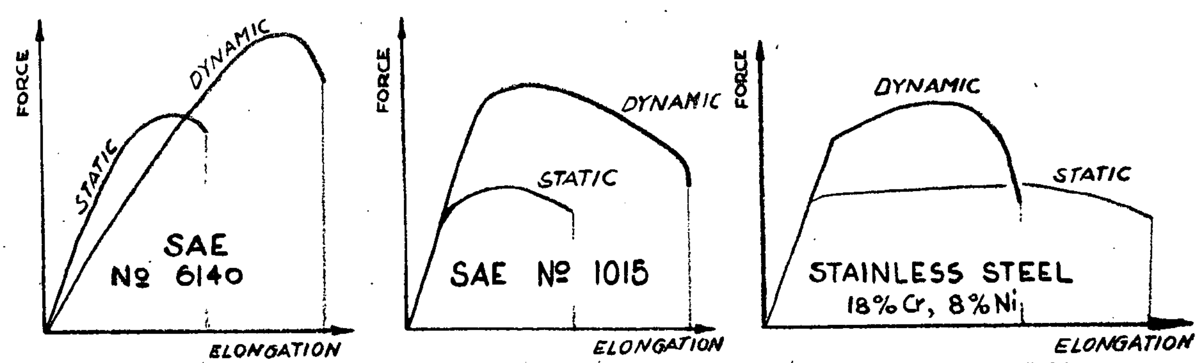

FIG.3. FORCE-ELONGATION DIAGRAMS FOR VARIOUS KINDS OF STEEL
IMPACT VELOCITY = 11.2 FT. PER SEC.

The force corresponding to a given elongation during impact loading is thus seen to be different from the force which would have caused the same elongation under static conditions. Moreover, the shape of the dynamic force-elongation curve depends upon the velocity of impact. Different curves would be obtained for different impact velocities. The static force-elongation curve may be considered itself as a limiting case when the impact velocity approaches zero.

The energy absorbed by the chain when it is broken by impact loading, or "fracture energy", is represented by the area under the dynamic force-elongation curve. In view of what has just been stated, it will thus depend upon the velocity of impact.

This fracture energy also depends upon the temperature of the specimen. The diagram on Fig. 4 shows that for low-carbon steel a variation in temperature may greatly influence the fracture energy in case of dynamic loading.

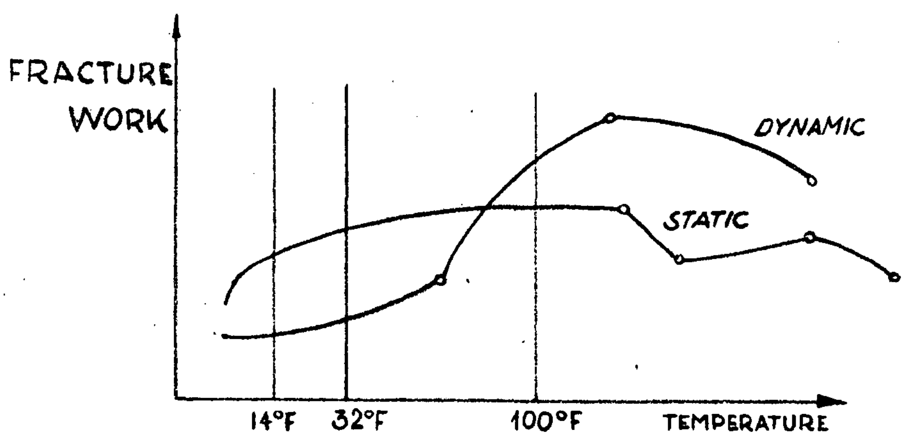

FIG. 4. INFLUENCE OF TEMPERATURE ON IMPACT AND STATIC TEST FOR 0.17 % C-STEEL [AND NOTCHED] SPECIMEN

Impact velocity and temperature are not the only factors on which the fracture energy depends. Other important parameters are: mass of the load being dropped, length of chain, shape and size of its links, composition and structure of the metal, rigidity of the supports.

All this means that if two chains A and B are tested under given conditions of impact velocity, temperature, load mass, length of chain, etc., and if the fracture energy of chain A is found to be larger than that of chain B, the only conclusion we may draw is that chain A is stronger than chain B under the given conditions.

We cannot however, from this test, predict whether chain A will still be stronger than chain B if a different load is dropped or if the impact velocity, temperature, etc. are different. To predict whether chain A will remain stronger under new testing conditions, new tests should be conducted or a better theoretical knowledge of the phenomenons involved should be gained.

III. STRENGTH OF A CHAIN

We have just discussed the "fracture energy" or area under the dynamic force-elongation curve, and we saw how its value may vary with a number of parameters. Before any attempt is made at gaining better knowledge of the fracture energy, however, we should make sure that this energy is an adequate measure of the strength of the chain.

We must at this point state more clearly what we expect from the chain. If we wish the chain to withstand only one blow, the area under the force-elongation curve corresponding to the impact velocity under consideration provides an adequate measure of the strength of the chain (Fig. 5a). This statement must be qualified, however: Indeed, if the impact is caused by a load dropped vertically, a smaller energy of impact may break the chain if the weight of the load is larger than the straight line segment AB bounding the area representing the energy of impact (Fig. 5b). This restriction need not be considered however if the impact is caused by a pendulum.

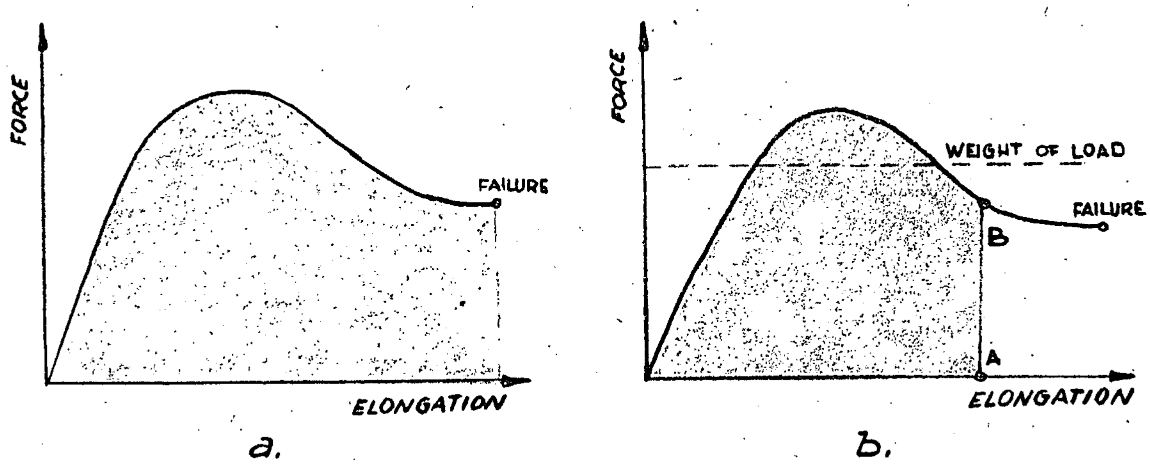

FIG. 5. ENERGY REQUIRED TO BREAK CHAIN IN ONE BLOW.

If the chain is to withstand an arbitrary number of blows, the area under the force-elongation curve does not represent an adequate measure of the strength of the chain. Suppose, for instance, that a first blow is administered, causing a maximum elongation x_m (Fig. 6a). The energy involved in this impact is represented by the shaded area. If x_m is larger than the elongation x_e corresponding to the elastic limit, there will be a permanent set. The chain will retain an elongation x_p. If another blow is dealt, the amount of energy the chain may absorb without breaking is reduced approximately to the area under the curve shown in Fig. 6b. Clearly, if the blows are repeated several times, the chain will break, provided, of course, that each blow brings the chain past its elastic limit.

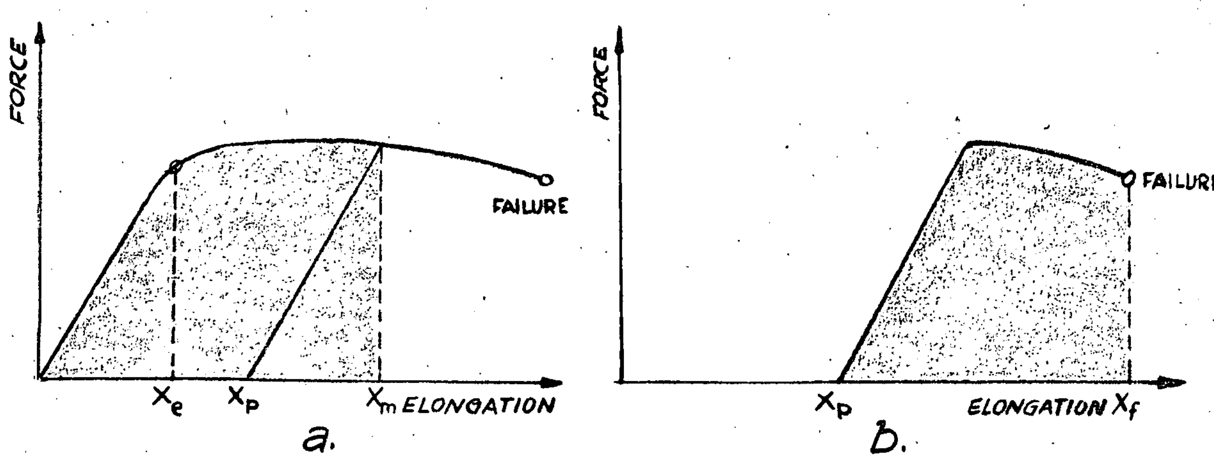

FIG. 6. BREAKING A CHAIN THROUGH REPEATED BLOWS.

If none of the blows brings the chain past the elastic limit, i.e. if the impact energy is never larger than the area bounded by the curve and the vertical of abscissa x_e (shaded area on Fig. 7), the chain will not break. We thus see that this area, which we shall refer to as the "elastic energy", and not the total area under the curve, is a measure of the strength of the chain in case of repeated blows.

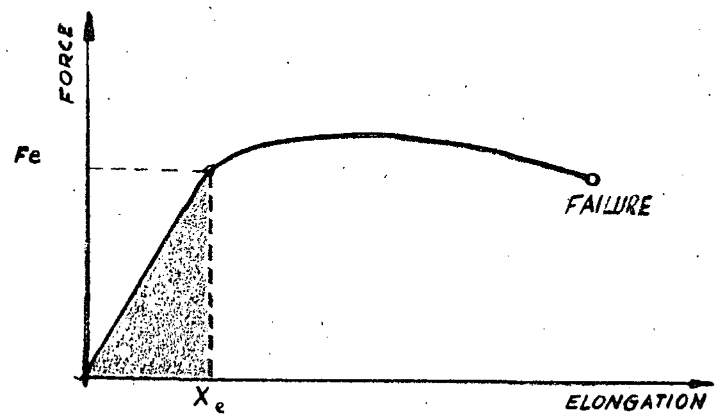

FIG. 7. ELASTIC ENERGY

IV. <u>CONCLUSION AND SUGGESTIONS</u>

We understand that the ACC is primarily interested in producing chains which will maintain their characteristics after a large number of repeated impact loadings. The criterion of chain strength that we should use is therefore the "elastic energy" that we have just defined.

But the impact test described in Section 1 of this report gives a measure of the <u>total</u> area under the force-elongation curve, including the plastic energy. True, there will be little difference between elastic and total energies for essentially non-plastic chains such as the alloy chains developed by the ACC. But for low-carbon chains there would be a large difference between the elastic energy (measure of the resistance of the chain to repeated loadings) and the total area under the force-elongation curve (measure of the resistance to a single loading). Now, one of the chief purposes of an impact testing program is to compare the resistance offered by alloy and by low-carbon chains. The testing method considered originally would place the alloy chains in a very unfavorable light and would fail entirely to show their superiority to low-carbon chains as far as resistance to repeated loadings is concerned. It is therefore our opinion that development of a testing program along the lines originally suggested should not be considered at the present time.

We propose instead that the dynamic force-elongation curves of various types of chains be investigated under variable conditions of temperature, impact velocity, length of specimen, and mass of the load which hits the chain. Once these curves have been obtained, the "elastic energy" could be measured and the resistance of the chain to repeated loadings could be evaluated under the various conditions considered.

Such data would be most valuable in designing or selecting chains for various uses. Indeed, as we saw in Section 2, the dynamic force-elongation curve and therefore the elastic energy depend upon the temperature. A chain which would be optimum for a certain use in warm climate might thus be shown to be unsatisfactory for use in arctic weather. Also the velocity of impact influences the dynamic force-elongation curve and the resistance of the chain to repeated loadings. We might therefore find that different types of chains are best suited for different functions. A chain may, for instance, be subjected to impacts with such low velocity that a static design may be found quite satisfactory, while another chain, which has to resist high velocity impacts, should be of a different type. In short, a thorough analysis of dynamic force-elongation curves would enable the chain manufacturer to decide what type of chain is best for any specific job.

The program of investigation just suggested would involve high speed measurements of strains and stresses. It would therefore be a long-duration program. A more limited program might first be carried out, for the specific purpose of comparing alloy chains with low-carbon chains. High speed measurements of strain and stress would be made for a few chain specimens - alloy and low-carbon - of same length, subjected to impacts of, say, three different velocities. The temperature would be room temperature. From these measurements, a force-elongation curve could be drawn for each specimen and each impact velocity. The elastic energy and the plastic energy would be measured in each case, yielding information on the resistance of each chain respectively to repeated impact loadings and to a single impact loading.

The superiority of alloy chains to low-carbon chains would thus be evidenced, particularly as far as repeated loadings are concerned. These results would by themselves be very convincing. They could, however, be complemented in the following way: Two chain specimens, one alloy, the other low-carbon, would be subjected to repeated impact loadings with a velocity corresponding to one of the impact velocities investigated, and with a load determined in such a way that the impact energy would be smaller than the elastic energy of the alloy chain, but larger than that of the low-carbon chain. Records of the tests would show that the low-carbon chain failed after, say, 4 blows, while the alloy chain had remained intact after 50 blows.

It is hoped that a meeting may soon be arranged with the ACC staff to discuss the proposed modifications to the research program.