Zeitschrift: IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht

Band: 6 (1960)

Artikel: The effect of notches at various temperatures upon the fatigue and other properties of structural steel

Autor: Vasarhelyi, Desi D.

DOI: https://doi.org/10.5169/seals-6943

Ia3

The Effect of Notches at Various Temperatures Upon the Fatigue and Other Properties of Structural Steel

Influence des entailles sur la fatigue et autres caractéristiques de l'acier de construction, sous différentes températures

Die Wirkung von Kerben auf die Ermüdung und auf andere Eigenschaften von Baustahl bei verschiedenen Temperaturen

DESI D. VASARHELYI
Associate Professor of Civil Engineering, University of Washington, Seattle, Wash.

I.

The response of structures to the effect of loads is influenced by the mode of application of the loads and by the physical and geometric properties of the structure itself. The generally recognized modes of application of the loads are the static loading, the impact and the fatigue. The physical properties are such as elasticity, plasticity, ductility, brittleness, etc., which can be described by so-called material constants regarded as independent from the geometry of the piece under consideration. The meaning of geometry does not need much clarification, it refers to the dimensions and their relations to each other and especially includes fillets and notches. Since the unit stresses in the various parts of a structure primarily depend upon the geometry, the presence or absence of so-called stress-raisers, it is easy to see what great significance the latter might have.

Among all modes of the application of the load, fatigue is the one under which the very dominant effect of surface geometry has been first recognized. But it is also known that physical properties such as yield and ultimate strength have noted influence upon the fatigue life.

Do physical properties and geometric ones have the same importance? Is there a certain border line at which one or the other of these factors becomes predominant? If it exists, is such a border line characteristic of fatigue only or similar phenomena can be observed under static or impact loading? These are the questions which are rather difficult to answer because of the numerous variables involved.

An attempt has been made in this study to obtain a set of organized data expressed in terms of very simple parameters, which if not accomplishing more, could indicate the way in which further research should be directed.

II.

The most commonly used structural steel of ASTM A-7 type has been chosen as the material of the specimens. The chemical analysis of this steel was the following:

C	Mn	P	S	Si	Ni	Cr	Cu
0.22	0.47	0.01	0.028	0.05	0.07	tr	0.066 %

Standard coupon test, parallel to rolling of the plate, yielded the following results:

A. Tested at +70° F (Room temperature)

Yield point	Ultimate strength	Elongation in 8 inches	Reduction in area
34.9 ksi	60.2 ksi	32.2%	60.7%

B. Tested at −50° F (Cooled)

Yield point	Ultimate strength	Elongation in 8 inches	Reduction in area
44.1 ksi	71.4 ksi	29.1%	55.8%

All specimens have been cut from the same plate, the plate being used in the as-rolled condition, with the mill scale left intact. All specimens have been cut in a direction parallel to the rolling of the plate, that is, so that the direction of the application of the load had to coincide with this direction.

The cuts have been made $^1/_8$-inch oversize by oxy-acetylene torch and the pieces ground to correct dimensions, thus removing any metal affected by the cutting.

As a means of varying the physical properties of the material, testing temperatures of +70° F and at −50° F have been chosen. This choice is quite arbitrary. It has been realized that it might not be sufficient to include the complete transition from ductile to brittle behavior. The range would however cover the variations in temperature met in most structural work.

In order to vary the geometry, internal notches of $^1/_{64}$-, $^1/_{16}$-, $^3/_{16}$-, and of $^5/_{16}$-inch radius have been used. The $^1/_{64}$-inch radius is the sharp corner radius of a saw cut, all other radii have been obtained by drilling. The ratio of the overall size or the diameter of the notch perpendicular to the direction of the force to the outside dimension (width) of the coupon has been constant for every group.

The shape and size of all specimens is shown on fig. 1, except the impact specimens. For impact standard Charpy specimens have been machined with the difference that the standard notch has been replaced by one which had a radius of $^1/_{64}$-, $^1/_{16}$-, $^3/_{16}$-, or $^5/_{16}$-inch.

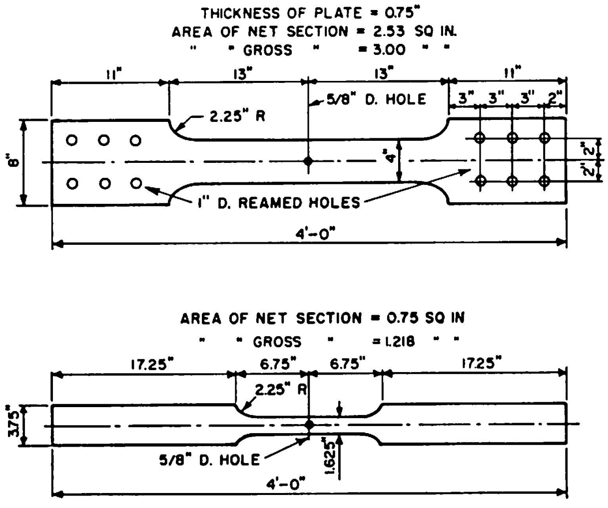

Fig. 1. Dimensions of Fatigue and Static Tensile Specimens.

The fatigue tests have been run in a constant deflection type structural fatigue machine. The number of cycles per minute of this machine is 240. All fatigue tests have been run at a constant 31.4 ksi nominal stress, average taken through the net cross-sectional area of the specimen. The number of cycles to fracture has been taken as a basis of comparison.

The impact tests have been of the Charpy type, using the 220-ft.-lb. striking position of the pendulum. The energy absorbed in ft.-lbs. has been taken as comparative value.

The static tension tests have been made in a slowly operated hydraulic testing machine. As comparative values, the ultimate stress (nominal) computed as the ultimate load divided by the original area, and the reduction in area in per cent have been chosen. Since both fatigue and impact tests are primarily fracture tests, it seemed to be logical to use only those values of the static test which characterize the behavior of the material at the instant of fracture. Since ultimate strength and reduction of area describe the change in strength and in ductility separately, it seemed interesting to try a parameter which would combine the two, thus having a more close resemblance to the characteristic value in the impact and fatigue test. The ultimate true stress, which is computed by dividing the ultimate load by the actual contracted fracture area of the specimen, has been chosen.

The cooling of the $-50°$ F specimens has been accomplished by using cold air circulated over solid carbon dioxide. The temperature has been controlled by a thermostat regulating the air flow and governed by thermocouples attached directly to the specimen.

It should be noted that the size of all specimens is such that any difference in fracture propagation velocity would be impossible to observe. This was intentional since we wanted to limit this specific study to the conditions at the initiation of the fracture.

III.

The test results are presented on the graphs shown on fig. 2, 3 and 4.

The parameter describing a change in the physical properties of the material on these graphs is the testing temperature. Thus we have on every graph a set of points obtained at $+70°$ F and another taken at -50 °F.

The variation of the geometry is represented as the radius of the notch and is shown as abscissa for all graphs.

The specific value characterizing a particular mode of the load application is shown as ordinate.

a) Fatigue Test

The number of cycles endured to fracture are shown for the fatigue tests on fig. 2. This graph very definitely reveals that the fatigue life considerably

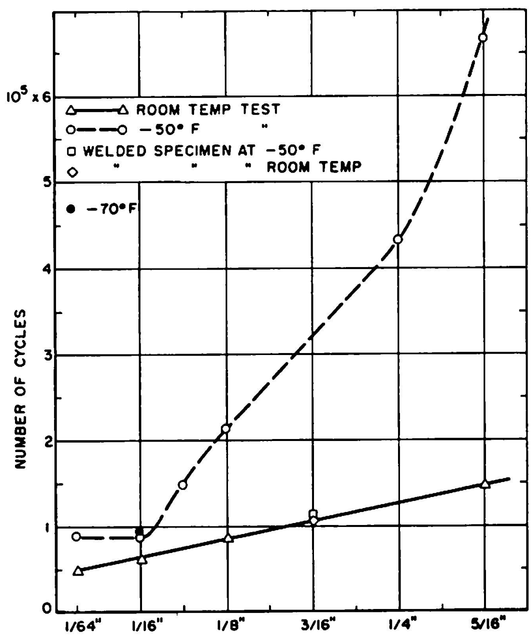

Fig. 2. Fatigue Life of Various Notched Specimens at $+70°$F and at $-50°$F.

increases as a result of the cooling if the radius of the notch is greater than $^1/_{16}$-inch. It seems that for notches with smaller radii, an improvement like the increase of the yield point and of the ultimate strength would have its influence overshadowed by the effect of the stress raiser.

Some tests have been added to the basic set of +70° F and −50° F, variable notch radius set.

One test, with $^1/_{16}$-inch notch radius, run at −70° F is shown, which ran to about the same number of cycles as the −50° F.

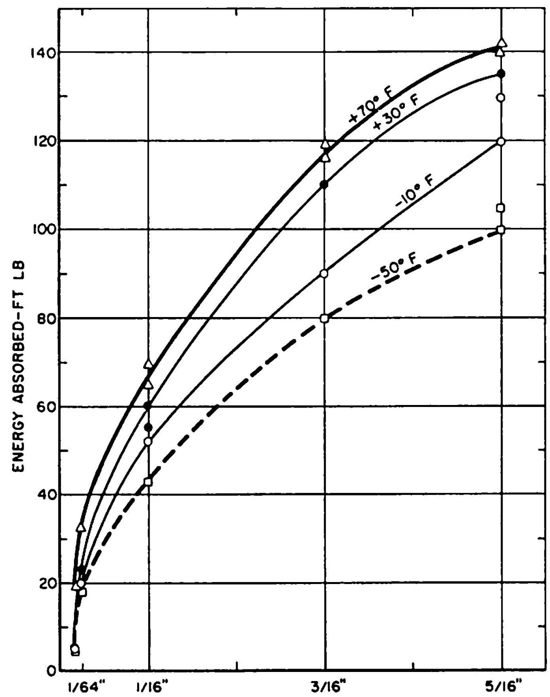

Fig. 3. Impact Energy (Charpy Test) of Various Notched Specimens at +70° F and −50° F.

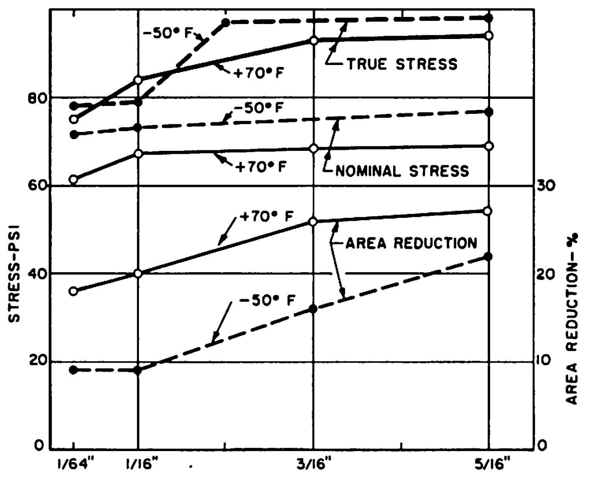

Fig. 4. Static Tensile Properties of Various Notched Specimens at +70°F and −50°F.

Five specimens have been cut and then rewelded so that the notch could be applied in the weld metal. The + 70° F test sustained the same number of cycles that would be expected for the base metal. However a similar specimen tested at − 50° F did not show the expected increase in the number of sustained cycles and broke at about the same number as the one tested at + 70° F.

Photographs of the fractured surfaces (except for Nos. 1 and 4) of the fatigue specimens are shown on fig. 5. Nos. 1, 2, 3, and 4 are the $^5/_{16}$-, $^1/_8$-, $^1/_{16}$- and $^1/_{64}$-inch notch radius specimens tested at + 70° F. Nos. 5 and 6 are the welded specimens, both with $^3/_{16}$-inch notches, No. 5 tested at + 70° F, No. 6 tested at − 50° F. Nos. 7, 8, 9, 10, 11 and 12 are the $^5/_{16}$-, $^1/_4$-, $^1/_8$-, $^3/_{32}$-, $^1/_{16}$- and $^1/_{64}$-inch notch radius specimens tested at − 50° F. Nos. 13 and 14 are $^1/_{16}$- and $^1/_{64}$-inch notch radius specimens tested at + 70° F, Nos. 15 and 16 are $^1/_{16}$- and $^1/_{64}$-inch notch radius specimens tested at − 50° F.

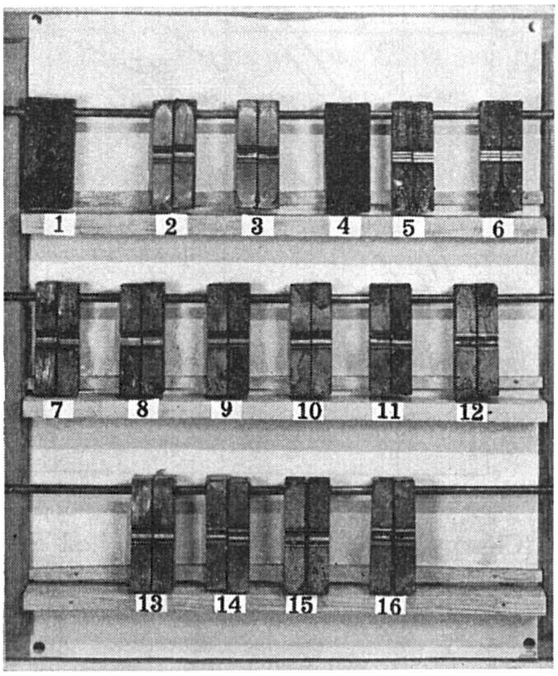

Fig. 5. Photograph of Broken Fatigue Specimens. (See Explanation in Text).

b) *Impact Test*

The energy absorbed in fracturing the Charpy-type specimen with the specified notch radius has been plotted against the notch radius on fig. 3. Additional test points obtained at + 30° F and at − 10° F have been added to the two original curves taken at + 70° F and at − 50° F. This is in order to show the prevailing trend of these curves. It is noticeable that the curves sharply converge below the $^1/_{16}$-inch radius range and that at $^1/_{64}$-inch the spread caused by the variable temperature (thus variable physical characteristics) is sharply reduced by the effect of the small notch radius.

c) Static Tensile Test

The loss of ultimate strength (fig. 4) due to the presence of notch is evident even in the values obtained with $^{5}/_{16}$-inch notch radius. When comparing the shown values with the results of coupon tests it should be remembered that the values on this plot are computed over the net area of the notched specimen. The decline in strength at the sharper notch is not as pronounced as the decline of fatigue and the impact characteristics were. It is remarkable to observe the gradual loss of ductility as presented by the decrease of area reduction, and which again does not show a sharp reduction at any notch radius. However, if we inspect the variation of the true ultimate stress (computed over the contracted net area), the decline of this value in the range of $^{1}/_{16}$-inch and less radius is more pronounced, especially for the $-50°$ F test. The different shape of the $+70°$ F and $-50°$ F curves suggest that at the low temperature the effect of the decrease in the notch radius becomes more effective than at $+70°$ F.

Photographs of the broken static tensile test specimens are shown on fig. 6. (The radius shown, $^{1}/_{32}$-inch, is erroneous and should read $^{1}/_{64}$-inch.) The reduction of the contraction and a lack of noticeable plastic deformation can be seen on these showing $-50°$ F tests at less than $^{5}/_{16}$-inch notch radius.

Comparing the three sets of data on figs. 2, 3 and 4, it is noticeable that both the impact (fig. 3) and the static tensile test (fig. 4) data show a convergence toward a minimum, as a certain small notch radius ($^{1}/_{16}$-inch) is approached and also a tendency of leveling off as a specific magnitude ($^{5}/_{16}$-inch) is reached. The second of these trends can not be observed on the plot of the

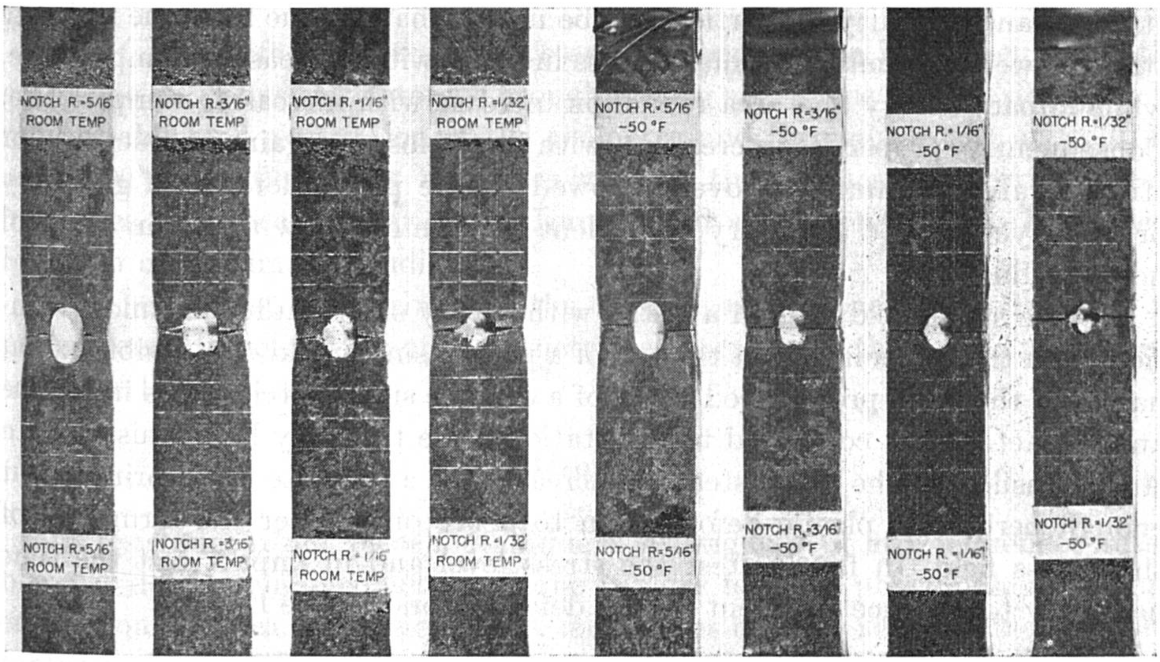

Fig. 6. Photograph of Broken Static Tensile Specimens.

fatigue data on fig. 1. The points for the $-50°$F test rather seem to tend toward a vertical asymptote, which would mean that at a chosen stress level and a sufficiently great notch radius the specimen, if its material properties would be increased, will have an endurance limit and would sustain an indefinitely great number of cycles. The chosen range of stress, temperature and maximum notch radius however is not adequate to ascertain this point. Even with this limitation though, some remarks can be formulated from the present information.

IV.

1. The fatigue test results particularly, and the impact and static tensile test results concurrently indicate that the decrease of the notch radius below a specific value of around $^1/_{16}$-inch — in the specific steel and within the given temperature range — becomes the governing factor of the fracture initiation. With a notch of such radius present, the fracture will be initiated and, in the case of our specimens especially designed to minimize propagation effects — influenced only insignificantly, if at all, by properties describable by the ultimate strength, yield point or area reduction. The true ultimate stress as defined previously might come closer to the idea of a significant parameter for static tests of fracture than do the just mentioned ones.

2. The present data may lead to a somewhat reserved formulation of the notch sensitivity. Thus it can be stated: If a notch of radius smaller than a specific limiting value is present, fracture will occur at a minimum number of cycles (or at a minimum energy absorption in impact test, or at a minimum true ultimate stress in static tensile test) regardless of eventual increase of strength and ductility properties. (To be noted, that fatigue life, true ultimate stress as well as nominal ultimate stress increase with decrease of temperature, while impact energy and area reduction increase with increasing temperature. Consequently properties increasing with both loss or gain in ductility or strength are the same way overshadowed by the preponderance of geometry or a not yet defined geometry dependent parameter below a certain range of notch radius.)

3. The stress field around a notch with a very small radius is almost identical with the stress field[1]) at the top of a progressing crack. A plausible explanation of the more pronounced effect of a definite small notch radius in fatigue and impact test as compared to the static tensile test may lie in this fact. In static tensile test the stress steadily increasing at a low rate could bring about enough peripheral plastic deformation to delay or to alter the formation of this stress field. In fatigue test the stress level and in impact test the time necessary to produce sufficient plastic deformation may be lacking.

---

[1]) See A. Wells and D. Post: The Dynamic Stress Distribution Surrounding a Running Crack. Proc. SESA. Vol. XVI. No, 1, p. 69.

V.

The foregoing tests and discussion do not pretend to open up new perspectives. However it was felt that these facts need a crude kind of demonstration and re-emphasis for a twofold purpose.

The structural engineer should realize that geometry, especially the geometry of potential stress raisers, has a primordial role in determining the strength of the structure, be it in terms of fatigue or other modes of loading. Under certain conditions improvement of the material properties can not counteract the effect of geometric deficiencies.

The role of geometry as revealed in these simple tests indicates the need of the engineer for a more thorough knowledge of the solid state. At the initiation of a fracture we impinge upon the basic structure of the material, governed by strict geometric laws of the crystalline structure. It is therefore evident that our present parameters describing strength and ductility are not sufficient.

VI.

The author is indebted to Mr. SATISH K. GROVER and Mr. MOHAMMED H. KASHANI-SABET, graduate students, for their help in conducting the experimental work and to Prof. F. B. FARQUHARSON, Director, for the sponsorship by the Engineering Experiment Station of the University of Washington.

Summary

The fatigue life of a structural steel member can be influenced by both geometric and physical factors. Through testing specimens with various notch radii establishing a variation of the geometry and through testing at $+70°$ F and $-50°$ F temperatures, and thus varying the physical properties, these influences have been investigated. Impact and static tensile tests have also been run under similar conditions.

All these tests, but primarily the fatigue and impact tests, indicate a preponderant effect of the notch geometry as the radius of the notch approaches a specific low value.

Résumé

La résistance d'une pièce métallique à la fatigue peut être influencée aussi bien par des facteurs géométriques que par des facteurs physiques. Les influences géométriques et physiques ont fait l'objet d'essais sur éprouvettes portant des entailles de différents rayons, ces éprouvettes ayant été soumises à des températures de $+70°$ F et de $-50°$ F ($+21°$ C et $-45{,}5°$ C). Des essais

statiques de traction et des essais de résiliance ont été effectués dans les mêmes conditions.

Tous ces essais et tout particulièrement les essais de fatigue et de résiliance mettent en évidence l'influence prédominante de la forme de l'entaille, lorsque son rayon atteint une valeur spécifique assez faible.

Zusammenfassung

Die Dauerfestigkeit eines Stahlteiles kann sowohl durch geometrische als auch durch physikalische Faktoren beeinflußt werden. Durch die Prüfung von Probestücken mit Kerben von verschiedenen Radien in Versuchen unter Temperaturen von + 70° F und − 50° F wurden die Wirkungen der geometrischen und der physikalischen Einflüsse untersucht. Statische Zugversuche sowie Kerbschlagversuche wurden unter gleichen Bedingungen ausgeführt.

Alle dies Prüfungen, aber insbesondere diejenigen der Ermüdung und der Kerbschlagzähigkeit zeigen einen überwiegenden Einfluß der Kerbform auf, wenn der Radius der Kerbe einen spezifisch kleineren Wert erreicht.

Ia4

Creep of Concrete. The Influence of Variations in the Humidity of the Ambient Atmosphere

Le fluage du béton. Influence des variations de l'humidité de l'air.

Das Kriechen von Beton. Einfluß der Variation der Luftfeuchtigkeit

TORBEN C. HANSEN
Research Engineer, Swedish Cement and Concrete Research Institute
at the Royal Institute of Technology, Stockholm

Introduction

The humidity of the ambient atmosphere is one of the most important factors which influence long-time deformation of cement mortar and concrete under sustained load.

Creep tests have usually been carried out in airconditioned rooms in laboratories where the temperature and humidity of the atmosphere have been kept more or less constant. Thus much information has been obtained about creep of concrete under such constant conditions. It is known that creep of concrete which is not exposed to any drying or wetting during the period of sustained loading (the so-called basic creep) is much smaller than creep of concrete which dries under load. Moreover, the basic creep is greater when concrete is loaded while it is wet, and decreases with decreasing water content (HANSEN, 1958).

Routine measurements of shrinkage and creep on cement mortar beams at the laboratories of the C.B.I. gave rise to the idea that creep is highly influenced by variations in the humidity of the surroundings. Later on it has been reported (R.I.L.E.M. Colloquium, 1958) that it was difficult to estimate creep of concrete structures on building sites on the basis of laboratory tests, this probably due to an unknown effect on creep of the varying climatic conditions of the surroundings. It was suggested that a change in humidity,