HSR:MPC
VIII-0

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON

Letter
Circular
LC486

January 6, 1937

METALS DO NOT "CRYSTALLIZE" UNDER VIBRATION
(Replaces LC204)

The fact that continued vibration of a metal structure may ultimately lead to disastrous results is widely recognized. The unexpected fracturing of an automobile axle, for example, has served to emphasize this to many. The transverse break in such a failed axle has a "clean-cut" appearance and unlike breaks produced by bending, twisting or tension is not accompanied by distortion of the adjacent metal. The process by which such a failure occurs, however, has been frequently misunderstood and erroneous ideas concerning it are prevalent.

A common explanation of this effect is that the metal has slowly changed as a result of vibration from a strong tough fibrous material into a relatively weak brittle one, the change being termed "crystallization". The fact that portions of the fractured surface often have a crystalline surface appearance which is in marked contrast to the fracture of the same metal broken in more familiar ways has fostered this idea of crystallization. The crystals which are most familiar to many of us, such as rock-crystal (quartz) and other mineral crystals, ice and sugar, are relatively hard, weak and brittle. Hence, it has been natural to consider these properties as characteristic of crystals, in general, and to impute these properties to "crystallized" metal. This view, however, is erroneous; the crystals of many metals are very ductile and tough.

The designation of metal as "crystallized", in one sense, is correct. All metals are crystalline in nature from the instant of their solidification from the molten furnace charge. The implication, however, that because of vibration the structure of a metal has changed and that a crystalline condition has been brought into being is entirely erroneous. The crystalline characteristics of any piece of metal have existed as long as that particular sample has. The process by which the metal has been fractured, however, may have served to reveal its crystalline nature in a striking manner.

The fracturing of a metal by repeated stressing, as in vibration, is always progressive in nature. Starting as a submicroscopic separation, the fracture increases in extent, though often at an extremely slow rate, until the part is so seriously affected by the spreading crack that it finally breaks suddenly, perhaps as a result of an unexpected jar or impact. It can be stated with confidence in most cases of this kind that the break has been in progress for a long time, often for months, previous to the final collapse.

What, then, is a suitable name that can be applied to this behavior of metals? Most metallurgists and materials-testing engineers, here and abroad, have adopted the term, "fatigue", for this. This name, however, is not entirely above criticism since nothing analogous to fatigue as it occurs in a living organism, or to recovery from fatigue by resting, occurs in metals. With this limitation to its meaning, however, this term appears more descriptive of what really happens than any other that has been used. It appears to be firmly fixed in the parlance of the metallurgist and the materials-testing engineer.

It should not be inferred from the foregoing discussion that, because a metal may be subjected continually to vibrational or cyclic stresses, it is certain to fail sooner or later as a result. Extensive investigations on the fatigue of metals have definitely shown that there exists for every metal an "endurance limit". In brief, this means that if the maximum stress, to which the metal part is subjected during the vibration or repeated stressing, does not exceed the endurance limit for that material, failure will not occur notwithstanding the fact that it may be stressed many million times. The endurance limit naturally varies with different metals but it has been found by laboratory tests that for many metals it is approximately equal to one-half of the tensile strength but for some metals such as aluminum alloys and some very hard steels, it may be as low as one-quarter of the tensile strength.

Fatigue failures in service are usually associated with surface defects, such as corrosion pits or other notches, or with abrupt changes in cross-section such as sharp angles instead of smooth fillets or with other incorrect features of design. Features such as these serve to raise locally any stress imposed on the piece very considerably above the average or nominal working stress. The metal then may be stressed locally far above its endurance limit and failure is simply a matter of time. Examples have been brought to this Bureau's attention of disastrous effects in a vibratory member resulting from such a seemingly simple cause as an identification number stamped into the surface of the metal. Another condition favoring early failure by fatigue of a metal is the simultaneous occurrence of corrosion and stress.

Samples of metals have been submitted at times to the National Bureau of Standards with the request that the extent to which "crystallization" has progressed be determined. On the basis of present knowledge, such questions are meaningless. What the inquirer really wants to know is whether the material has been damaged by the fluctuating stresses to which it has been subjected. Unfortunately, this question cannot be answered definitely by any testing procedure now known. The best that can be done is to locate fatigue cracks after they have progressed sufficiently to make their detection certain. The use of certain non-destructive testing methods now plays an important part in the service inspection of highly stressed parts such as airplane propellers. Magnetic, electrical and etching methods have been developed for this purpose. The best that can be done by any of them, however, is to show whether or not cracks have developed. If so, there is only one answer, the member must be replaced at once.