HAMMER DESIGN PARAMETERS

Introduction

The IAAF Handbook at Rules 191.4 to 191.9 inclusive gives the physical parameters for the hammer.

Hammer Wire

The most important characteristics for determining the stresses developed in the hammer handle and wire are the weight of the hammer and the length of the hammer.

As the men's hammer is the heaviest that is the one that I will consider here.

When the hammer is swung for a throw the centripetal force applied by the thrower to keep the hammer under control is given by the formula:

$$F = mv^2/r$$

Where F = centripetal force
m = mass of the hammer < 7.285kg
v = tangential velocity of the hammer head
r = radius at the centre of gravity of the hammer head

Obviously some small amount of the total mass of the hammer is in the handle and the hammer wire. For the purposes of this calculation I will ignore this and use the nominal mass of the hammer 7.26kg to give a conservative result.

The radius of the centre of gravity of the hammer achieved during a throw depends on the maximum length of the hammer wire (1215mm) and the minimum radius of the head (55mm) giving a maximum distance of 1160mm from the inside of the grip to the centre of the hammer head. The maximum distance from the centre of gravity of the thrower to the inside of the grip will depend on the anthropometric characteristics of the thrower and the phase of the throw. A very detailed study (1) of throwers at the Seville World Championships 1999 indicated that the maximum radius to the centre of gravity of the hammer achieved was 2.00m at the point of release. At earlier stages of the throws the radii were less but the tangential velocity was also less such that the maximum kinetic energy was achieved at the point of release. The maximum tangential velocity measured in the study was about 30m/s that is somewhat less than the 32m/s velocity used in hammer cage netting design so there is a margin of safety.

Therefore a conservative calculation of the maximum centripetal force in the hammer wire would be:

$$\begin{aligned} F &= mv^2/r \\ &= 7.26 \times 32^2 / 2.00 \\ &= 3.717\text{kN} \end{aligned}$$

The corresponding hammer wire stress in a minimum 3mm diameter wire is 526MPa that is well below the yield stress of hard drawn spring steel that can have ultimate tensile stresses ranging between 1410Mpa and 2080Mpa. There seems to be a reasonable margin to allow for any fatigue or strain hardening of the wire in use. This is borne out by experience.

From above the minimum factor of safety for 3mm diameter hammer wire therefore is from 2.68 up to 3.95. If larger diameter wire is used the factors of safety would be increased.

Engineering design is based on ensuring that stresses in materials do not exceed the yield or ultimate strengths of the material by applying appropriate factors of safety. The factor of safety is increased when there are dynamic effects that may cause fatigue in the material. For a situation where there is gradual repeated loading of a ductile material a factor of safety of up to 6 may be applied to the ultimate strength of the material to determine a maximum allowable working stress.

The elastic extension of the hammer wire under 526MPa stress is about 2.6mm.

If poor quality steel wire is used for making hammer wires then there is a real danger that the wire will be overstressed such that permanent extension of the wire during competition could occur and the wire ultimately fail. There is a need for a minimum ultimate tensile stress to be stipulated for hammer wire to ensure that an adequate factor of safety is maintained. Also as a practical issue, hammer wires might be made from oil tempered spring steel because then the wire comes out straight from the wire reel.

Hammer Handles

The stresses that will be generated in hammer handles are more complex than for the hammer wire as it will depend upon the construction of the hammer handle and how one assumes that the grip is held by the athlete in resisting the hammer's centripetal force.

Henry Cardenis, then Director R & D, Gill Athletics in a proposal he submitted to the IAAF for approval to undertake a study of hammer throwing at the Edmonton 2001 World Athletic Championships wrote:

"During the Men's Hammer final at Sydney it was observed that deformations in the certified hammer grips was occurring. The initial concern raised by officials is the out-of-rule dimension achieved in the overall length of the implement during a throw. It is arguable that this deviation introduced some degree of unfairness. One option currently before the IAAF Technical Committee is to set a prescribed maximum allowable deformation of the grip. Unfortunately such a ruling would expose athletes to hazardous lacerations (or worse) due to fatigue degradation leading to catastrophic failure of the grip. Dangerous stress loads (that lead to initiation of microscopic fatigue cracks) are achieved at only 1/4 the energy level that is necessary to cause significant deformation. Simply increasing grip sizes to reduce these stresses would yield a heavy handle that a given athlete would find unacceptable to throw. With some materials even this approach will not work. For example materials such as aluminium, a stress level low enough to prevent fatigue does not exist. Virtually any stress level is sufficient to start a fatigue crack in aluminium. One option that does not require a significant increase in handle weight is to modify the design such that the mode of failure does not threaten the athlete with laceration. This change could be achieved by adding an additional linkage that would fail first (if at all). This mode of failure would not allow the grip to unfold and slide out of the hand while exposing a sharp edge. In order to render these options as lightweight as possible, it is necessary to characterize the forces that modern grips are currently being exposed to. To achieve this insight it is necessary to obtain a true indication of actual hammer mass velocities."

In a subsequent paper entitled "Analysis of Hammer Handle Safety Summary of Findings", dated 7 March 2002, Cardenis wrote in part:

"It is observed that the simple tension developed in the corner of the handle can easily exceed 160Mpa. A notch effect in this region can magnify these stresses by a factor of 4-5. From these considerations alone it is clear that aluminium is an inappropriate material from which to construct a handle. Also from a fatigue standpoint, the strength of the material should exceed 500Mpa in order to mitigate the nucleation of fatigue cracks in this region.

In the lower section where the wire is connected to the handle, the stresses are complex. Typically, a weld is applied here to augment the strength in this region. Unfortunately, the high strength allows (sic) used here are susceptible to weld weakening issues such as residual stress, grain boundary segregation of alloy species, and crack nucleation. As a result this region is susceptible to failure.

With this type of handle structure, a failure at the lower end may lead to unbending of the handle such as observed in Figure 1. These sorts of failures can be extremely damaging - even career ending. A simple modification to this structure can prevent the unbending of the handle where the lower loop failure occurs."

Just before the Paris Congress there was discussion between Technical Committee members via the Internet on what should be the appropriate minimum handle breaking strength. Eventually a figure of 20kN (2000kgf) was determined. As will be seen from the above calculation this would seem to give a factor of safety of 5.38 compared with the maximum tensile force in the hammer wire. It remains to be seen whether testing of hammer handles will show that this factor of safety is too conservative compared with the minimum factor of safety of 2.68 calculated above for hammer wire or cause problems in the manufacture of hammer handles of reasonable weight. It can be argued that the stresses are more complex in the hammer handle and more dangerous for the thrower if the handle fails in use than if the hammer wire breaks.

For IAAF Product Certification purposes there needs to be a standard hammer handle test that stipulates inter alia the rate at which load is applied to the hammer handle and how the hammer handle is gripped so as to simulate the grip by a thrower.

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Reference:

(1) Gutiérrez, M., Soto, V.M.,Rojas, F.J. (2002). A biomechanical analysis of the individual techniques of the hammer throw finalists in the Seville Athletics World Championship 1999. IAAF New Studies in Athletics 2.2002, 15-26.