

Analysis of hammer handle performance and safety

by Henry Cardenas

The dimensional stability of hammer handles came into question at the 2000 Olympic Games in Sydney when an implement that stretched during the competition became popular among the throwers. While initial attention focused on the violation of the relevant rule, another consideration regarding implement safety also surfaced. In this work, the forces and stresses acting on the hammer handle are explored with the aim of reducing exposure to injury and ensuring the fairness of the competition. Video analysis of the implement velocity was used to calculate an estimated handle force. This force was used to demonstrate vulnerability of current handle specifications in regard to injury as well as deformations that could generate an unfair advantage. These findings were used to develop a proposed handle specification that requires the presence of a crossbar, which reduces the likelihood of injury while minimising stretch.

ABSTRACT

Henry Cardenas was born in Havana, Cuba in 1965. He studied engineering mechanics in the Department of Theoretical and Applied Mechanics at the University of Illinois at Urbana-Champaign, USA, where he received a bachelor's degree in 1989 with an emphasis in biomechanics and materials behavior. From 1989 to 1998 he worked at the US Army Construction Engineering Research Laboratories in the Materials Science and Technologies Division. In 1998 he was appointed Director of Research at Gill Athletics in Urbana, Illinois. His work at Gill focuses on biomechanics, advanced facilities construction technology, and materials performance. In September 2002 he defended his doctoral thesis in advanced materials processing in Civil Engineering. He has over 40 publications. His development of throwing implement technology and research has been used to set two NCAA and two national records.

AUTHOR

Introduction

During the Hammer Throw competition at the 2000 Olympic Games in Sydney, it was observed that one particular hammer had become somewhat popular during the event. It was later observed that this implement had stretched during the

course of the competition. The fact that a longer implement provides for a longer throw is indisputable. What is disturbing however is the micro-structural damage that leads to this deformation. When material stresses are large enough to cause deformation, the associated micro-structural material damage can cause the development of fatigue cracks such as that which lead to the handle failure exhibited in Figure 1.

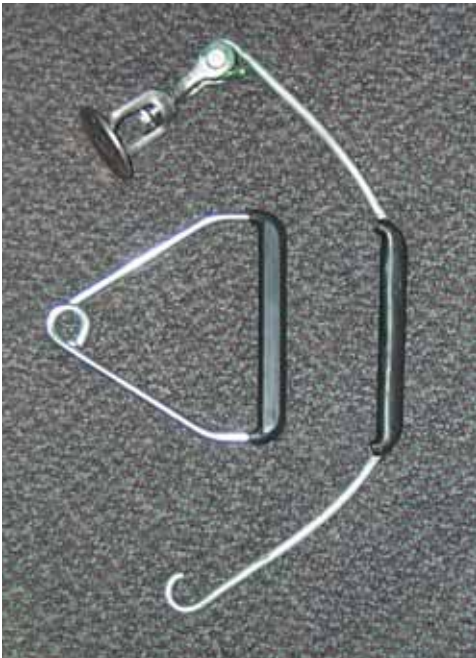


Figure 1. Tensile weld failure of a hammer handle

This study provided an analysis of the force and stress developed in the hammer handle during a throw. The findings were used to develop a proposed handle structure that will provide stretch mitigation as well as a mode of failure that does not allow the handle to straighten.

Approach

In order to assess the forces in the handle it was necessary to obtain an accurate velocity for the ball during a significant throw. Such a measurement was collected during the men's final of the hammer throw at the

2001 IAAF World Championships in Athletics in Edmonton. For this work a JVC GVL 9500 digital video camera was used to record ball displacement shortly after release. Figure 2 contains the image used to generate the displacement data required for the velocity measurement. Still frames were captured using Studio DV video editing software. Dimensional analysis of these images was conducted using AutoCAD 2000i software.

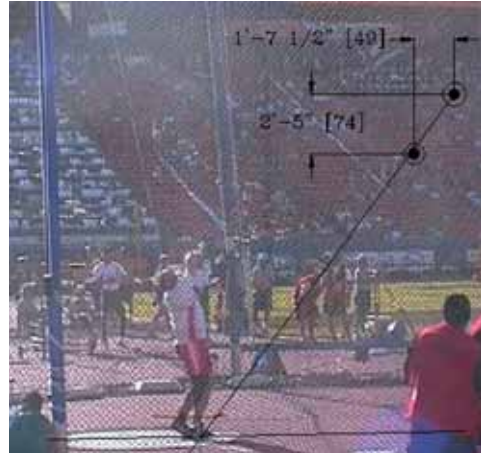


Figure 2. Velocity analysis of an 83.38 metres hammer throw at the 2001 World Championships in Athletics

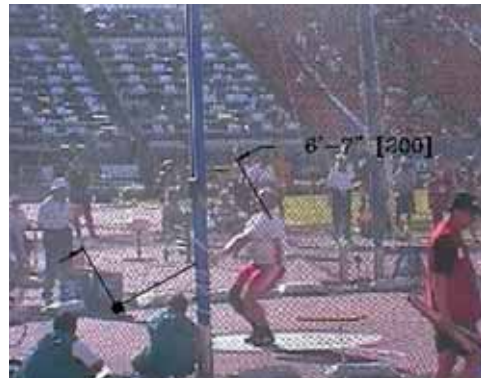


Figure 3. Orbit radius of an 83.38 metres throw: ~200cm.

Displacement data obtained from the figure was corrected for angular observation distortion and used directly to measure velocity. The force transmitted to the handle was calculated by squaring the velocity of the ball and dividing by the radius of rota-

tion. This radius was determined directly from Figure 3. Stress calculations conducted on the handle were developed using simple equations of linear elasticity. Recommendations on handle structure were based on these measurements and calculations.

Results and Discussion

A free body diagram of the principal forces acting on the ball of the hammer during orbit is presented in Figure 4. It was observed that the winning hammer toss of 83.38 metres exhibited a cage exit velocity of 30m/s +/- 2 m/s. When the upper bound of this value is squared and divided by the radius of rotation (2m) and multiplied by the mass of the implement (7.26kg), the resultant handle force is found to be 3700N. This force is equivalent to the weight of a ball with a mass of approximately 380kg. Conceivably, an athlete with a less refined technique may apply additional force while attempting to "power past" a given fault in technique.

Under such loads, a given handle may incur a permanently stretched deformation in the range of 0.5cm – 1cm. This extension can cause the throw velocity to increase and

thus produce an increase in distance. From the principles of kinematics, it can be shown that the distance of a throw is approximated by the following equation:

$$D = \frac{2v^2 \sin(\theta)\cos(\theta)}{g}$$
, where D is the distance thrown, v is the velocity at release, θ is the angle of release and g is the acceleration due to gravity.

For a release velocity of 28m/s and an angle of release of 45°, this expression yields a throwing distance of 80 metres. If this athlete/hammer system were to exhibit a ball turning radius of 1.9 metres then a handle stretch of 0.5cm would cause the release velocity to increase to 28.07m/s. Applying this velocity to the distance equation would yield an enhanced distance of 80.42m. Note that the difference between the first and second place distances at Edmonton was 0.46 metres. From this information, it is clear that a stretched handle could possibly alter the finish order of a given competition.

Application of the estimated force applied to the handle for the winning throw at Edmonton is illustrated in Figure 5. It is observed that the simple tension developed in the corner of the handle can easily exceed

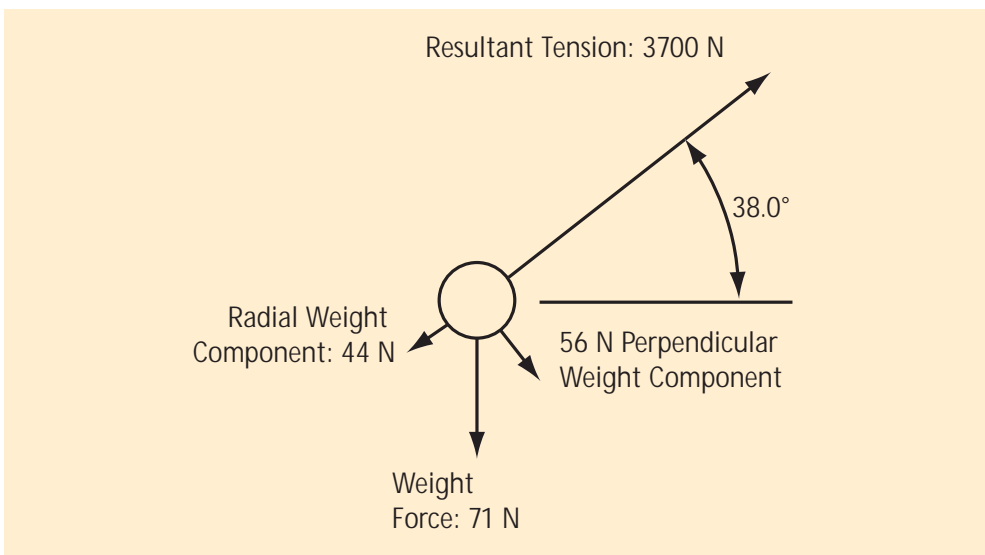


Figure 4. Free body diagram of forces acting on ball of hammer during a throw.

140 MPa. A notch effect in this region can also magnify these stresses by a factor of 4-5. From these considerations alone it is clear that the use of aluminum in this structure must be considered carefully. Also from a fatigue standpoint, the ultimate strength of the material should exceed 500 MPa 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 alloys used here are rather susceptible to weld weakening raising issues such as residual stress, grain boundary segregation of alloy species, and crack nucleation. As a result, this region is susceptible to failure.

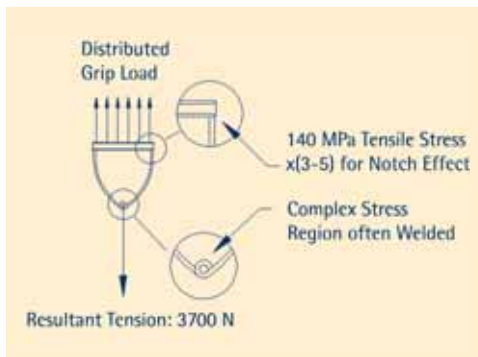


Figure 5. Force analysis on typical handle

With this type of handle structure, a failure at the lower end may lead to the 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 when a lower loop failure occurs.

Figure 6 contains an illustration of a proposed new handle structure. In this case, an additional bar is required between the handle bar and the wire connection. This structure keeps the handle intact after a connection failure has occurred. An added benefit is that this structure also mitigates the lateral deflection of the sides of the handle, which can lead to the deformation observed in Sydney.

Other features of the handle include a width of 130mm, which has come to be very popular in the 16kg throwing weight used for indoor competitions. The distance of 70mm from the grip to the restraining bar has been found to provide good comfort and hand clearance among North American indoor weight throwers.

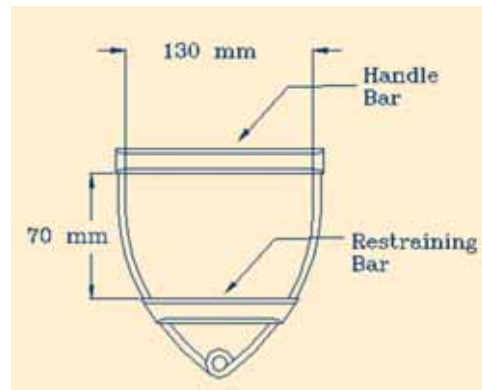


Figure 6. Proposed handle designed to resist deformation and control the mode of failure

Recommendations

It is recommended that the use of aluminum be implemented carefully and not in locations that are susceptible to fatigue damage, since these alloys tend to exhibit inferior fatigue resistance.

It is further recommended that a restraining bar be added to the specification of the handle in order to avoid permanent deformations and to eliminate a mode of failure that can lead to severe injury.

Acknowledgement

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