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The effect of temperature on the capability of industrial safety helmets to absorb impact energy

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ABSTRACT

The fundamental document specifying the requirements and testing methods applicable to industrial safety helmets in European Union member states is the standard EN 397:2012. According to that standard, one of the most important parameters of a helmet is shock absorption, determined for an impact of a striker with a kinetic energy of 49 J. The shock-absorbing performance of a safety helmet involves absorbing the energy of a striking object associated with a deformation of the shell and cradle, as well as an increase in the force transferred to the user's head. The paper presents a study conducted with the aim to estimate the actual amount of energy absorbable by various helmet types without exceeding the threshold value of the force acting on the user's head. A method of testing helmet deformation and the force acting on the helmet during an impact exerted by a falling object is presented. The effect of the temperature used for conditioning various helmet types on their capability to absorb impact energy was determined. The causes of deterioration of that capability due to temperature changes are analyzed for various designs of helmets made of different materials, and possible solutions to that problem are offered.

1. Introduction

According to the data presented by the Central Statistical Office for 2012 [1], in Poland there were 8241 accidents involving injuries resulting from an impact of a falling object. Nearly half of that number happened at industrial worksites, and over 230 were the consequence of not using appropriate protective equipment. The above data provide compelling evidence for the scale of the problem and, consequently, for the necessity to protect workers. Considering the risk associated with the impact of falling objects at worksites, it is evident that the human head is most exposed to that risk. At many industrial worksites, it is possible either to organize work so that employees do not need to be in the zone with the highest risk of contact with falling objects or to use group protection solutions. However, there are also many worksites where the use of industrial safety helmets is the only viable solution.

The fundamental document specifying the requirements and testing methods applicable to industrial safety helmets in European Union member states is the standard EN 397:2012 [2]. It describes a number of requirements concerning the protective properties of such helmets, as well as methods for testing them.

According to that standard, one of the most important parameters of a helmet is shock absorption. This is a parameter defining the manner in which the helmet alleviates the effects of an impact of a moving object. As specified in the method-

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ology of testing that parameter, a helmet placed on a headform is hit centrally by a 5 kg hemispherical striker falling freely from a height of 1 m. During the impact of the striker, the value of the force acting on the basis of the headform underneath the helmet is measured.

According to the requirements of EN 397:2012 [2], the measured maximum value of that force must not exceed 5 kN. The above value was adopted during the development of this standard taking into consideration the open head injury criterion and the neck injury criterion, presented, among others, in the publications by Gilchrist and Mills [3] and Hulme and Mills [4]. As a result, the testing method involves an assessment of whether the safety helmet sufficiently reduces the force transferred to the user's head during the impact of a moving object with an arbitrarily adopted kinetic energy of 49 J.

In view of the above, the question arises of how the currently used industrial safety helmets behave during impacts exerted with higher energy, as well as under various thermal conditions at worksites. For that reason, studies were undertaken at the Central Institute for Labour Protection – National Research Institute with the aim of determining the maximum energy of an impact of a falling object on the helmet that would generate a force of 5 kN acting on the headform. Helmets of various design and construction and made of different materials were selected for the tests. It was also assumed that the investigated parameters would be determined for helmets conditioned at various temperatures.

2. Test objects

Seven types of standard industrial safety helmets manufactured in European Union member states (Germany, the United Kingdom, and Poland), consistent with EN 397:2012 [2] and CE certified, were selected for the tests. The selected helmets were characterized by various design and construction, and were made of various materials, as specified in Table 1.

The common design characteristics of all the selected helmets included the presence of a shell and cradle, and a lack of protective padding that could absorb impact energy, as presented in Fig. 1.

In this kind of helmet construction, only the shell and the cradle are responsible for absorbing impact energy, i.e., for the shock-absorbing properties. Additionally, Table 1 specifies the internal vertical distance determined according to EN 397:2012 [2], roughly corresponding to the value X in Fig. 1, for all the tested helmets.

3. Testing method

An impact exerted by a moving object is accompanied by deformation of the shell and cradle of the helmet. In the case of impacts to the highest point of the shell and directed vertically downwards the most significant deformation occurs within the area of height X (Fig. 1). The deformation of helmet elements results in absorption of the impact of the striking object, which is accompanied by an increase in the force transferred to the headform. In order to determine the value of the energy absorbed by the helmet when impacted by a moving object generating a force of $F = 5$ kN, the following theoretical equation was used (1)

$$E_5 = \int_0^{\Delta x_5} F(\Delta x) d\Delta x \tag{1}$$

where Δx is the deformation of the helmet according to Fig. 1, Δx_5 the deformation at the moment when force F reaches the value of 5 kN and $F(\Delta x)$ the load-deformation in the direction x characteristics of the helmet.

The application of the above formula requires the availability of $F(\Delta x)$ characteristics describing the correlation between the force acting on the helmet during the impact and the total deformation of the helmet in the direction x. The data necessary for determination of the energy absorbed by the helmet during impact were obtained using the test stand presented in Fig. 2.

The mechanical part of the stand is mounted on a monolithic base (1) weighing more than 500 kg. The base is designed to maintain the structure supporting the stand (2) as well as to take over the dynamic forces acting during impact on the test helmet. Two vertical slideways (2) of about 3.5 m, with a trolley (4) moving along them, are installed on the stand. A striker (7) with a construction conforming to EN 397:2012 [2], which hits the test helmet (10) in the final phase of its fall, is attached

Table 1
Design of the tested industrial safety helmets.

Symbol	Shell material	Cradle material	Cradle construction	Internal vertical distance (according to EN 397:2012) (mm)	Temperature of helmet use
A	Polyethylene	Textile tapes	Six-point	41	From −10 °C to +50 °C
B	ABS	Polyethylene	Eight-point	42	From −20 °C to +50 °C
C	Polyester–glass composite	Textile tapes	Four-point	38	From −20 °C to +50 °C
D	Polyethylene	Textile tapes	Six-point	46	From −30 °C to +50 °C
E	ABS	Textile tapes	Six-point	47	From −20 °C to +50 °C
F	Polyethylene	Textile tapes	Six-point	43	From −20 °C to + 50 °C
G	Polyamide	Textile tapes	Four-point	46	From −30 °C to +50 °C