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STRUCTURAL AND THERMAL ANALYSIS OF PCM-COOLED SAFETY HELMET

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Abstract: Worker's safety and well-being is the fundamental requirement in each and every workplace in the industrial and construction sites. Taking this into consideration, we tried utmost to cover this important aspect and focused to fill this narrow gap that often goes neglected. This research aims to fabricate a safety helmet along with provision of a sustainable cooling atmosphere, which would fit the economic feasibility and would be within industry approved design standards. To verify the safety of the helmet, we simulated our helmet in set conditions. As for the cooling, a phase change material (PCM) was selected due to its high efficiency to store high thermal energy, phase changing properties and recharging abilities. The temperature distribution and time required for the PCM to completely change its state i.e from solid state to liquid state was simulated through CFD Analysis. During our experimentation analysis, we used Paraffin wax as our phase change material (PCM) which was encapsulated in aluminium foil packets which were sealed to ensure that heat conduction to the PCM was facilitated easily and without leakage. In this way, our structural and thermal design analysis of the safety helmet was successfully finalized.

Index Terms **- Cooling helmet, Phase change material (PCM), Paraffin wax, Aluminium packets, Impact absorption, Foam, CFD.**

I. INTRODUCTION

India is bestowed upon with varying climates depending predominantly on the season and geographical location. But the majority of the year is marked with hot to very hot climate. Workers in the construction sites need to work to the fullest even in these conditions due to which they get exhausted or drained out. Research have observed that although workers at the construction sites wear safety helmets to prevent head injury, wearing it in the aforementioned conditions result in tiredness, physical and mental challenges, and less productivity. To overcome this, we have developed a safety helmet embedded with PCM cooled gel packs. This along with a foam not only increases efficiency of the helmet, but also helps in maintaining the strength of the helmet in case of accidents. This thus increases the productivity and aids in well-being of the workers.

The project was aimed at implementing certain modifications without compensating the existing safety standards of IS. We covered different results obtained for various foam materials. Depending upon the shock-absorbing ability and thermal conductivity, these materials were found to be more efficient for the desired application.

II. NEED OF THE PROJECT

In our global warming crisis, to tackle existing working environments for workers on construction sites, it is quite a challenge. These heating issues have created a stigma in construction workers against the use of helmets, which further reduces demand for companies to produce such helmets. Generally, safety is to be prioritized but it does not produce the desired results.

Most cooling helmets are manufactured for safety of riders but there is not much development when it comes to industrial-safety helmets. Also, most of the helmets available in industrial and rescue applications either compromise on the safety or cooling of the helmet. Such a compromise is counter-productive in solving this very serious challenge.

To resolve this major issue such as high temperature working conditions, we aimed at a newly modified safety helmet which will provide a cooling effect on the head area to the workers with the help of PCM embedded inside the helmet. In addition to this, we have provided foam protection inside the helmet with respect to fall protection and against impact. We have identified a cheap cooling solution that also has a high latent heat capacity and can perform for longer hours, such being the finding that was aimed for. Also, at most of the construction sites and industrial sectors, workplaces are situated in huge open spaces or high altitudes, according to working situations. This will ensure a steady air circulation that enables PCM cooling, an ideal solution in this case. The solution would bear in mind the weight, comfort, peak temperatures, sturdiness, charging of the PCM and novelty.

III. LITERATURE SURVEY

Sai Cheong FOK et al examined the use of phase change material for cooling and presented the experimental investigations on the influence of simulated solar radiation, wind speed and heat generation rate. They showed how the temperature was dependent on the ramp air but very little on the solar radiations [1]. A. Chelliah et al focused on absorbing the heat produced inside the helmet. To achieve this, a suitable Phase change material (PCM) Glauber Salt was encapsulated inside an Aluminium Foil. The material used for the inside foam was polystyrene. The paper mentioned the advantages of using Glauber's salt as PCM. The design details including the layers of the helmet, its materials, CFD analysis, and physical properties were shown [2]. This gave us an idea of the requirements for our research and also the conditions to be considered during our simulation. Cornelis P. Bogerda et al aimed to summarize different findings and not only gave a complete overview on this topic but also showed a new perspective. Headgear increases head insulation and therefore is mainly problematic under warm conditions, which was the focus of this review [3].

Jianqing Chena et al studied different types of metal foam for increasing the effectiveness of PCMs and the thermal conductivity and convective heat transfer of the composite PCMs. It was noted that high temperature PCMs are used in solar power plants while the low temperature PCMs are used for heat recovery systems, hence making the latter suitable for our use. Since the use in helmets will be of comparatively low temperature, organic PCMs are better. Effects of pore size on the conductivity of the PCM was studied and helped to correctly select the same. The research methods used in the investigation of conductive, convective and phase change heat transfer processes in composite PCMs was also reviewed.[4].

Hanumesha Pujar et al used a fan for cooling, in closed spaces or in the areas where there is negligible air circulation. The thermal comfort of the mining helmet during the mining process is important as it can affect the physiological and psychological condition of the worker. Their project dealt with the development of a cooling system for mining helmets using powerful fan technology [5]. Vikrant Katekar et al explained the implementation of PCM in a helmet as a cooling solution [6]. Although it is to be noted that this paper is for bike helmets and not for safety working-helmets. The differences arise in the areas where there is no concentration of heat in safety helmets but working conditions that are strenuous. Hence design changes will be required to make the PCM leak-proof. Ajay Nair et al's paper focused on the charging and discharge analysis of Paraffin wax (melting temperature of 58-60°C) which is used as phase change material in thermal energy storage system. It focused on charging of Paraffin wax PCM by Solar Energy and charging-discharging period analysis of Paraffin Wax was done [7]. Gowtham Vigneswaran et al proposed a method to reduce thermal discomfort by using Paraffin wax as PCM packed in thin, flexible aluminium casing placed inside the helmet. The helmet was studied under solar radiation with no airstream condition [8].

IV. METHODOLOGY

A. Design

1. HELMET

Since the purpose of the project was to create a cooling solution for construction helmets, an existing polycarbonate helmet was modelled on SolidWorks 2014. The model was made using the original dimensions. Modifications of the helmet design was made with respect to safety, such as addition of foam. The thickness of the foam was selected as 3 mm considering the comfort of the worker and transfer of heat from the head to the PCM Packets.

Another modification was making of slots in the foam of the helmet. This was done to ensure easy removal and insertion of PCM packets to and from the helmet. The helmet design was analysed to check if these slots pose any safety risk to the structure of the helmet.

2. PACKET

For packet design, thin flexible Aluminium foil was used. Aluminium has high thermal conductivity and this thin foil makes effective heat transfer.

Table 1: Helmet Components and Properties

Components	Material	Density (g/cm^3)
Helmet Shell	Polycarbonate	1.22
Packet	Aluminium	2.70
PCM	Paraffin Wax	0.83
Foam	EPS	0.03

B. Selection of PCM

Inorganic PCM was not considered due to their unavailability in crystalline form. Amongst the organic PCMs, Paraffin wax is safe, less expensive and non-corrosive. We used Grade 6035 due to the closeness of melting point with respect to the working conditions of the helmet.

Table 2: Properties of the PCM - Paraffin Wax (Grade 6035)

Parameters	Values
Specific heat (solid/liquid)	2.384 KJ/kg °C / 2.44 KJ/kg °C
Melting/Solidification temp.	56 °C
Density (solid/liquid)	833.66 kg/m^3
Thermal conductivity	0.15 W/m K
Weight	4.380 kg

C. Structural Analysis

As previously mentioned, the helmet was analysed in Ansys 2021 to check if the slots made were detrimental to safety of the worker. The helmet was tested under impact loading conditions and was compared for two things: Stress concentration and Deformation.

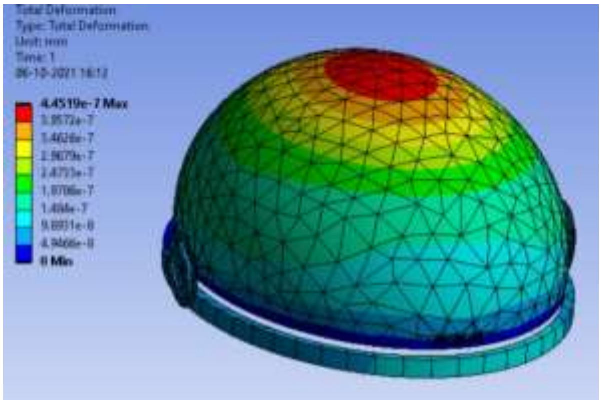

Fig 1. Helmet without Foam

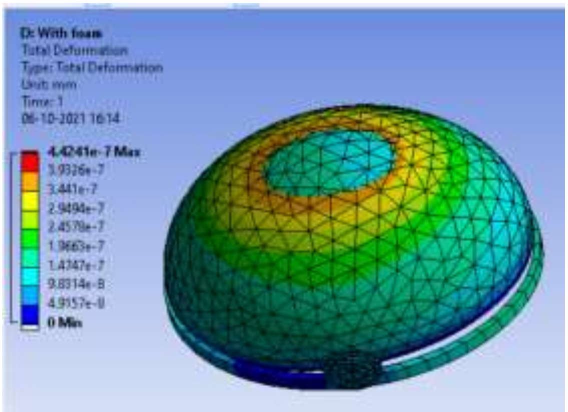

Fig 2. Helmet with Foam

When the foam was added in the helmet, the stress was evenly distributed throughout the curved surface. Maximum stress concentration level was reduced along with the maximum deformation. The presence of slots had negligible effect on the stress concentration or deformation on the top surface. This proved that most of the force was absorbed by the foam.

D. Thermal Analysis

a) Experimentation: To see the variation in temperature with time, a monitoring system was set up. This included taking temperature inputs through a K-type thermocouple. It was connected to Arduino-UNO via MAX6675 module. Data was automatically received on the Arduino IDE monitor.

Before involving the PCM, the inside surface temperature of the helmet was noted by keeping it in conditions similar to those of the working environment. The Temperature-Time graph was plotted. The initial melting point of the Paraffin Wax was 56℃ which is above the working conditions of the worker. Temperature inside the helmet would not reach this temperature and hence desired results were not obtained. Hence, we needed to lower the melting point of the Paraffin wax. To do so, paraffin wax was melted in mineral oil in the fixed quantity: 25 gm in 100 ml. The heated liquid was then poured in Aluminium foil packet, frozen and incorporated in the helmet. The temperature variation vis-à-vis time was observed using the above-mentioned set-up.

It was observed through experimentation that the cooling time was directly proportional to the amount of the PCM mixture that we use inside the helmet as more heat will be required to be absorbed before the phase change process is completed. The initial temperature of the helmet was 38℃ and then subsequent readings were obtained.

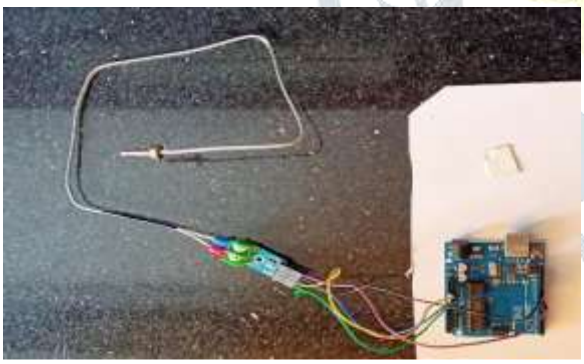

Fig 3. Arduino-UNO Setup with thermocouple

Fig 4. Experimental setup under ideal conditions

Table 3: Temperature-Time Readings of Helmet with PCM

Time	Temperature (℃)
12:00	24
12:30	24.25
13:00	26.75
13:30	28.25
14:00	29.25
14:30	30
15:00	30.75
15:30	30.75
16:00	31.25
16:30	32.25

Between 13:00 and 15:30, the temperature remained constant i.e., satisfying the human comfort range (26℃-32℃**).** Given that the readings were taken at the hottest time of the day, the cooling duration was satisfactory. Adding any more PCM would increase the weight of the helmet to an uncomfortable extent, and could jeopardize the safety. Hence by reducing the melting point of the PCM to approximately 30℃ the effective cooling duration was significantly increased which is also reflected in the simulation analysis further.

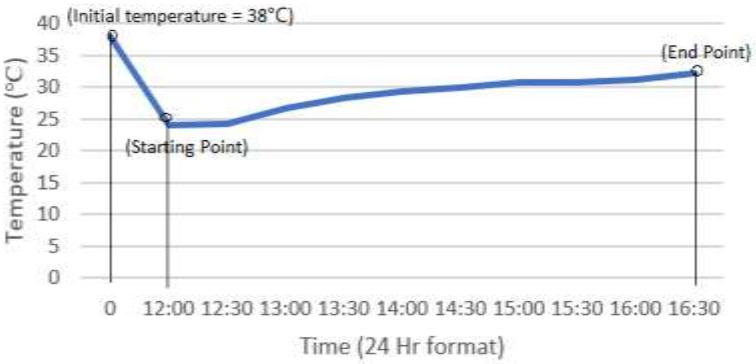

Fig 5. Time vs Temperature graph of Helmet with PCM

b) CFD Analysis: This following figure shows the contour profile. The outer curved surface has ambient air temperature and the inner curved surface is at around 30℃ which is in contact with the head. Also, the inner PCM region is at around 27℃. The average facet value obtained from the FLUENT solver is around 30℃ that lies with the comfort zone condition and we can also observe uniform distribution of cooling because of high thermal conductivity of Aluminium.

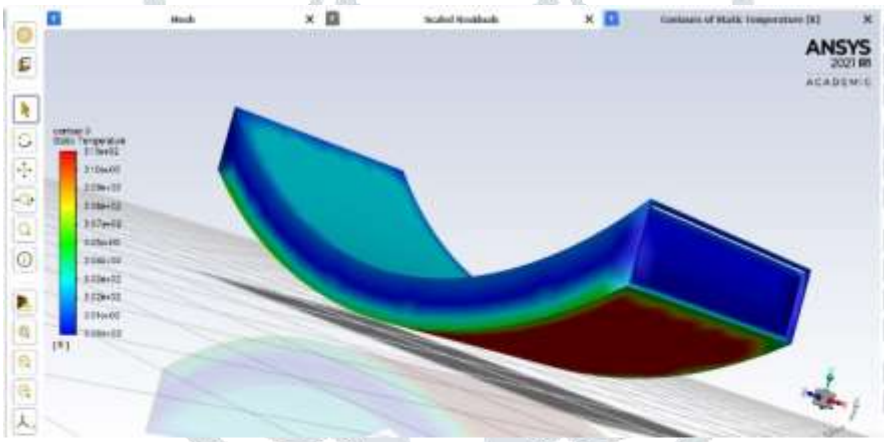

Fig 6. Temperature distribution profile of PCM cooling pack

V. CONCLUSION

This paper highlights the method with which Paraffin wax, as PCM, effectively provided cooling in safety helmets. Addition of foam proved beneficial in terms of achieving overall reduction in deformation and stress concentration. From the experiments carried out, the results proved that reducing the melting point of the Paraffin wax enhanced cooling capability of the PCM packets and improved thermal comfort. Our helmet's application may extend up to areas where there are long working hours, high temperature environment and risk of accidents, some of them being shop floor and construction sites. Cooling Requirement is cross sectoral and an essential part of economic growth and its demand is set to rise in the future and by doing this we can ensure high working efficiency among its users and safety with the fall protection measures, which is an important factor to be considered.

VI. ACKNOWLEDGMENT

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