Project no. COOP-CT-2003-508179

PRO-HEAD

Hybrid Thermoplastic Composites for Recyclable and High Performance Head Protection Systems

Co-operative research Project

PRO-HEAD Project

Publishable Final Activity Report

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TABLE OF CONTENTS

1 Project Execution

During the two project years' project time the partners have progressed remarkably in each workpackage and the final helmet demonstrators for bicycle and motorcycle applications have been successfully produced.

In order to design an innovative high performing helmet shell, a preliminary scientific analysis has been carried out to analyze the properties of several superelastic alloys (Nickel-Titanium based binary alloys and Copper based ternary alloys) and thermoplastic materials (Twintex, Towflex, Azdel Laminate, MFT, PURE, etc.).

The investigation on Shape Memory Alloys has led to the conclusion that the NiTinol can be considered the best compromise between cost and performance being a bit more expensive than the Copper based alloys but providing larger recoverable deformation in a wider temperature range. The selected NiTinol alloy for PRO-HEAD has a superelastic temperature range that meets the operating range of the helmet and is stable up to 220°C for few minutes without loss of its superelastic property. This temperature allows a sufficient safety margin for the thermoplastic composite thermoforming process at 130° - 180° C. The NiTinol wires have been woven into a textile structure and further embedded into the all-thermoplastic layers that compose the composite.

As far as the thermoplastic material is concerned, Polypropylene (PP) is the major thermoplastic construction material of the future in view of its impressive growth figures of the past years. PP can also be easily processed, modified and recycled using existing technology, and so adapted to many applications. However, due to its low mechanical properties, PP has to be reinforced with glass or natural fibres to meet the high demands on stiffness and strength in engineering applications. The presence of these "foreign" reinforcements within PP composites makes problems for traditional thermomechanical recycling of PP. So an alternative strategy is to improve plastics' properties while retaining the materials' recyclability and ease of forming. Self-reinforced polymers (SRPs) can be a solution to this problem: these materials, in fact, represent 100% single polymer composites, where the molecular chains are highly aligned to create reinforcing “fibres” and the thin surface layer acts as the matrix. SRPs offer high stiffness and weight savings making them attractive materials to manufacturers and developers. There are currently two main SRPs on the market - the Curv and the MFT Technology. Both the products have similar mechanical properties: they are 30% to 60% lighter, at the same stiffness, than PP, HDPE, ABS, PP/glass-mat composites, steel and aluminium; they also provide two to 15 times higher impact resistance than typical thermoplastic composites, even at temperatures down to – 40°C. However, MFT is preferred with respect to the Curv technology because the processing temperature window is larger: for PRO-HEAD Project, both pre-consolidated sheets and fabrics have been used for manufacturing the prototypes.

In order to manufacture the hybrid composite made by superelastic material and self-reinforced PP material, an innovative manufacturing methodology has been analysed and developed: a single step forming process. The fundamental stages involved are heating the pre-consolidated all-PP sheets with embedded the SMA fabric, forming and cooling in the mould, then removing and finishing the helmet. Heating by means of infrared radiation is the method used for manufacturing the PRO-HEAD demonstrators. Using this method, cycling time ranging from 30 seconds to 1 minute has been achieved.

Figure 1 shows the PRO-HEAD demonstrators that have been manufactured. The prototypes have been tested using the standard regulation (BS EN 1078:1997 for bicycle helmet; UNI ECE R22 for motorcycle helmet) and all helmets passed the safety requirements and present deceleration values lower (hence better) than the commercial helmets.

Figure 1: PRO-HEAD Helmet demonstrators

Consortium

The PRO-HEAD consortium consists of two RTD performers and eight SMEs. Contractors are given in Table 1:

Table 1: List of participants of PRO-HEAD Project

Co-ordinator: D'Appolonia S.p.A.	www.dappolonia.it e-mail: donato.zangani@dappolonia.it	Italy
Engineering Team S.r.l.,	www.engineeringteam.com	Italy
Epsira OY	www.epsira.com	Finland
Saviplast s.n.c	www.saviplast.it	Italy
Prendas Deportivas NZI S.L.:,	www.nzi.es	Spain
Sociedad Anónima Grober	www.sagrober.com	Spain
Foam Techniques Ltd.	www.foamtechniques.co.uk	UK
Aerovac Systems Ltd.	www.aerovac.com	UK
TMBK Partners	www.technologypartners.pl	Poland
Pera Innovation Limited	www.pera.com	UK

PRO-HEAD-project was financed by the Sixth Framework Programme of European Commission;

2 Dissemination and Use

In PRO-HEAD, the following innovations have been developed:

- a novel **hybrid superelastic Shape Memory Alloys (SMAs) textile** composed by Nickel-Titanium Alloy (Nitinol) wires weaved with polypropylene yarns. The Nitinol material is superelastic with an active Af lower than 0° C. The hybrid textile architecture has been designed to best use the properties of SMAs wires in terms of energy absorption;
- a **novel hybrid thermoplastic composite** composed by self-reinforcing thermoplastic sheets (produced by Milliken) and Nitinol fabric: the lay-up configuration and the location of SMAs reinforcing fabric has been designed to optimise the impact dissipation properties and penetration strength of the composite shell. The thermoplastic sheet is composed by multiple layers of fabric based on a polypropylene tape yarn, woven into a twill weave construction. The matrix is incorporated into the tape yarn making the sheet a self-reinforced polypropylene composite material. The manufacturing process is based on a single step environmental friendly, cost effective forming process. The SMA hybrid thermoplastic sheets are heated (preferably by IR-heater and then quickly moulded by using silicon and metal moulds: this method allows to reduce drastically the manufacturing time with respect to the technology presently used in the helmets sector.

A mathematical model for textile structures has been developed for an analytical design and optimisation of the thermoplastic textile structure as well as of the hybrid composite lay-up and after that the proposed composite design has been virtually verified by impact analysis made with LS-DYNA. Following the composite material design phase and the virtual prototyping phase the composite material manufacturing process has been designed and optimised by mean of a testing campaign on all-thermoplastic and hybrid thermoplastic flat samples. Impact test on hybrid thermoplastic flat samples showed an increase in the absorbed impact energy of about 30% with respect to similar only thermoplastic flat sample with superelastic fibres volume fraction about 0.1. Standard impact tests preformed on preliminary motorcycle helmet made of all-thermoplastic composite showed an increase of about 10% of the absorbed impact energy with respect to a conventional glass-fibre motorcycle helmet of the same weight.

Result Description	Possible market applications	Stage of development	Collaboration sought or offered	Collaborator details	IPR granted or published	Contact Details
Novel hybrid superelastic (SMAs) textile	Composite reinforcement for high energy absorbing applications	Demonstrator	None	None	None	lorenzo.perelli@dappolonia.it
Novel hybrid thermoplastic structure	Helmets, Protective Clothes, Military Applications	Demonstrator	Collaboration	Milliken	None	lorenzo.perelli@dappolonia.it