Development of a cost-effective and lightweight hand pallet truck for application in material handling

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1 Executive Summary

The stationary technical and technological content in materials, machinery and products of the material handling sector together with the high percentage incidence of costs due to manual operations have resulted in a heavy rise of products being imported from low labour cost countries, such as China. Launching cost-competitive products with high technological content and superior technical performances could indeed face this trend. This perfectly marries the wish of plastics manufacturers. As a matter of facts, the manufacturing of plastic products has dramatically decreased during the last years. Therefore, several SMEs are opening their market to a wide range of not exploited sectors and developing advanced/innovative products through the use of cutting edge materials and technologies. The hand pallet truck (HPT) production has been identified as one possible application where techno-plastics could play a crucial role in, totally modifying the performances as well as the business of the material handling sector.

The main aim of the project ECOPAT is to design and develop the new generation of all-plastic, lightweight, chemically passive and cost-effective HPTs to be efficiently used in material handling applications. This purpose has been achieved thanks to the **production of one full-scale HPT prototype made of glass-reinforced plastic** which has allowed the final evaluation of the performances of the product and the benefits on health and safety in handling environments. The novel HPT is more than **55% lighter** than traditional steel pallet trucks which turns into easiness of use, greater manoeuvrability and reduced noise and is also deemed to have better aesthetical quality, easiness in keeping it clean and strong resistance to corrosion. The novel HPT has therefore considerably improved handling performances over existing products though still allowing the safely lift of **loads up to 1000 kg**.

In parallel, basic research on self-reinforced plastic materials and their manufacturing processes has been conducted in the project, with the future aim to apply this novel category of plastics to the HPTs production. Dog-bone samples have been produced from self-reinforced pellets and sheets by injection and compression moulding processes and used for characterization of mechanical and physical properties. Also, two heating methods have been applied, i.e., classical resistance heating and novel induction heating. Test samples have been compared against percentage and orientation of reinforcing fibres, layout and processing conditions. The following conclusions have been achieved:

a) Despite the narrow processing window between low melting matrix polymer and high melting reinforcing fibres and independently on the heating system applied, the **fibres still exist** in the test samples.

b) **Injection** moulded samples have only **marginally improved mechanical properties** over the un-reinforced samples because of relaxation, partial degradation and agglomeration of fibres. **Further research is needed** to improve the properties of self-reinforced pellets and their application to the injection moulding process before proceeding with the scale-up of the processing route – co-extrusion and injection moulding – from laboratory to industrial level.

c) **Compression** moulded samples show **considerably increased mechanical properties** over the un-reinforced samples. Mechanical properties evidently benefit from the presence of fibres especially if oriented along the direction of the applied load. No further basic research is needed but the **scale-up of the processing route** – winding and compression moulding – from laboratory to industrial level.

d) **Induction heating** is proved to allow **shorter processing cycles and faster controller response**, to be **more energy-efficient** and not to affect the properties of the self-reinforced material. If applied to the moulds for compression, it requires careful design supported by FEM analyses to ensure uniform heating of the parts. Oppositely, its application to injection equipment is easy and turns into substantial energy savings.

2 Summary description of the project context and the main objectives

The stationary technical and technological content in materials, machinery and products of the material handling sector together with the high percentage incidence of costs due to manual operations have resulted in a heavy rise of products being imported from low labour cost countries, such as China. Launching cost-competitive products with high technological content and superior technical performances could indeed face this trend. This perfectly marries the wish of plastics manufacturers. As a matter of facts, the manufacturing production of plastic products has dramatically decreased during the last years. The economic crisis has hit the plastics industry severely for the first time in more than 30 years, causing the global plastics production to steadily decrease since 2008. There is therefore a huge need for the plastics industry to overcome the ongoing crisis and to come out with major potentials. Therefore, several SMEs are paving the way to new business strategies by opening their market to a wide range of not exploited sectors and developing advanced as well as innovative products through the use of cutting edge technologies. In particular OMP, involved in the manufacturing of plastic components mainly for the electro-mechanical, conditioning and furnishing industrial sectors, has explored the potential of introducing plastics manufacturing techniques and technologies in the field of material handling, indeed a sector which could deeply benefit from the advantages provided by employing lighter materials. The hand pallet truck (HPT) production has been identified as one possible application where techno-plastics could play a crucial role in, totally modifying the performances as well as the business of the material handling sector.

HPTs are handling trolleys able to raise pallets of goods or small containers slightly and to move them safely, thus increasing the efficiency in mechanical handling operations and making easier the unattractive manual labour. Despite of their apparent simplicity, HPTs are quite articulated objects. Two parts, namely the chassis (which consists of the "chest" and the forks welded together into one piece) and the hydraulics, are the key components of standard HPTs. In addition, the truck is equipped with front and rear wheels and a vertical tow bar with a loop handle on top. Few strokes of the tow bar allow the user to actuate an oil pump located inside the hydraulic unit body which causes the frame to lift up. A rocker arm and push rods positioned below the frame make the two forks to evenly lift with respect to the ground. Bearings and breaks let the operator nimbly and safely move weights as high as 2.5 tons for easy material storing/handling/transport. The HPTs main parts are typically made from sheet steel that is further bent and cut into the right profiles to make the parts. There are also a small number of special stainless steel trucks produced for particular end uses, e.g., in environments where it may be in contact with corrosive substances or for extra hygienic applications.

Several potentials and advantages are linked to the introduction of lighter polymeric materials in the HPT production, as low service weight, that reflects in higher manageability and lower manoeuvre efforts improving the operator working conditions, reduction of raw materials and manufacturing costs, high technical and technological content which prevents the manufacturing steps to be exported to low labour cost countries, major chemical inertia which would reduce corrosion and contamination risks thus allowing HPTs healthy use in the food industry within wet/salty environments where stainless steel HPTs are nowadays employed, significant operation noise reduction, eco-compatibility, improved functional ergonomics.

Self-reinforced plastics are in principle suitable materials for the HPT fabrication. In these materials, a polymeric matrix is reinforced with high-tenacity fibres or tapes of the same polymeric family, such as polypropylene-reinforced polypropylene, creating a material with

typically 3-5 times the strength and stiffness of the un-reinforced polymer, giving the ability to use less material for the same mechanical properties in a component. Additionally, unlike glass or carbon reinforced plastics, self-reinforced plastics are not contaminated with high levels of mineral fibres, so they have the same level of both recyclability and density as the base polymer.
Within this framework, the main aim of the project ECOPAT is to design and develop the new generation of all-plastic, lightweight, chemically passive and cost-effective HPTs to be efficiently used in material handling applications. The main drivers and needs which address this specific goal are:

1. To **improve hand pallet truck technical characteristics and operational performances**, such as strength, stiffness, lightness, life cycle, to name but a few;
2. To **reduce hand pallet truck environmental impact** through the employment of resource efficient manufacturing processes;
3. To **improve health & safety working conditions**;
4. To **extend business markets and employment sectors** by guaranteeing technically competitive cost-effective HPTs.

Based on these primary drivers, the project has been broken down into a series of likely solutions to the problems. Fostering research on self-reinforced plastics and moulding technologies needed to produce components from this new family of materials is key to the development of novel HPTs with high technical and technological content. At the time of the proposal submission, early commercial grades of self-reinforced plastics were only available as non-flowing sheet materials, which was restricting their use to simple parts with constant wall thickness. Moreover, the properties of plastics were only improved by adding mineral powders or fibres, which increases the weight of the material, significantly reduces the recyclability (and the purity of the recyclate) and increases the wear of tools and processing equipment. In this context, the project ECOPAT would lead to a step change in cutting-edge self-reinforced plastics technology by developing flowing and mouldable versions of self-reinforced plastics. Complex, net-shape parts would be possible, thereby reducing material use and eliminating trimming waste and process energy. This would reduce the amount of material required to make a part and open the door to a vast range of applications for these sustainable materials. The related scientific and technical objectives which mainly concern self-reinforced plastics definition and manufacturing processes were identified to be:

- Identification of the most suitable polymer materials to be processed both as matrix and fibres among polyolefins, polyamides and polyesters, based on a critical analysis of their mechanical and thermal properties;
- Maximization of the difference between the melt temperature of the matrix phase and the temperature at which the reinforcement phase becomes unstable;
- Identification of suitable impregnation methods of the high melting polymeric fibres with the low melting polymeric matrix to produce self-reinforced composites for subsequent injection and compression moulding;
- Determination of suitable moulding process conditions taking into account the need for selectively pre-heating – by means of classical and novel heating techniques – the compound in order not to affect the properties of fibres;
- Manufacturing of small-scale samples and definition of an experimental testing campaign introductory to analyze the developed self-reinforced plastic characteristics in terms of mechanical and chemical properties;

- Designing of HPT components through the identification of the most simple HPT geometry though taking into account the static and dynamic structural response of the parts, the constraints from the moulding processes and the need for easy assembling/disassembling;
- Full-scale prototype manufacturing followed by its industrial validation accomplished through both traditional testing procedures and material handling in-field demonstrations;
- Dissemination of the findings/results of the project and patent issue request.

The claimed scientific and technical objectives have been achieved thanks to the **production of one full-scale HPT prototype made of glass-reinforced plastic** which has allowed the final evaluation of the performances of the product and the benefits on health and safety in handling environments. The novel HPT is more than **55% lighter** than traditional steel pallet trucks which turns into easiness of use, greater manoeuvrability and reduced noise and is also deemed to have better aesthetical quality, easiness in keeping it clean and strong resistance to corrosion. The novel HPT has therefore considerably improved handling performances over existing products though still allowing the safely lift of **loads up to 1000 kg**.

In parallel, basic research on self-reinforced plastic materials and their manufacturing processes has been conducted in the project, with the future aim to apply this novel category of plastics to the HPTs production. Dog-bone samples have been produced from self-reinforced pellets and sheets by injection and compression moulding processes and used for characterization of mechanical and physical properties. Also, two heating methods have been applied, i.e., classical resistance heating and novel induction heating. Test samples have been compared against percentage and orientation of reinforcing fibres, layout and processing conditions. The following conclusions have been achieved:

a) Despite the narrow processing window between low melting matrix polymer and high melting reinforcing fibres and independently on the heating system applied, the **fibres still exist** in the test samples.

b) **Injection** moulded samples have only **marginally improved mechanical properties** over the un-reinforced samples because of relaxation, partial degradation and agglomeration of fibres. **Further research is needed** to improve the properties of self-reinforced pellets and their application to the injection moulding process before proceeding with the scale-up of the processing route – co-extrusion and injection moulding – from laboratory to industrial level.

c) **Compression** moulded samples show **considerably increased mechanical properties** over the un-reinforced samples. Mechanical properties evidently benefit from the presence of fibres especially if oriented along the direction of the applied load. No further basic research is needed but the **scale-up of the processing route** – winding and compression moulding – from laboratory to industrial level.

d) **Induction heating** is proved to allow **shorter processing cycles and faster controller response**, to be **more energy-efficient** and not to affect the properties of the self-reinforced material. If applied to the moulds for compression, it requires careful design supported by FEM analyses to ensure uniform heating of the parts. Oppositely, its application to injection equipment is easy and turns into energy savings.

The Consortium’s common purpose in relation to the project ECOPAT is to ultimately achieve a commercially competing material/technology/product to be introduced in the respective market. The project is therefore a business-oriented initiative, aimed at both:

1. proving in a first instance the **technical viability of the intended processing routes** to better evaluate a possible industrial exploitation for the research advancements and results achieved concerning self-reinforced polymeric materials and related moulding technologies in a medium and long term perspective;
2. drawing concrete perspectives towards **commercialization of the novel HPT** already designed, developed and tested in a short term perspective.

Accordingly, the 4 SMEs of the Consortium (OMP, ITI, CHABE and CONSTR) joined a clearly **business-oriented Consortium** that also involved the Large Enterprise LIFT which will become an important industrial as well as commercial partner for the proposing SMEs. Together these partners represent a **complete supply chain** as well as a strong business partnership in view of a possible mass production and commercialization of the novel HPT. The project ECOPAT thus represents a **big opportunity for the SMEs to increase their technical competitiveness and economical advantage** in the short term period.

3 Description of the main S&T results and foreground

The concept of the project ECOPAT is based on the development of Self-Reinforced Plastics (SRP) to be employed as materials suitable for the manufacturing of structural parts of HPTs. The starting point of the project was a deep investigation of materials from the family of polyolefins, polyamides and polyesters suitable for the considered application. Polymer features which are relevant are directly linked to mechanical strength, processing conditions, recyclability and cost. Material families were compared with respect to these features and selection of most suitable polymers was done. In parallel, initial considerations on payload capacity, dimensional constraints, weight, noise and safety characteristics and on specific requirements for the HPT together with a static multi-body analysis performed on a standard steel HPT allowed the definition of minimum specifications in terms of structural, thermal and chemical properties for the material and the parts that make up the truck itself. Results obtained guided the selection of the new SRP material with related compounding and moulding processes.

In this first phase of the project, minor activities were also developed in parallel. The project website was created and the methodology to drive the project results towards attractive markets with specific business strategies aiming at the generation of profits was defined.

Experimental research was then conducted to study the behaviour of selected polymers during melting and crystallization. The melting and crystallization temperatures of investigated polymers were determined by means of Differential Scanning Calorimetry (DSC). Based on the analysis of DSC heating and cooling curves as well as the derivative (DDSC) of the melting and crystallization curves – the last determining the temperature when the melting and crystallization occur with the highest intensity – several thermal properties were determined. Careful design of selected class of polymers targeting well distinguishable processing windows was conducted to reduce the matrix melt temperature and to increase the thermal stability of fibres. As the difference between melting temperature of selected polymers is rather low, the danger exists that both elements of composite melt during heating. To avoid such situation, the effect of nucleating agents onto the thermal properties of the selected polymers was investigated. Also, the heating system shall keep the melt temperature as close as possible to the matrix melt temperature during both compounding of matrix polymer with reinforcement polymer and during compression/injection moulding of the compound. Possible heating principles – resistance, infrared, microwave and induction – were therefore deeply investigated. Two most promising heating methods were identified.

At this point of the project, research on compounding techniques, moulding technologies and heating systems serving the production of self-reinforced plastics in suitable forms to feed the respective moulding processes had to be divided into different routes. Briefly, self-reinforced polymeric materials in the form of sheets and pellets were produced to be used in either compression or injection moulding processes. Both types of self-reinforced materials were obtained from commercial bi-component fibres as well as from neat polymers. Customized experimental setups were designed and developed and lab-scale experiments were conducted. Induction heating as well as resistance heating were also applied to moulding machines and compared against cost-effectiveness, energy-savings, temperature control characteristics and properties of the test samples produced.

The main S&T results and exploitable foreground generated within the project are described with detail in the following together with further research steps necessary to achieve a maturity level for the materials, technologies and products developed in the project allowing their industrial and commercial exploitation.

3.1 Description of the exploitable foreground

PELLETS AND SHEETS FROM COMMERCIAL BI-COMPONENT FIBRES

Commercial bi-component fibres were initially used to produce self-reinforced semi-finished sheets and pellets and feed injection and compression moulding machines.

Semi-finished non-woven sheets were produced through thermo-bonding process directly derived from the textile industry (see Figure 3.1 – left). Since the process heats the bi-component fibres up to their softening temperature, no change of properties occurs, i.e. the properties of the non-woven sheets are those of the commercial raw material.

Pellets were instead produced by means of the extrusion process. Because during extrusion the material undergoes phase change and is subjected to high temperatures and pressures, morphological and physical characterization were needed to assess the presence of fibres and the rheological properties of the compound.

Tests on injection moulding with pellets and on compression moulding with both pellets and non-woven sheets were done with the aim to optimize processing conditions of these materials (see Figure 3.1 – right).

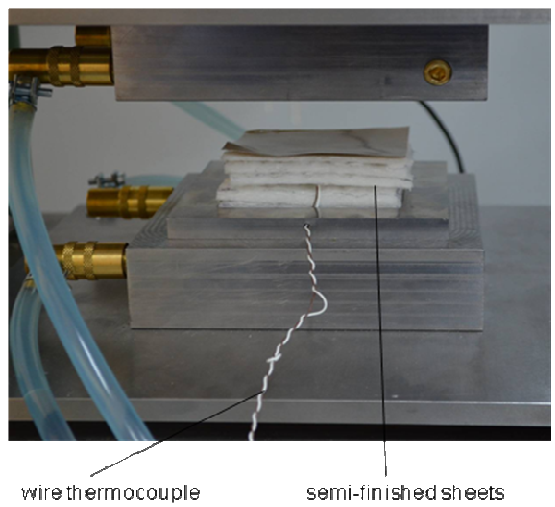

Figure 3.1 – Sample of non-woven sheet from CoPP/PP fibres (left) and stack of the sheets prior to compression moulding (right)

Results of mechanical and physical tests on compression moulded samples visible in Figure 3.2 show that:

- **reinforcement PP fibres caused the growth of the tensile strength of moulded SRP compound** up to 86% in comparison to low strength PP matrix, reaching the R_m value 44.7 MPa;
- together with tensile strength growth **the elastic modulus decreases**; the minimum value of elastic modulus was found for the SRP sample with the highest tensile strength. In comparison to matrix material, the SRP compound shows decrease of elastic modulus up to 18%;
- **elongation at break of SRP compound is significantly lower** in comparison to matrix material value and decreases by about 57 – 64%.

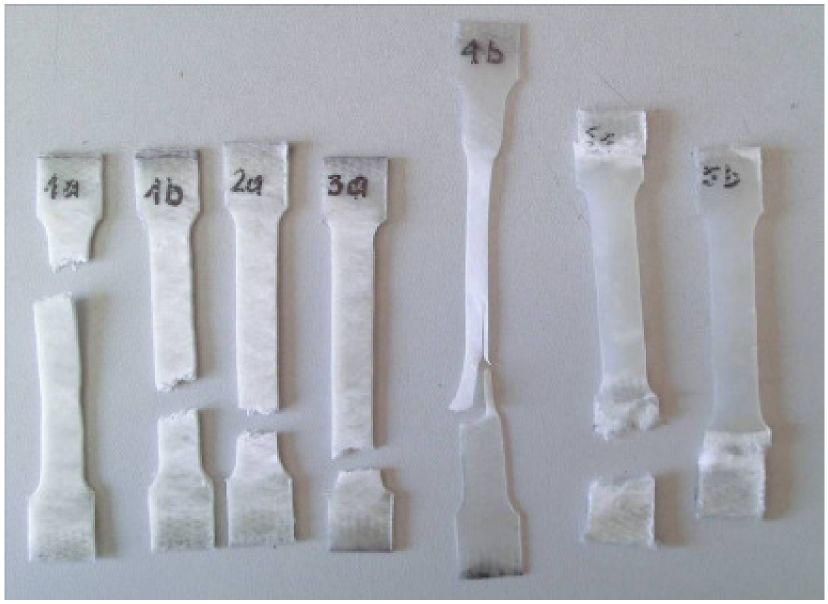

Figure 3.2 – Dogbone samples after tensile strength tests

Results of mechanical and physical tests on injection moulded samples show that:

- **process conditions did not save the reinforcement fibres** which were submitted to considerable degradation;
- mechanical properties of samples are comparable to properties of unreinforced material.

The approach with the use of commercial bi-component fibers as a raw material for compression and injection molding technologies showed to be a **low cost and effective method to obtain SRP compounds**. Initial use of these commercial fibres allowed the Consortium getting insight into behaviour and processing of self-reinforced materials. This foreground generated was indeed useful in the next production of own-made self-reinforced materials and their moulding.

SHEETS FROM NEAT POLYMERS

Metocene PP matrix polymer and nucleated Moplen HP500N reinforcement polymer were used to produce semi-finished sheets. Semi-finished sheets were produced by means of a motorized winding process which allows laboratory production of uni-directionally and bi-directionally self-reinforced sheets with different combinations of reinforcing layers (see Figure 3.3 – left). Sheets were then pressed and plates heated up by resistance and induction heating alternatively.

The applied method of pressing of oriented polypropylene fiber layers and low-melting PP film leads to **effective production of SPC of acceptable mechanical properties** (see Figure 3.3 – right). When applied as composite matrix, polypropylene Metocene 648T facilitates lowering the temperature of SPC pressing. However, it requires precise selection of processing conditions which would enable a proper connection of matrix with reinforcing phase, while preserving the excellent mechanical properties of the latter. Additional challenge is the choice of film layer of appropriate thickness and the amount of fiber layers which is crucial to obtain a composite containing maximum number of fibers and the most advantageous mechanical properties.

The results of tensile strength tests can be considered satisfactory. **Significant increase of tensile strength in comparison to neat matrix** can be obtained with even small amount of oriented PP fibres into PP matrix. When the content of fibres in the composite amounts to about 30% tensile strength equals 130 MPa (about +225% in comparison to neat matrix) while E modulus is about 1.7 GPa (about +20% in comparison to neat matrix). By the way, the **mechanical properties of SPC compound substantially depend on reinforcing fibres arrangement**. The fibres arranged parallel to the load direction make the material clearly stiffer and reinforced. On the other hand, perpendicular arrangement of the fibres results in material weakening. Tensile tests of samples from compression molding with inductive system, despite technical problems like non uniform heating and matrix flow from mould show very common results.

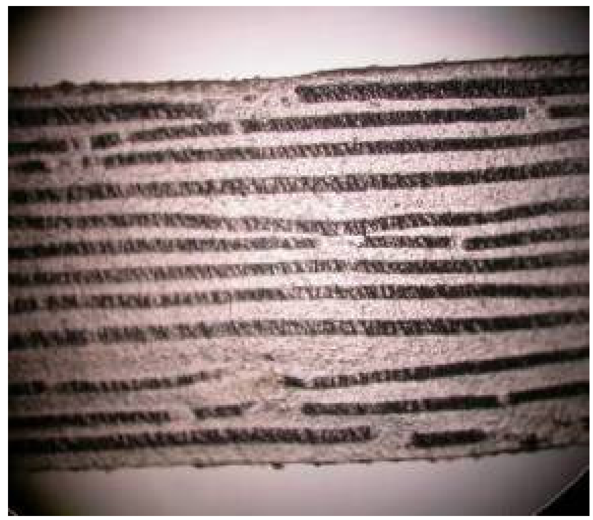

Figure 3.3 – Sheet with cross-ply configuration (left) and microscopy image of the cross-section of moulded sheet containing 24 layers of fibres in 12 clusters (right)

PELLETS FROM NEAT POLYMERS

Lumicene CoPP matrix polymer and nucleated Moplen HP500N reinforcement polymer were used to produce pellets by means of co-extrusion process. Because during co-extrusion the material undergoes phase change and is subjected to high temperatures and pressures, morphological and physical characterization were needed to assess the presence of fibres and the rheological properties of the compound. Careful tuning of processing conditions assures presence of fibres in the pellets (see Figure 3.4).

Figure 3.4 – View of the SRP pellet

Pellets were then injection moulded by simple piston machine, whose barrel was heated up by resistance heating and induction heating alternatively. Dogbone samples were produced with fibres still existing.
Tests for characterization of mechanical and physical properties of these composite materials followed (see Figure 3.5). The **results of tensile strength tests can be considered satisfactory**. When the content of fibres in the composite amounts to about 35% tensile strength equals 30 MPa (about +7% in comparison to neat matrix) while E modulus is about 1.5 GPa (about +10% in comparison to neat matrix). Half quantity of reinforcing fibres yields the same results. The probable reason for this unexpected behaviour is **aggregation of fibres inside the samples** for high fibre quantities. Tensile tests made on samples produced by injection moulding with induction heating system show very similar results.

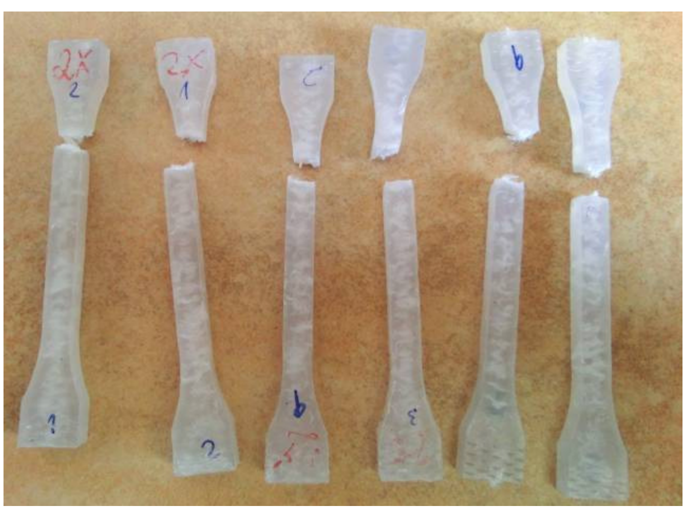

Figure 3.5 – SRP specimens after tensile strength test

<u>INDUCTION HEATING APPLIED TO LABORATORY COMPRESSION MOULDING MACHINE</u>

The tests with **induction heating** confirm this heating method **is more efficient** than resistance one, considering particularly cycle time which can be shorter thanks to faster heating of the mould at the same or even at lower value of heating power. Simultaneously **the temperature control is more accurate** and keeping a practically constant temperature while compressing is possible – the temperature deviation does not exceed 0.5°C. However the main problem of this heating method applied for compression moulding is **non-uniform temperature distribution** on the moulding surface of the mould. This strongly depends on the mould and inductor design. In general it seems to be impossible to ensure ideal uniform heating – by very careful analysis in order to ensure the uniform heating of the part to be moulded. In order to ensure the temperature distribution to be possibly most uniform, an **inductor geometry optimization is necessary**. The optimum inductor design may be done by careful FEM analysis of induction heating process.

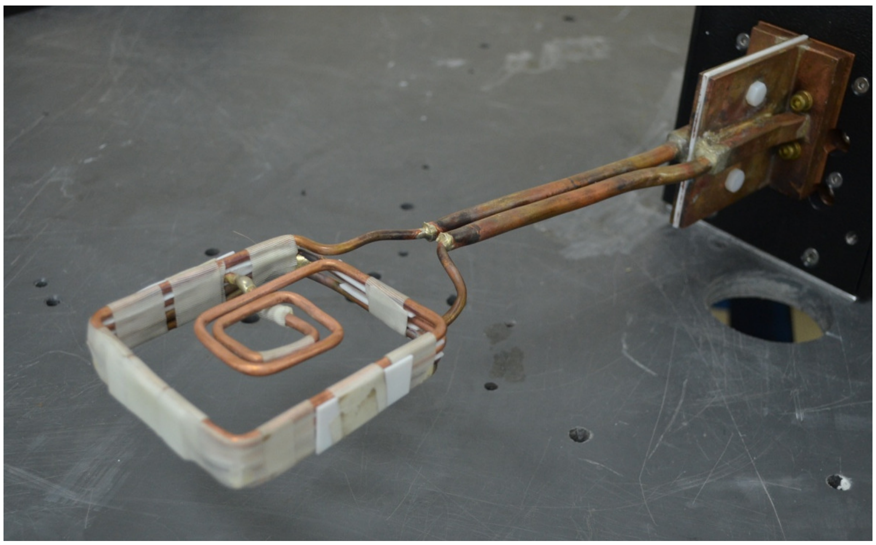

Figure 3.6 – Optimized design of the inductor coil

INDUCTION HEATING APPLIED TO LABORATORY INJECTION MOULDING MACHINE

Investigations of **induction heating** system undertaken for piston injection machine show this heating technique **can be easily adjusted and applied to existing injection machine**. In opposite to compression moulding where the design of inductor and heating parameter strongly depends on shape of molded part and must be done for each case individually, a design of barrel induction heating system depends only on barrel geometry, numbers and localization of heating zones and plastic processing parameters. The numerical experiments by FEM simulation as well as laboratory trials show **high heating efficiency and excellent temperature distribution** along the heated steel tube.

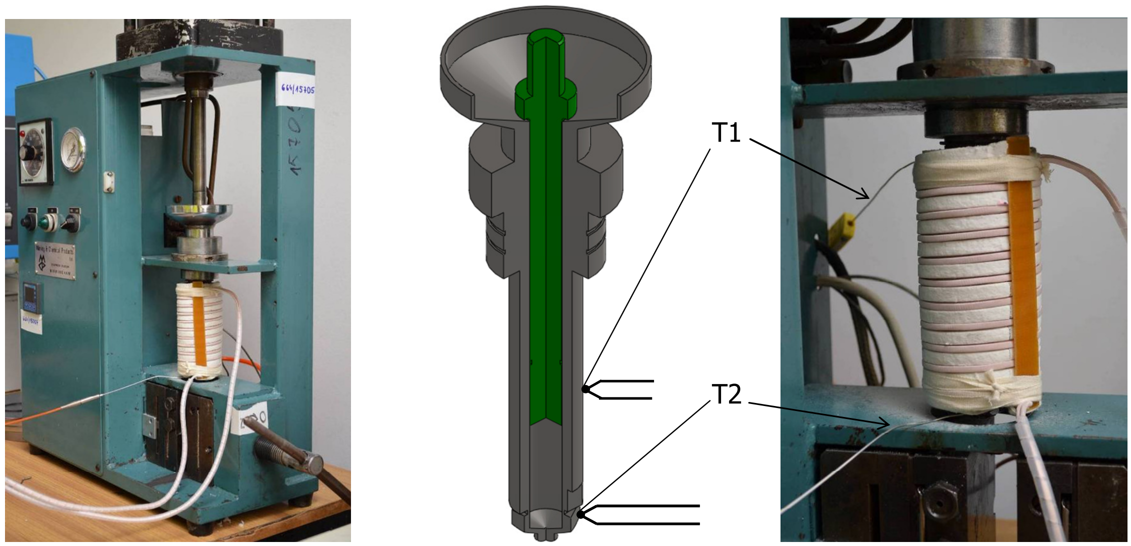

Figure 3.7 – Inductor coil wrapping the steel cylinder of the piston injection machine

HPT PROTOTYPES

The design and prototyping of frame and hydraulic body parts and related moulds were carried out taking the glass-reinforced composite as reference material. Static structural analyses and dynamic impact analyses were performed considering both glass-reinforced polyamide and self-reinforced polypropylene properties. The design load was changed from 1 ton for the glass-reinforced material to 200 kg to reflect the reduced mechanical properties of the self-reinforced PP material when produced by injection moulding. Moreover, numerical analyses of the injection moulding process were done for both materials. The prototypes of the project, namely:

- **the frame and the hydraulic body made of glass-reinforced composite**,
- **the assembled version of the HPT with parts made of glass-reinforced composite**,
- **the lever of the hydraulic group made of the novel self-reinforced PP material**,

were successfully produced (see Figures from 3.8 to 3.10) and tested on test benches. The full glass-reinforced HPT prototype was also used for in-field demonstration and real life operation loading and moving pallets with an average weight of 700/800 kg each.

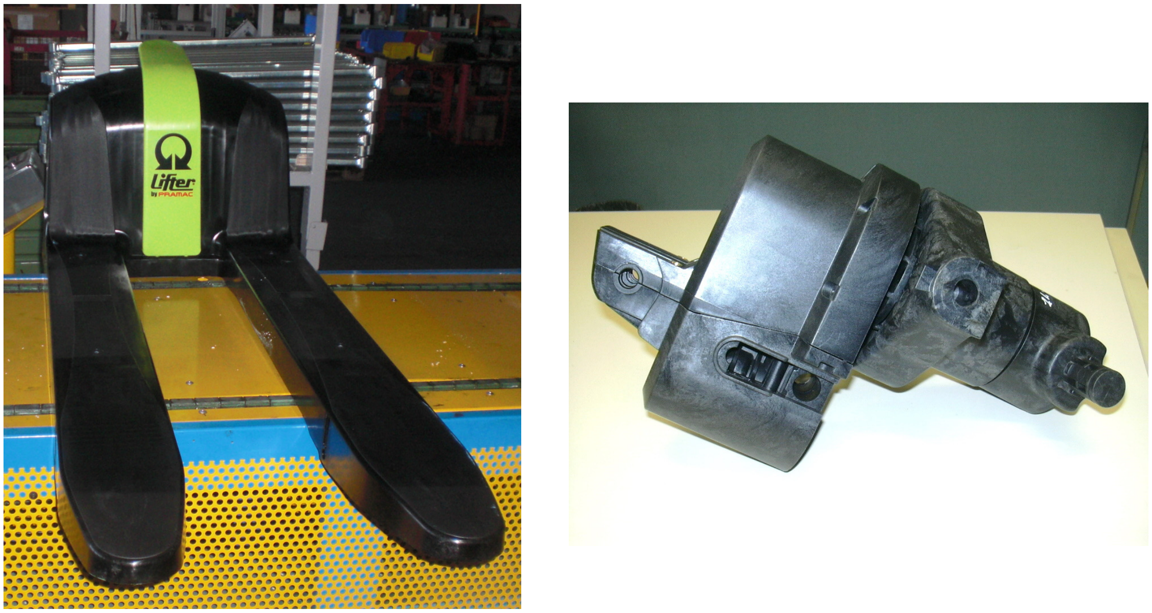

Figure 3.8 – Pictures of the HPT frame (left) and of the HPT hydraulic group body (right)

Figure 3.9 – Picture of the Hand Pallet Truck prototype

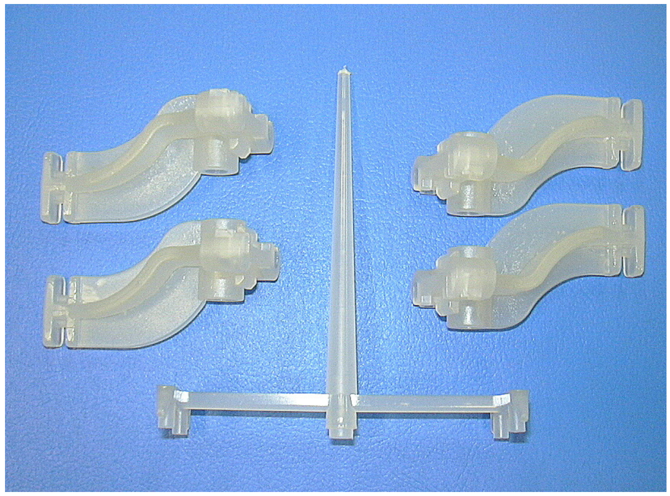

Figure 3.10 – Picture of the lever of the hydraulic group made of SR PP

3.2 Further research necessary

The results claimed by the project and summarized in:

1. Self-reinforced polymeric materials for injection and compression moulding,
2. Induction heating technology for injection and compression moulding,
3. Full-scale glass-reinforced Hand Pallet Truck prototype,

have reached a different level of maturity in terms of potential industrial and commercial exploitation, as described in the following.

Results n. 1 and 2 – Materials and technologies

Though the project has successfully demonstrated the basic technical and technological feasibilities concerning production of self-reinforced polymeric materials in different forms and their use in injection and compression moulding processes, further research is indeed necessary to overcome the limitations encountered above all for the injection moulding route. The limits of the achieved results and proposed next steps are detailed in the following.

INJECTION MOULDING ROUTE

The main achievement is that **the fibres still exist and are visible in the moulded parts** despite:

- the narrow processing window (about 30°C) between low melting CoPP matrix and high melting reinforcing iPP fibres;
- the double heating process that matrix and fibres undergo (co-extrusion at first and secondly injection moulding);
- the heating system employed during injection (induction or resistance).

Also, **the fibres do not cause weakening** of the mechanical properties of the samples, i.e., they do not act as inclusions causing sudden failure of the material.
Nevertheless, **the fibres improve only marginally the mechanical properties of the un-reinforced matrix material** (about 7 to 10% increase in E modulus and tensile strength). In addition, despite two types of pellets were produced with different amount of reinforcing fibres (35% and 17%), samples with higher amount have same mechanical properties than those with lower amount. This unexpected behaviour might be due to several reasons such as:

- **relaxation** of fibres. The high mechanical properties of the fibres in their drawn condition are lost during injection moulding, when fibres tend to bend. This behaviour might be limited by reducing the length of the fibres and the diameter of the bundles the fibres are arranged in;
- **degradation** of fibres. The temperature of the melt – which includes reinforcing fibres at solid state – increases crossing the injection gate due to shear against the gate walls. The local increase of temperature might yield softening or even melting of fibres despite the high velocity of the flow. The type of injection gate is therefore very important. For instance, slit gates would be preferable to point gates since the orifice is larger. The selection or re-design of best type of injection gate could reduce this behaviour;
- **agglomeration** of fibres. The fibres are arranged in tight bundles. The melt matrix material does not flow in the bundle properly surrounding each fibre in the bundle. This causes not homogeneous distribution of fibres and not proper bonding between fibres and matrix material. The injection machines equipped with a screw might help distributing the fibres in a more homogeneous way. Also, the co-extrusion process might be revised to avoid agglomeration since the beginning. For example, the number of tight bundles may be increased, each containing reduced number of fibres. This would improve penetration of melt matrix among the fibres and matrix-fibres adhesion.

Concerning induction **heating system** applied to existing injection machines, the outcome is summarized in the following:

- this heating technique **can be easily adjusted and applied to standard equipment** without a great manufacturing impact. The main contribution to the overall equipment cost is the power supply unit, whose impact is reduced in % for big machines;
- induction heating **does not affect the properties** of the self-reinforced material, which are practically equal to the ones of samples produced by employing standard heating system;
- induction heating **allows fast controller response** enabling injection of self-reinforced pellets characterized by a narrow processing temperature window and ensuring small variations of barrel temperature during injection and **high heating efficiency** which turns into energy savings.

On the basis of the deep knowledge acquired during the 2-years project, further research is needed to improve the co-extrusion and injection moulding processes and proceed with their scale-up from laboratory to industrial level. The partners agree that a long term exploitation perspective is required.

COMPRESSION MOULDING ROUTE

The main achievements are:

- the applied method of pressing oriented PP fibre layers and low melting PP film alternately leads to **effective production of single polymer composites of acceptable mechanical properties** – with about 120 MPa tensile strength and 1.7 GPa E modulus, mechanical properties evidently benefit from presence of fibres if oriented along the direction of the applied load;
- the **mechanical properties significantly change** with fibre content and orientation in the material as well as with matrix-fibres bonding properties.

Concerning **induction heating** system applied to existing compression moulding machines, the outcome is summarized in the following:

- induction heating applied to the mould **allows the processing cycle to be shorter and more energy-efficient**, but it requires very careful FEM analysis in order to ensure the uniform heating of the parts. The **temperature distribution may be non-uniform** even for a simple shape of the mould;
- induction heating **does not affect the properties** of the self-reinforced material, which are practically equal to the ones of samples produced by employing standard heating system;
- induction heating **allows fast controller response** ensuring **high heating efficiency** which turns into energy savings.

On the basis of the deep knowledge acquired during the 2-years project, no further basic research is needed but the scale-up of the process – winding and compression moulding – from laboratory to industrial level. Possibility of exploitation in the medium term is achievable.

Result n. 3 – HPT prototype

The full HPT prototype was used for in-field demonstration and real life operation loading and moving pallets with an average weight of 700/800 kg each by CHABE and CHABE's main customers. The staff considered that the prototype is **less heavy** than others of its kind, it is **easy to use** and it allows accessing to any area in the warehouse easily. In general its easiness of use and **great manoeuvrability** when working were pointed out. Furthermore, the novel HPT was deemed to have **better aesthetical quality and easiness in keeping it clean** since it does not strip and rust. The novel HPT is built to the highest specifications though it seems to be less stable when the forks are lifted and pallets of high height are to be moved. The overall impression is that the prototype is **ideal for light and heavy loads below 1 ton**. The advantages initially foreseen for the novel HPT were thus confirmed by the real life testing.

No more research neither design/optimization steps are needed for the glass-reinforced parts of the HPT prototype, which can be scaled-up to industrial massive production without any difficulty and could enter the EU market in the short term.

4 Description of the potential impact and the main dissemination activities and the exploitation of results

4.1 Potential impact in the short term

The new generation HPT is expected to capture around 5.6% of the worldwide HPT market by the 3rd year after commercialisation, as reported in Table 4.1. This results in 5.74 M€ turnover for the entire Consortium.

Area	Quantity	Market share (reference year 2009)
Europe	40 k	10.4%
America	25 k	7.6%
Asia	10 k	2%
ROW	5 k	2.5%

Table 4.1 – Composite HPT target quantity estimate

The traditional comparable steel hand pallet trucks are normally sold for 180 €/unit considering an average European price, as reported in Table 4.2.

Products	Dealer purchase price
Europe quality	180 €
China source	150 €
Stainless steel	900 €

Table 4.2 – Market range price

A detailed life cycle cost analysis conducted for the steel HPT highlights that the margin/HPT unit (HPTU) is roughly 19% over its cost, that is 30 €/HPTU. The remaining 150 €/HPTU are thus split costs:

- 50 €/HPTU (33%) manufacturing processes and assembling operations carried out by LIFTER;
- 100 €/HPTU (67%) raw materials, semi-finished and finished parts purchased by LIFTER from suppliers in the steel industry.

Concerning the glass-reinforced HPT, OMP and LIFT estimate an appealing and competitive sale price of around 198 €/HPT unit out of 168 €/HPT cost. In addition to the 30 €/HPT (18%) margin over its cost, the 168 € are thus split costs:

- 37 €/HPTU (22%) manufacturing processes and assembling operations carried out by LIFTER;
- 131 €/HPTU (78%) raw materials, semi-finished and finished parts purchased by LIFTER from suppliers in the steel and plastics industry.

Out of the 131 €/HPT cost of raw materials and parts, the production and sale of glass-reinforced parts from OMP to LIFTER is worth of 86.40 €/HPT (66%) with a margin of about 14 €/HPT (19%) for the injection moulding company and 9 €/HPT for the supplier of raw plastic material.
Applying these figures and percentage incidence to the value chain of the new lightweight eco-compatible HPT, and considering an average price of 198 €/HPTU and a worldwide market of 80 kU/year, since the margin on manufacturing operations and raw materials purchase are about 19%, the total turnover of the innovative product commercialisation has been calculated as 4.24 M€ (0.72 M€ raw materials supplier + 1.12 M€ injection moulding company + 2.40 M€ assembling company), taking into account only on the conventional end-uses. Considering also the revenues coming from the employment HPTs in new sectors embedding use by private citizens and by pharmaceutical/food warehouses, being preliminarily estimated in 1.5 M€ by year 3 after commercialisation, a total turnover of 5.74 M€ is calculated.

4.2 Dissemination activities

The goal of the communication and dissemination activities organised within the project was to spread the project image and information about the achieved results to the target public in order to increase the potential future commercial opportunities for the hand pallet truck developed in the project as well as to set the basis for the potential industrial partnerships Europe-wide. First of all, a project identity was created in order to provide a common image of the project to the public and gain a higher visibility at dissemination events. The most convenient method to achieve this goal was by graphic designs. A project logo was created together with common documents format to give the public an immediate recognition about the project. In addition, specific dissemination actions were undertaken during the entire extension of the project (1st August 2010 – 31st October 2012) including creation of a dedicated project website, participation at fairs and events, deployment of results to the scientific community, etc., as described in the following.

ECOPAT WEBSITE

The aim for the website was to increase the visibility of the Project ECOPAT to the public and provide them with an updated reference on the project activities during the whole course of the project. The website was also used to communicate results among the project Partners as well as to exchange supporting material or other documents of interest. In order to accomplish these two main purposes, the website was made up of two parts, i.e., a public part and a private one. The project website was completed at the end of Month 3 (October 2010) according to foreseen schedule and will stay active also after the end of the project for at least two more years. The link is www.project-ecopat.eu.
Any public document generated in the frame of the project (such as presentation of Partners, ECOPAT brochure, ECOPAT poster, pictures of fairs, publishable summary, public deliverables, etc.) is available for download in the public area.

POSTER

Three versions of the ECOPAT poster were prepared at different development stages and used during dissemination events such as fairs, conferences and exhibitions.

The first version of the poster contains basic project information, i.e., project goal, needs and drivers from industry and expected project results. Also, the Logo of each Partner is present together with contact details of the Coordinator Enterprise (OMP) and the website address. It has been ideated to disseminate information concerning the project to a broad audience, therefore deep technical information is missing.
The second and third versions of the poster were intended to disseminate the achievements of the project – with specific reference to materials being studied and developed – at events of the plastics industry with main academic nature. Technical information and images are included being the posters intended for an audience with deep scientific background. The second version of the ECOPAT project posters describes the context of the research on self-reinforced plastics and provides the details of materials analyzed and the results of DSC investigations.
The third version of the ECOPAT project posters describes the achievements of the research carried out in the frame of the project concerning materials used, processing procedures and material properties of moulded samples.
All versions of the poster proved to be very useful for dissemination of the project.

BROCHURE

The brochure of the project ECOPAT was printed and distributed by the Partners participating at relevant fairs and exhibitions of both plastics industry sector and material handling sector. This document was fundamental at dissemination events as it is portable and easy to read.
The external side shows the logo and the title of the project, the contact details of the Coordinator Enterprise (OMP) and the website address, the logos of the Partners. A particular HPT image out of any traditional HPT image is shown to give the visitors an idea of its content at first sight.
The internal side describes the goal of the project, the status of research and the steps beyond the end of the project, which are indeed needed to scale-up the processing route at industrial level. In addition, the availability of the Consortium to tackle any initiative or idea with the aim to spread and use the developed materials and technologies in other applications than material handling trucks is openly stated.

LEAFLET ON LIFE CYCLE ASSESSMENT RESULTS

The comparative Life Cycle Assessment has lead to very interesting results concerning environmental footprint of innovative glass-reinforced HPTs (Inn HPT) in comparison to standard steel HPTs (SoA HPT). Given the more and more social attention to environment-related aspects of products in the market, the Consortium decided to promote the outcome of the LCA by means of an Executive Summary Report in the form of leaflet (one page). The leaflet is being distributed at fairs and exhibitions attended by the Partners which concern material handling.

EVENTS

All events at least one of the Partners of the project ECOPAT attended during the 27 months of project duration are extensively described in the following. The events are numbered on the basis of attending date. The posters, the brochure, the leaflet and also dedicated presentations were used for dissemination.

1. CeMAT 2011 – The World's Leading Fair for Intralogistics

On May 02-06, 2011, LIFTER took part in the world's leading fair for intralogistics – CeMAT 2011 – held in Hannover (Germany). The first poster of the project ECOPAT was shown at LIFTER's stand. A general description of project goals, methodology, planned activities and expected results was given to an interested public. The event concluded with positive results and discussions from public and other experts which were considered as a valuable input during the future developments of the project.

2. PPS 2011 – The Polymer Processing Society 27th Annual Meeting

On May 10-14, 2011, PUT took part in the 27th Annual Meeting organized by the Polymer Processing Society – PPS 2011 – held in Marrakech. Two oral presentations partly based on research performed in the project ECOPAT were presented to the audience by PUT, with title "Frequency Analysis as a Tool for Describing the Instabilities of Polymer Melt in Extrusion Process" and "Influence of Multiprocessing on Rheological and Application Properties of Polypropylene based WPC".

3. Eurofillers 2011 – 9th Meeting of Eurofillers International Conference

On August 21-25, 2011, PUT took part in the 9th Meeting of the Eurofillers International Conference organized by Leibniz Institut fur Polymerforschung Dresden together with Technische Universitat Dresden and held in Dresden (Germany). Given the main scientific background of the audience, the second poster of the project ECOPAT was shown with title "The influence of low containing specific additives on the processing window of polypropylene self-reinforced composites (SRC)". High interest was observed from scientific community and research centres who asked further information on the project.

4. Meeting with XALOY Enterprise

On September 08, 2011, the Coordinator OMP met the Italian branch of the XALOY Enterprise to discuss issues related to the project ECOPAT. XALOY is a global leader in plastics processing equipment and is considered one of the most innovative companies in the field. The aim of the meeting was to discuss and take information on the heating system NXHEAT, which is the first heating system applied on big-size injection moulding equipment based on induction principles. The meeting represented the chance to spread information about the project to a third industrial party outside the Consortium and deep in the field of plastics.

5. PAT 2011 – Polymers for Advanced Technologies Conference

On October 02-05, 2011, PUT took part in the Polymers for Advanced Technologies Conference held in Lodz (Poland). PUT was given 20 minutes to discuss the research on application of polypropylene for self-reinforced composites being performed in the frame of the project ECOPAT to a scientific audience who showed great interest in it. The presentation was entitled "Mechanical properties and melting behaviour of single polymer composites as a function of the processing temperature". Also, PUT printed several brochures to provide further information on the latest advancements and contacts to the attending audience. This dissemination event proved to be successful as the interested scientific community asked for details on the current status of the project and requested further information on next research activities and foreseen industrial application.

6. IPACK-IMA 2012 – Processing, Packaging and Material Handling Exhibition

From February 28 to March 03, 2012, LIFTER took part with its own stand at the exhibition on Processing, Packaging and Material Handling – IPACK-IMA 2012 – held in Milan (Italy). The first poster of the project ECOPAT was shown at LIFTER's stand (see pictures below). A general description of project goals, methodology, planned activities and expected results was given to an interested public. Some people also requested further information concerning the expected date of entrance of the composite hand pallet truck in the market. A number of ECOPAT brochures were distributed with the main aim of providing basic information about the project and contact details of Partners for business opportunities. This dissemination event was very successful. Some pictures are reported displaying the view of pavilions and LIFTER's stand with the ECOPAT poster.

7. Dissemination at Warsaw University of Technology

On April 19, 2012, PUT attended the Polymer Conference organized by Warsaw University of Technology. MSc and PhD students and interested members of Polish scientific community such as researchers and professors took part at the event. The research activities carried out by the Department of Polymer Engineering of the Institute of Materials Technology (PUT) in the frame of pure research and co-funded national and EU projects were shown to the audience and ECOPAT among others. Given the main scientific background of the audience, the third poster of the project ECOPAT was shown with title "Bi-component fibres as a material for injection moulding". Several questions concerning properties and processing of bi-component materials were asked to the speaker, who directly answered but also made reference to the project website.

8. PLASTPOL 2012 – The 17th International Fair of Plastics and Rubber Processing

From May 29 to June 01, 2012, PUT attended the 17th International Fair of Plastics and Rubber Processing – PLASTPOL 2012 – held in Kielce (Poland). PUT attended the fair as visitor. A number of ECOPAT brochures were distributed to industrial parties with the main aim of providing basic information about the project and contact details of Partners for business opportunities.

9. P2012 – 15th International Conference "Polymeric Materials"

On September 12-14, 2012, PUT attended the 15th International Conference "Polymeric Materials" – P2012 – held in Halle (Germany). Given the scientific background of the audience, the third poster of the project ECOPAT was included in the Poster Session with title "Production and properties of thermoplastic composites made of bi-component fibres". The properties and processing conditions of bi-component fibres were discussed with reference to concrete applications. Even in this case ECOPAT brochures were distributed to interested people.

<u>POST-PROJECT DISSEMINATION AND PUBLICATIONS</u>

The Consortium has agreed carrying on dissemination activities also after project completion. Dissemination activities will continue to spread information about the achieved results, particularly during the activities bringing to commercialisation of the first composite hand pallet truck. The identified dissemination channels will be used. The dissemination material prepared during the project will be used as a basis for the future dissemination activities as it proved to be effective and suitable for attracting attention to the project. Each Partner will be involved at its own degree in the dissemination of foreground beyond the project.

No scientific publications were issued during the project, however possible publication of scientific articles is being considered, at first since research on polymeric materials and processing technologies have brought interesting results and secondary because of the real interest shown by the very heterogeneous audience encountered at the range of dissemination events attended.

4.3 Plans for exploitation of results

The Consortium's common purpose in relation to the project ECOPAT is to ultimately achieve a commercially competing material/technology/product to be introduced in the respective market. The project was therefore a business-oriented initiative, aimed at both:

1. proving in a first instance the **technical viability of the intended processing routes** to better evaluate a possible industrial exploitation for the research advancements and results achieved concerning self-reinforced polymeric materials and related moulding technologies in a medium and long term perspective;
2. drawing concrete perspectives towards **commercialization of the novel HPT** already designed, developed and tested in a short term perspective.

Accordingly, the 4 SMEs of the Consortium (OMP, ITI, CHABE and CONSTR) joined a clearly **business-oriented Consortium** that also involved the Large Enterprise LIFT which will become an important industrial as well as commercial partner for the proposing SMEs. Together these partners represent a **complete supply chain** as well as a strong business partnership in view of a possible mass production and commercialization of the novel HPT. The project ECOPAT thus represents a **big opportunity for the SMEs to increase their technical competitiveness and economical advantage** in the short term period.
In support to this and in order to make the most of developing potentially competing materials/technologies/products in the landscape of plastics and material handling sectors, a market analysis was conducted along the project and the evaluation of the current status of the market in view of a possible commercialization was assessed. The current market scenario and the future potential market for the plastics and the material handling sectors were identified and carefully analyzed.
In addition, an exploitation strategy was developed in the last year of the project with a twofold goal:

1. Identifying potential industrial partnership opportunities to further develop and scale-up the developed materials and technologies in the plastics business for a medium and long term take up;
2. Identifying potential commercial and industrial partnership opportunities and exploitation routes to enter the material handling market with the novel HPT developed in the project.

Also, a Life Cycle Cost Assessment was carried out providing an estimate of the production costs and sale price of the novel glass-reinforced HPT in support to the exploitation strategy.
Within the framework of the project ECOPAT, the following exploitation routes would be envisaged by the Consortium for each result claimed according to its maturity level.

EXPLOITATION OF RESULTS N. 1 AND 2 – MATERIALS AND TECHNOLOGIES
From a survey of the existing market, it is known to the Partners that only few companies in Europe are moving towards the production of self-reinforced plastics and that much effort is being afforded at research level to produce all-plastic reinforced materials in the form of fabrics, tapes, sheets and pellets for thermoforming as well as compression and injection moulding. For example, the project ESPRIT ended with the production of self-reinforced pellets based on PET.

Also, it is known that induction heating is applied at industrial level as alternative to steam heating to obtain shining surfaces of moulded parts. By the way, the heating system is applied directly on the mould and not on the processing equipment. The company Xaloy already offers two different solutions to heat the barrel of injection equipment. The first solution is a heating system entirely based on induction, the second one is a hybrid resistance-induction heating system. These systems are not applicable yet to extrusion or co-extrusion units.

The achievements of research performed in the project ECOPAT together with the findings from the market survey underline that **self-reinforced polymeric materials and the technologies for their moulding are promising from a technical and technological point of view as well as appealing from a market and economical point of view**. Furthermore, due to their high recyclability level and limited impact on environment, resources and health, their deployment would be **favoured by governmental policies** as composite materials replacing the state-of-the-art materials reinforced with low amounts of traditional mineral fillers such as talc or glass. A number of applications might be envisaged for this new class of composite materials, such as:

- Luggage, domestic boxes and cases;
- Covers of a variety of devices including industrial equipment;
- Furniture;
- Protective helmets;
- Bumpers and similar parts in the automotive and material handling industry;
- Semi-structural components in the construction and civil industry, including safety barriers and benches.

Beyond, the foreground knowledge generated along the project opens the frontiers to even **new processes** customized for the processing of self-reinforced plastics. CIM has put forward the co-extrusion process might be employed to produce single bi-component fibres. Thermo-bonding would produce non-woven fabrics to be used either in compression moulding or in hot compaction plus thermo-forming. The low cost technology in this novel processing chain would allow the production of self-reinforced plastics with high mechanical properties, establishing a low cost alternative to products made of low amount of glass reinforcement.

Nevertheless, it is too early to detail a commercial exploitation plan given the further research steps required to improve self-reinforced materials properties and their moulding processes or to establish a customized processing route as suggested by CIM, including the scale-up of the technology from laboratory to industrial level. Because of the lack in the Consortium of a company in the business of producing and supplying composite materials as well as the further research steps on self-reinforced materials and processes needed to enter the market with an appealing and competitive technology/product, the SMEs acknowledge at this stage the possibility for PUT to **patent the co-extrusion process** developed in the project.

The possibility to ultimately commercially exploit the results achieved by the SMEs will definitely depend on proving the technical, economical and commercial viability of the intended materials and processing routes at the end of adequate further development steps and an adequate time to market. This shifts the industrial and commercial exploitation potential in the medium and long term. Thanks to the valuable dissemination strategy and channels, the Partners are identifying potential industrial partnership opportunities to further develop and scale-up the developed materials and technologies in the plastics business for a medium and long term take up. The partners of EU research projects having the objective to foster the development of self-reinforced polymeric materials and related moulding technologies represent the primary target. The SMEs of the Consortium are also evaluating the opportunity to apply for a **Demonstration Action**, which would allow them to further develop the materials and technologies, to scale-up them from laboratory to industrial level and to extend their applicability to other sectors than material handling, such as automotive, civil, protective equipment and domestic thus demonstrating their technical, economical and commercial viability.

EXPLOITATION OF RESULT N. 3 – HPT PROTOTYPE

Out of the plastics industry, the Partners are confident that the material handling sector will benefit from the commercialization of the composite hand pallet truck. Taking into consideration the Hand Pallet Trucks available in the market, the competitive advantages of the new HPT in composite materials have been identified and include:

- Lightness;
- Higher manageability and lower manoeuvre efforts, thus improving the operator health and safety conditions at work;
- Reduction of raw materials and manufacturing costs, allowing the price to be competitive versus overseas products;
- High technical and technological content, which prevents the manufacturing process to be exported to low labour cost countries;
- Major chemical inertia, which would reduce corrosion and contamination risks thus granting HPTs safe use in the food/health industry within wet/salty environments as well as in highly hygienic environments where stainless steel HPTs are nowadays employed;
- Significant operation noise reduction;
- High eco-compatibility which reduces HPTs environmental impact and extends their life cycle;
- Wide range of extended applications within industrial sectors, mainly due to the possibility of creating a wide number of shapes and geometries, thus yielding HPT smart use in lifting materials even if they are not arranged/stocked on pallets;
- Improved functional ergonomics and no paint wear / rush;
- Possibility of direct sale in stores, enabling private citizens to move goods/furniture and thus extending HPTs use to a wide community of end users for daily operations.

From a supply chain point of view, the competences required to accomplish the production of new HPT may be outreached through the ECOPAT consortium partners, in detail the ECOPAT companies having the following profiles and advantages taken from ECOPAT project results.

I.T.I. is an SME specialized in plastics process recycling. Its core business is based on production and sale of milled, agglomerated and re-milled plastic materials. The company's product range comprises polymer–based products. ITI as consequence has a role of recycling material supplier derived from end-life HTP production.

OMP is involved in the production of thermoplastic components. The increase and the continuous introduction of new technologies have led the company to differentiate the manufacturing processes and to own a wide range of machinery for processing metal/plastic/rubber parts. OMP takes advantages introducing the new concept

plastics/moulding processes in its facilities for the development of the cost-effective lightweight HPT and also for other numerous industrial sectors such as automotive, technical textile, medical and construction due to the possibility of creating a wide number of shapes and geometries.
LIFT develops, manufactures and sells a complete range of trucks for internal and external material handling, including manual and electric pallet trucks, stackers, reach trucks and counterbalance forklifts. High quality production methods are incorporated into each machine, utilizing the best design solutions and components available. LIFT as HTP producer takes advantages by the final production of the HPT in composite material.
CONSTR is a leading construction company in Eastern Europe. They are well known for their continuous research for novel applications in the area of energy efficiency as well as new lightweight materials for bridges and infrastructures. CONSTR validated the developed new material in terms of structural properties and it is also an end-user for the glass-reinforced HPT.
CHABE is company which is involved in inland transport (national and international transport by road). Workers employ hand pallet trucks throughout their daily work and therefore the company represents a typical end-user of the innovative HPT developed within the project. The ability to manually lift the lightweight HPT for easy loading and unloading operations results in pulling down time consuming operations which in turn could strengthen CHABE competitiveness over the transport SMEs thus increasing their orders.

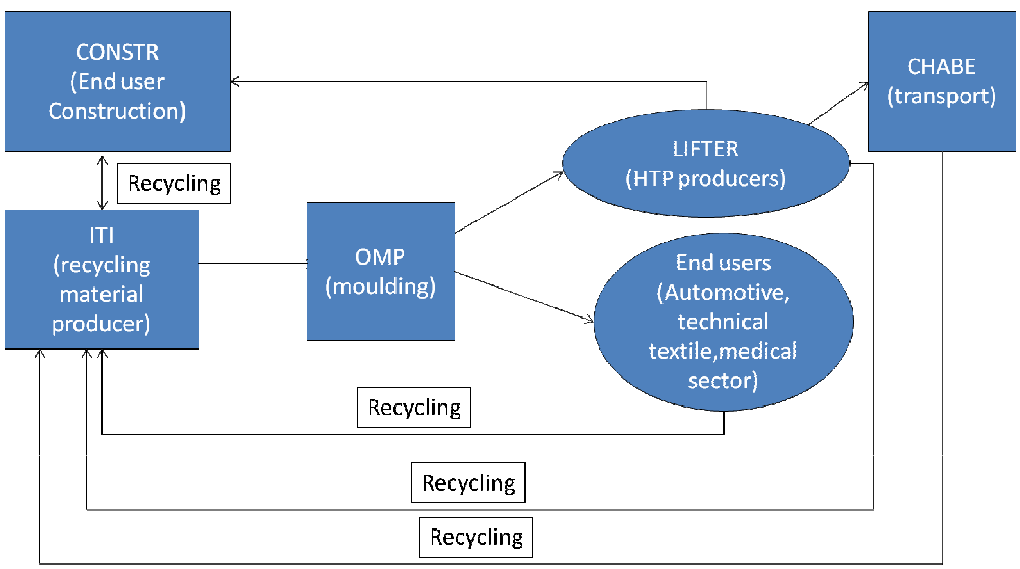

Figure 4.1 – Supply chain for the novel glass-reinforced HPT

According to the above scheme, the envisaged industrial as well as commercial exploitation routes entail that **SMEs take care of producing, supplying or recycling** essential components of the novel HPT. Thanks to its leading position in the European material handling market and challenging market share intended to target, **LIFT would guarantee a massive as well as smooth market introduction of the novel HPT** taking advantage of its already established commercial networks. According to this framework, the Life Cycle Cost Assessment has provided a quantitative estimate of the production costs and sale price of the novel glass-reinforced HPT as well as of the expected direct economic benefits for the SME participants in support to this exploitation strategy. On the basis of production costs estimates and on target market share expected to be captured in 3 years after commercialization, the turnover for each party in the Consortium provided by the commercialization of the novel HPT has been calculated, for a **total turnover of 5.74 M€**. This gives the SMEs a clear idea of the industrial and commercial worthiness of the project in terms of expected increase in revenues. **Agreements are being established** between the large enterprise LIFT and the small enterprises in the Consortium concerning supply of the parts (OMP), direct use of the trucks and dissemination of its use (CHABE and CONSTR), recycling at end-of-life (ITI).

GENERAL CONCLUSIONS

The project ECOPAT is deemed to have deeply contributed to the trend of the plastics industry providing evidence of the wide exploitability and real commercial interests behind self-reinforced materials. Given the more and more attention of governments and companies to sustainability of processes and products, the self-reinforced materials could indeed enter the market as concrete alternative to the use of composite materials reinforced with low amounts of traditional mineral fillers such as talc or glass in a variety of applications.

The Partners – and specifically the SMEs – are satisfied of:

- **the results of research and the advantage gained over competitors linked to the foreground generated**. Though scientific and technological complexity of the project has exceeded what expected at the beginning, huge amount of work has been carried out by RTDs with success and promising results have been shown. Despite the mechanical performance of the self-reinforced pellets produced in ECOPAT is limited, the co-extrusion process set-up at lab scale might be applied to other thermoplastic resins than PP, yielding production of self-reinforced pellets with enhanced properties. Also, the production of test samples and prototypes made of reinforced PP material has demonstrated the technical feasibility of applying compression and injection moulding for massive production of all-plastic structural parts. The Partners are conscious that the project aimed at investigating the very forefront of the plastics and processing knowledge and agree that the results of research push forward the boundary of knowledge and technology in the plastics sector;
- **the economical advantage gained over competitors linked to the commercialization of glass-reinforced HPTs in the short term**.

Once all the results of the project will be sufficiently mature to draw concrete perspectives for commercialisation and industrial exploitation, a more detailed business plan will be prepared and shared among the industrial partners describing in details the commercial strategies for a successful and gainful deployment of the foreground generated. This plan will follow the business model identified in the project and will include an updated market assessment on the global and European trends in the plastics and material handling sectors important for the evaluation of the market possibilities for the materials, technologies and products developed in ECOPAT. Moreover, it will define the roles of each industrial partner in the supply chain and cover competition restrictions, licensing agreements and any other form of agreement with potential external partnerships intended to protect the rights of each company during the commercialization phase.

5 Public website address and relevant contact details

The address of the project website is: www.project-ecopat.eu
The contact point of the project is: ompecopat@gmail.com

The contact details of the Coordinator of the project are:

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