Contract No.: 31602

PlugIn

Plug Materials Influence on Final Part Quality in Thermoforming Process

Co-operative research project

Deliverable D2
Final Activity Report

Due date of deliverable: 15. January 2009
Actual submission date: 08. May 2009

Start date of project: 1. October 2006	Duration: 26 months
Lead contractor	Jacob Kunststofftechnik GmbH
Revision:	Revision 1
Author	Mr. Marco Jungmeier

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	X

Content

Section 1 – Project objectives and major achievements during the complete project duration

This reports cover the activity during the complete duration of the project; started on 1st October 2006 and ends on 30th November 2008.

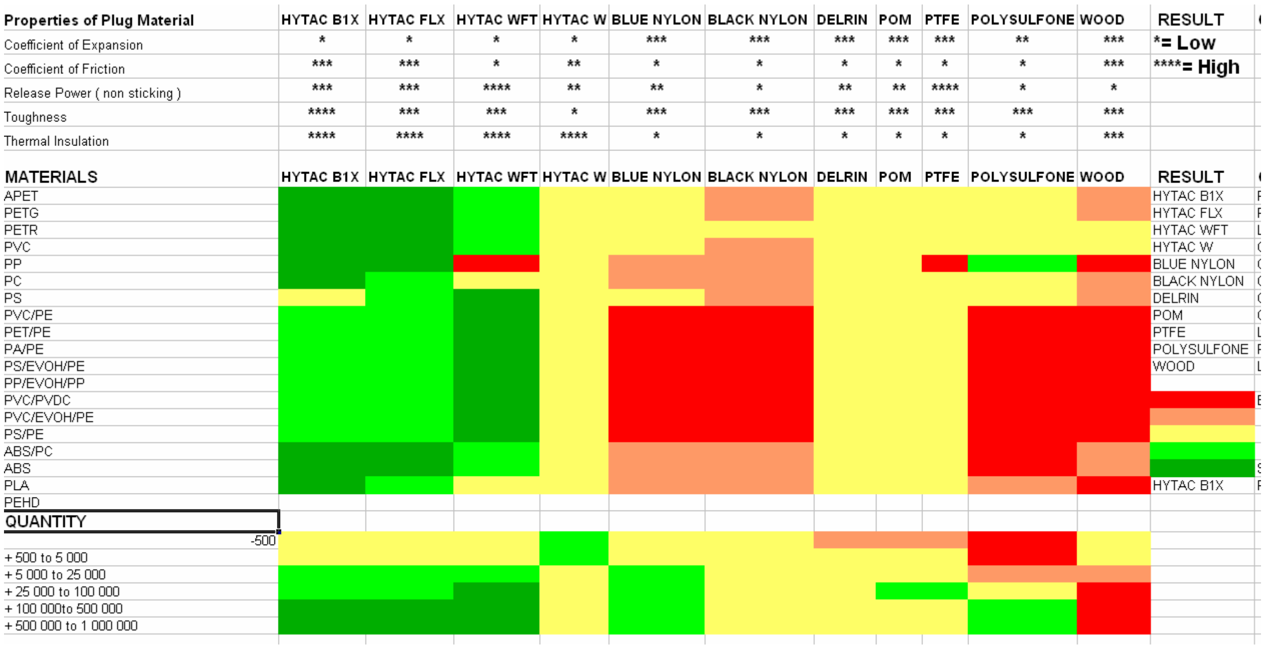
The main objectives in the reporting period of months 12 – 26 are the investigation of the plug (work package 4) and the industrial trials (work package 6). A great part of the investigation of the plug was done at QUB and delivered us for the first time an idea of the forces working during the plugging process. These results together with the results from the industrial trials performed at Jacob Kunststofftechnik and Holfeld Plastics were the input for the models for the plugging step. The models have been implemented in the T-Sim software which was fundamentally improved through this knowledge gained during the project.
The expert system as the last work package in the project includes all the results we gained during the plugin project. The consortium decided to have the expert system as a kind of tool which is accessible via the plugin web-site.

Also the reduction of the strong delay of work package 3 was one big issue in this period. During the months 12-18 the delay in WP 3 was reduced but could not completely be eliminated. The remaining delay is not perceived as a risk to the project completion but will influence the start time of the relating work packages due to a shortage of resources.
Work package 4 “Investigation of Plug” started on time but due to the mentioned delay in WP 3 this work package will be not completed on time. Due to the fact that work package 6 started before the planned time there will be enough time in reporting period 18 – 24 to complete the remaining work.
Also the finalisation of WP 5 will be delayed due to the delay in the inputs from WP 3 and 4.
For those reasons a project extension of 2 month was requested and approved to get all work done.
By the end of month 26 all the work could be completed.

Section 2 – Work package progress of the period

WP 1 Knowledge-base Acquisition

Work package 1 should deliver a plug selection guide for plug materials used in the thermoforming industry. The results of this WP have been used to define the scope of the study in terms of the polymer sheet and plug materials to be included in the investigations of WP2, 3 and 4. This WP started with a short delay caused by some understanding problems amongst the partners. Once the questions have been clarified the WP made good progress and could be finished with a delay of 6 months. The Tasks 1.1 to 1.3 were handled by answering a questionnaire set up by CIFRA. As a result an Excel spread sheet was designed which was then translated into a software tool including an intuitive user interface. Meanwhile this software was revised several times and is available in different languages such as German, French, English, ect. The complete software tool is public available on the plugin web-site and will be distributed on Exhibitions as CD Version.



Properties of Plug Material	HYTAC B1X	HYTAC FLX	HYTAC WFT	HYTAC W	BLUE NYLON	BLACK NYLON	DELRIN	POM	PTFE	POLYSULFONE	WOOD	RESULT
Coefficient of Expansion	*	*	*	*	***	***	***	***	***	**	***	*= Low
Coefficient of Friction	***	***	*	**	*	*	*	*	*	*	***	****= High
Release Power (non sticking)	***	***	****	**	**	*	**	**	****	*	*	
Toughness	****	***	***	*	***	***	***	***	***	***	***	
Thermal Insulation	****	****	****	****	*	*	*	*	*	*	***	

Figure 1: Detail of the database for the plug selection guide.

Work package 1 was completed satisfactory. Milestone 2 and Deliverable D3 could be delivered with a delay of 6 months.

WP 2 Investigation of Friction

The scope of work package 2 was the development of a new test procedure and the characterising of typical thermoform materials under thermoforming conditions. The determined friction behaviours are the basis for research of a friction model which reflects the detected coherences for using these results in the following work packages.

The first step was a literature research for possible test procedures and documented friction values. An analysis of the thermoforming process shows that the results of the friction measurements depend on the conditions of application. Thermoforming of polymers demands on the friction measurement high testing temperatures, a plane contact between the friction partners, a relatively low loading pressure, different speeds and a translative friction movement. Detailed and extensive discussion was carried out between USTUTT and QUB on the possible ways of friction testing using USTUTT's rotating disc and QUB's moving sled apparatus. The problems in measuring friction properties of polymers especially at elevated temperatures have been investigated broadly. Both universities have also looked into alternative friction testing devices.

To realise all requirements a new test rig was constructed and built at the IKT.

The new test rig was adapted on a rheometer. The test rig has an upper and a lower part. Between these elements the friction partners are placed. The specimen, consisting of the sheet material is fixed on the lower part of the test rig. The plug material has the form of a ring. Therewith, the friction movement converges to a translation movement. The measured parameters are normal force and torque. For application of the normal force at the sheet material the test rig has a pneumatic cylinder, which is located in the upper part of the test rig. The contact time of both surfaces is thereby preferably equal and short. Possible tilting of the friction rig, caused by unevenness of the specimens, is balanced by a suspension of the lower rig part, consisting of a gudgeon with hemispherical top.

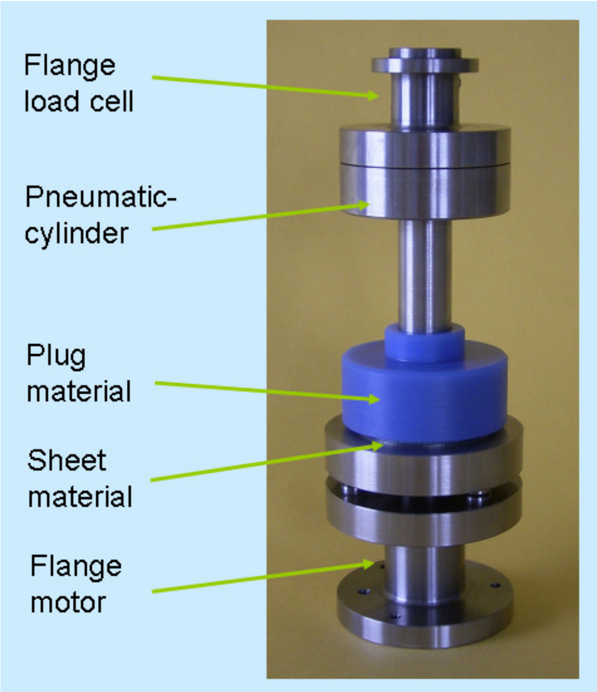


Figure 2: New constructed test rig to determine the friction behaviour of polymer materials under thermoforming conditions

This test rig allowed us to determine the friction coefficient between the two friction partners according to the following interrelationship:

$$\mu = \frac{3T\left((R_i)^2 - (R_o)^2\right)}{2N\left((R_i)^3 - (R_o)^3\right)}$$

Where:

μ = Coefficient of friction

T = Torque

R_i = Inner Diameter

R_o = Outer Diameter

N = Normal Force

For the measurement of the friction properties the project partners supplied the University of Stuttgart with four sheet and four plug materials.

Sheet materials: Polystyrene (PS)
Polypropylene (PP)
Polyethylene terephthalate, amorphous (APET)
Polyvinyl chloride (PVC)

Plug materials: Polyoxymethylene (POM)
Hytac B1X
Hytac WFT
HS Nylon Blue (polyamide, PA)

To characterise the sheet and the plug materials, a DSC analysis was done as well as the adherence temperature of the friction partners were determined. The aim of this analysis was the determination of the crystallization and the melt temperatures of the materials. Polymers change significant their material behaviour by this temperatures. Following an experimental design was developed. The performed test parameters are shown in table 1.

Table 1: Performed test parameter

Temperature [°C]	**Normal force [N]**	**Test speed [mm/s]**
RT	4	50
60	8	100
80	12	150
90		200
100		
bis $T_{adh.}$		

The surface roughness of all specimens was measured for documentation before the friction tests started.

The results of the friction measurements are shown exemplarily for the material combination PS – B1X in Figure 3 and PP – WFT in Figure 4. The diagram shows the influence of temperature. The glass transmission temperature as the area of adherence (melting temperature of PP) is specified, too.

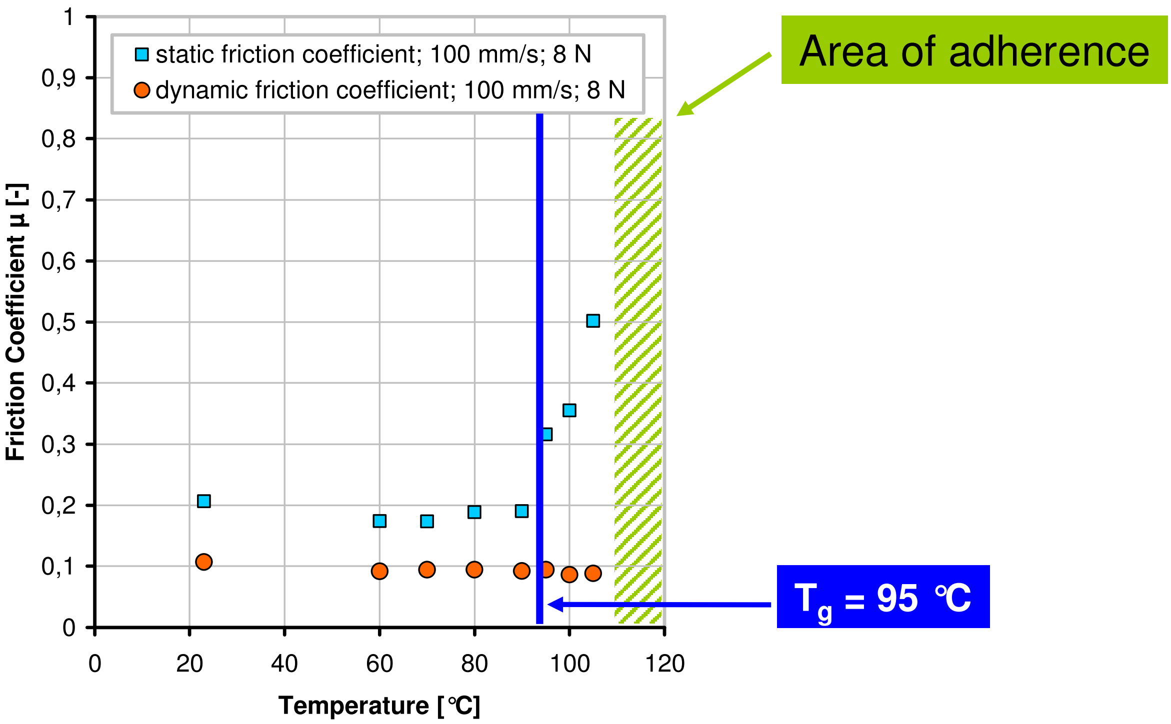


Figure 3: Results of friction measurement, influence of temperature, friction partners PS-B1X

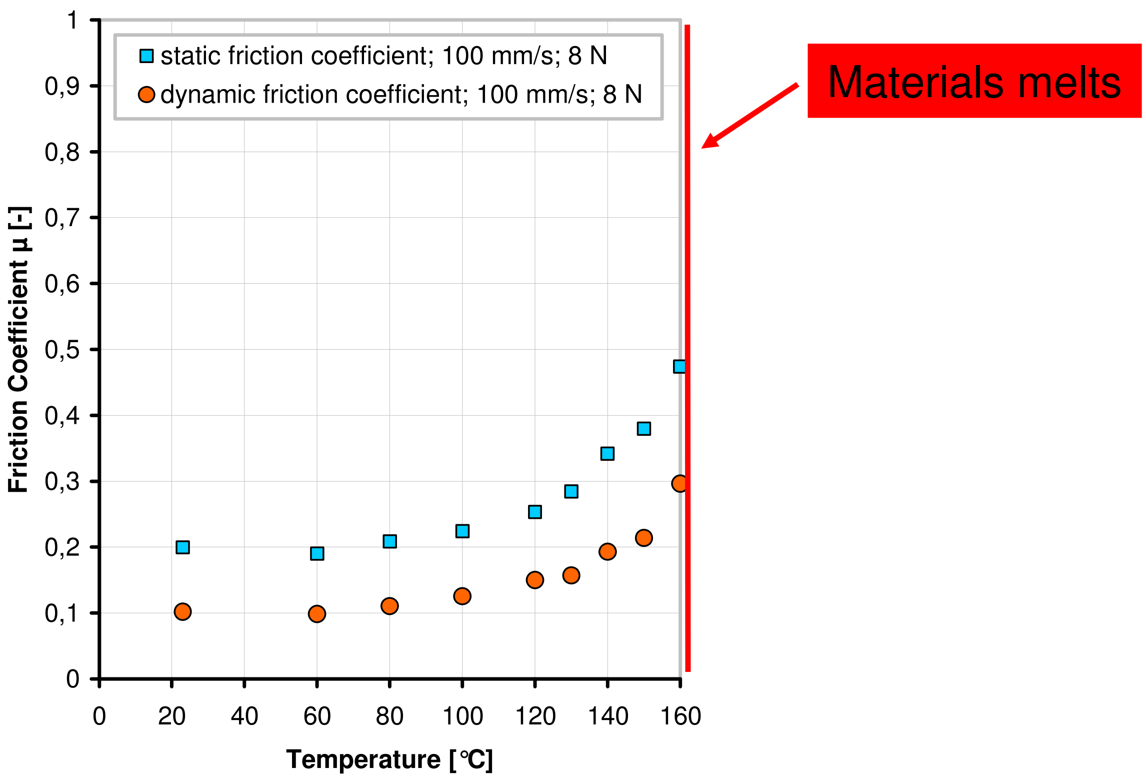


Figure 4: Results of friction measurement, influence of temperature, friction partners PP – WFT

A second focus of the friction measurements is to determine the influence of normal force and the influence of relative speed between the friction partners. Results are exemplary in
Figure 5.

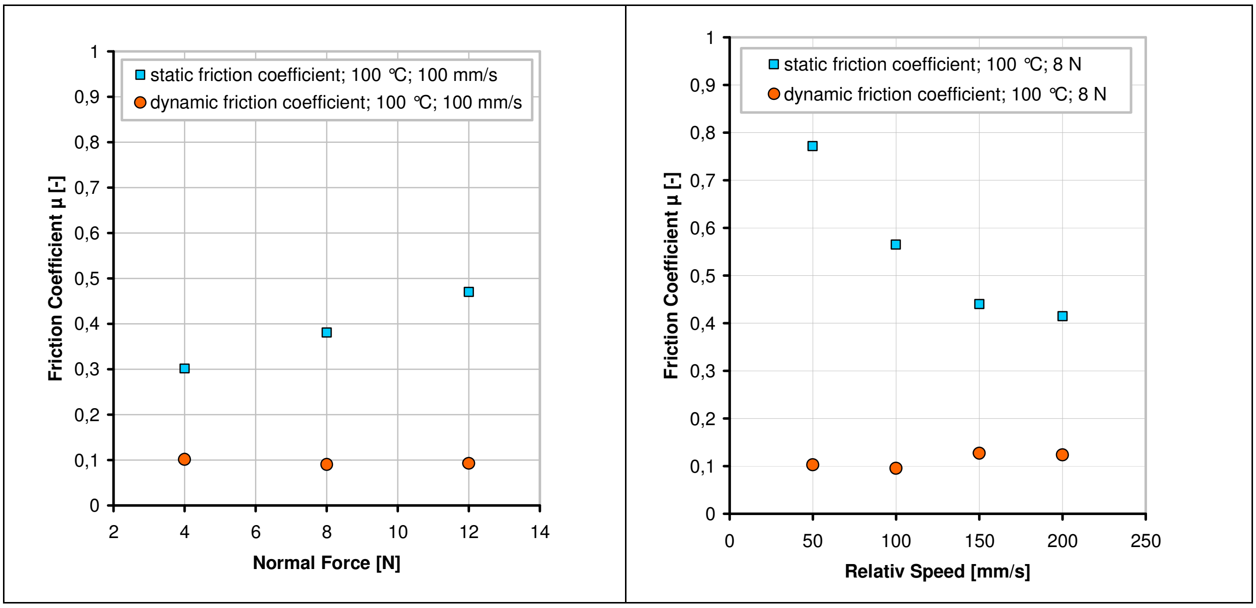


Figure 5: Results of friction measurement, influence of normal force, friction partners APET-WFT (left side) and influence of relative speed, friction partner PVC-POM (right side)

An analysis of the tested specimens by microscope clarifies the reason of the temperature dependency of the tested sheet materials.
Figure 6 (left side) shows sheet material after friction test by temperatures over the glass transition temperature. The plugs sink in the sheet material. Is the plug in movement, it grates on the softer sheet surface. By temperatures close to the adherence temperature or close to the melting temperature the plugs sink deeper in the now soft sheet surface. Is the plug in movement, it brings shear strain inside the sheet material.
Figure 6 (right side) shows a sheet surface, which is damaged by shear strain at 160°C.

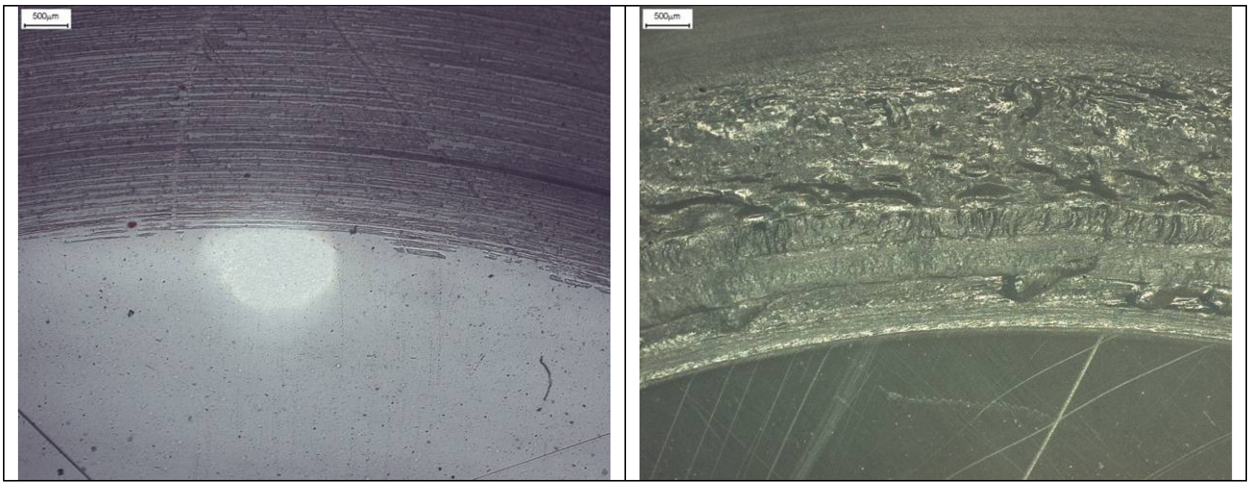


Figure 6: Microscope picture of the sheet surface after friction test. Contact area upper part of the picture. Left picture APET sheet after friction test with WFT, right picture PP sheet after friction test with WFT

Static and dynamic coefficients of friction have also been measured for polymer/plug pairs using QUB's moving sled apparatus. Test temperatures and speeds were varied. The results were compared with measurements from IKT's friction apparatus and demonstrated good correlation between the two techniques. Measurements from the sled technique became increasingly unreliable with increasing temperatures due to the effects of adhesion.

Several friction models have been investigated in published literature and reviews of the handling of friction in polymer process simulations have been done. The approaches vary from simple Coulomb behaviour, which is often assumed, to more complex models that include the effects of contact pressure. At QUB a standard FE simulation was done to model the friction test and evaluate the performance of the different friction models. Then the model/or models that most closely predict the test behaviour have been selected and validated by laboratory trials. The results of this Work package have then been transferred to the T-Sim FE simulation software.

By the end of the project Milestone 3 and deliverable 5 (friction models) could be finished completely.

WP 3 Investigation of Heat Transfer

The Heat transfer test should include the ability to adjust the degree of contact, through variation of contact pressure and surface roughness. Viscoelastic flow of the heated polymer will also need to be considered. A simple experimental rig to measure heat flow during contact between polymeric materials was developed. Various standard methods of measuring heat flow such as guarded and unguarded axial heat flow apparatus have been investigated for their suitability to measure TCC. A visit to National Physical Laboratory (NPL) in London was carried out to find out the method they used to measure TCC between polymer and metal interface.
Based on all the information, an axial heat flow apparatus has been designed and built to measure the TCC between plug and sheet materials in thermoforming. It consists of flux meters, plug and sheet materials, a heater and a cooler. Preliminary measurements showed that heat loss was considerable via convection and radiation in the test rig. This proves to be a problem in measuring TCC for polymers. Hence, additional work had to be carried out.
In order to minimise heat loss via convection, a vacuum chamber was further designed and built to house the apparatus. The vacuum chamber is capable of a vacuum of about 60% (0.6 bars) In addition, all specimens and flux meters were enclosed with aluminium foil and glass cotton to further minimise heat loss via radiation and convection.

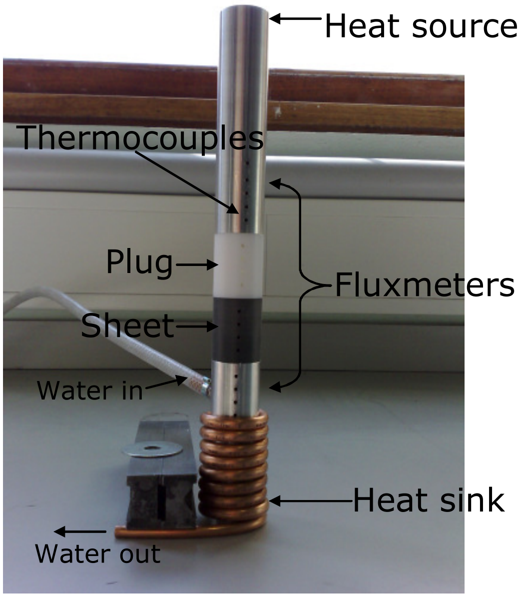
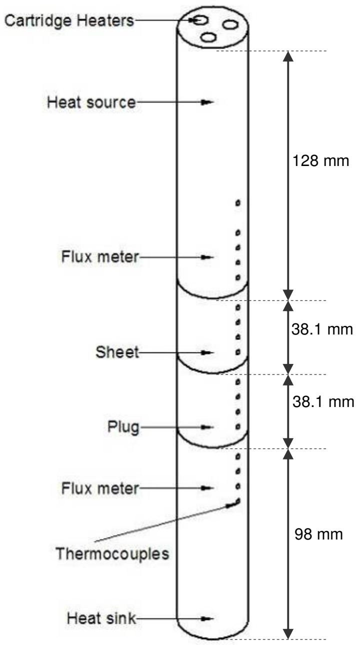


Figure 7: Axial heat flow apparatus to measure the TCC between two polymeric materials



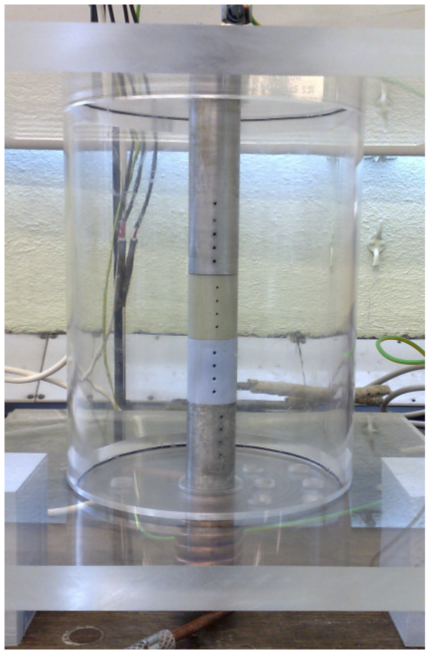


Figure 8: Axial heat flow apparatus with vacuum chamber

Reference measurements were carried out in the vacuum chamber at heater temperature of 160 °C to determine the workability of the vacuum chamber. Test was carried out using two stainless steel 303 (SS303) specimens with thermal conductivity of 16.14 W/m-K. The objective of this test was to measure the thermal conductivity and compare the measured value against the data sheet value.
The thermal conductivity was measured to be 16.33 W/m-K with a standard deviation of 0.41. The percentage error from data sheet value was about 1%. This proves that the rig is in working order.

The TCC between the SS303 was also calculated. One of the measured values gave a TCC value of 2550 W/m^2-K. Values reported previously for polished SS304 [2] was about 2500 W/m^2-K.
Input from this work package was needed in work package 4 and 5 but the results can be subsequently implemented in these models.
The milestone (M4 –Heat flow relationships established) and deliverable (D5 – Report on thermal properties, proposal of heat flow models) were successfully completed within this work package.

WP 4 Investigation of Plug Contact

The plug contact is a further main research issue in the plugin project. We used the thermoforming material characterisation rig to conduct experiments where plug samples are forced into sheet samples under isothermal conditions. The resulting plugged shapes have been frozen and their wall thickness distributions recorded. From this and high speed video imaging of the actual deformation process, the position and degree of slip have been determined. This behaviour was related to the chosen friction models and these have been refined if necessary. Further tests examined the effects of temperature and plugging speed on the results.
The company CGP designed a specialised plug which enabled us to investigate the material distribution in dependency of the friction. Therefore three different plug shapes have been designed showed in the figures below:

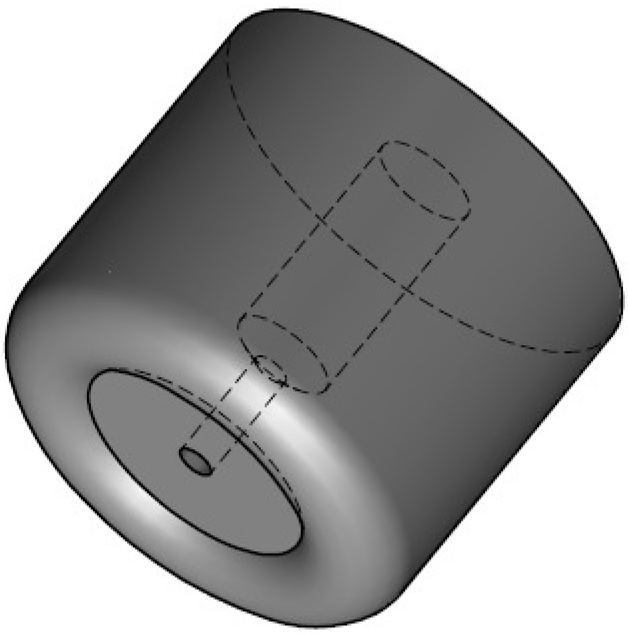


Figure 9: 8mm „fat“-Plug

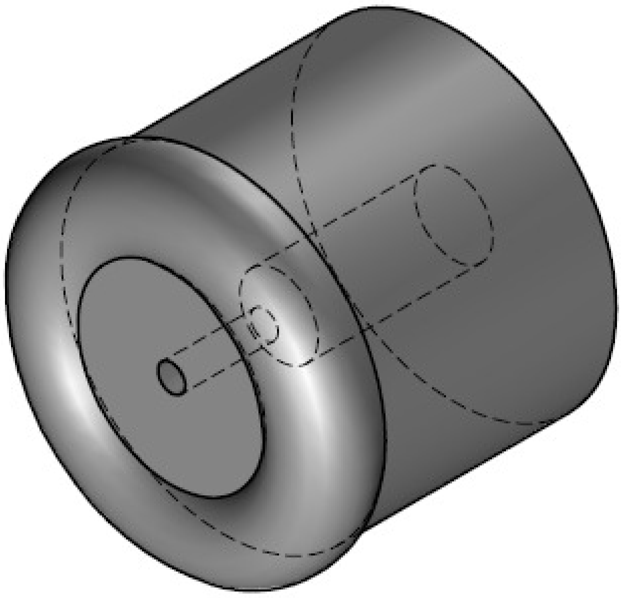


Figure 10: 8mm „standard“ Plug

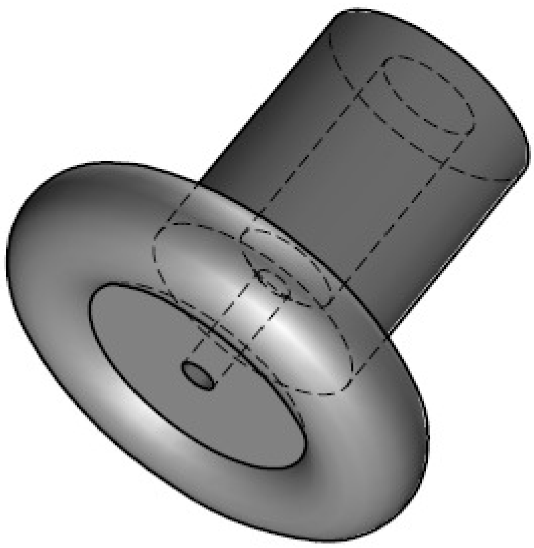


Figure 11: 8mm „slim“ Plug

The tests have been done at Queens University of Belfast and IKT University Stuttgart. All results of this work package can be found in Deliverable D7 “Report on plugging effect”. Milestone 5 could be achieved successfully.

WP 5 Modelling of Plug Contact

The adaptation of software and modelling of the plug contact was completed successfully. The first inputs form work packages 2, 3 and 4 have been available at the end of month 18. Now all these results and experiences have been implemented into the T-Sim software. The programming and testing of the software had a delay of 3 month due to the delay of WP 3, WP 5. The extension of the project saved us to complete the whole programming of the algorithms. Comparison calculations showed at the end of the project that we could improve the matching of the simulation results by the new plug contact models. Milestone 6 was achieved successfully.

WP 6 Thermoforming Trials

During reporting period 1 the preparation for this work package has already started. The work in this work package focused on understanding the change in material wall thickness distribution between the plugging and blowing stages of the thermoforming process. A specially designed plug set was used for these investigations, which was provided by CGP. Task 6.1 consisted of several trials run using the existing plug force measurement system in QUB. The trials were run on PP sheet material and for a plug shape. Initial trials were run using the plug linear displacement sensor which could determine the position of the plug during the plugging stroke. Sheet material was provided by Cifra and plug material was provided by CGP. The knowledge gained from the starting system was then used when continuing onto the development of the instrumented plug system. The picture below shows the plug used for this trials:

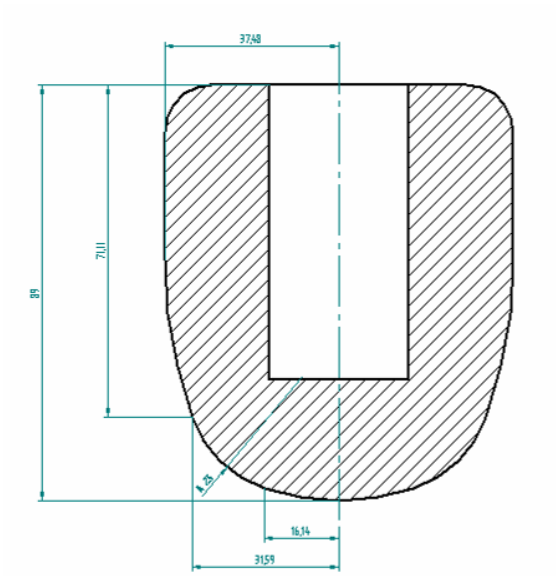


Figure 12: Section View of the Plug Used During the Initial Trials.

The following figures show the test mould at Jacob. In addition to that a second mould was built at Holfeld Plastics Ltd. This gave us a wider spectrum of results which have been compared to simulation results generated in work package 4 and 5.

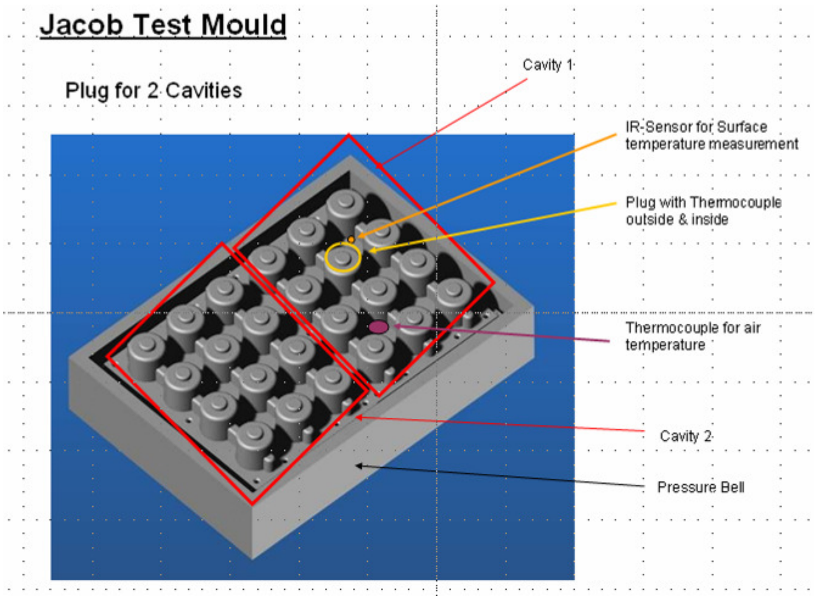


Figure 13: Drawing of the plug of the test mould at Jacob Kunststofftechnik

In addition to the sensors in the plug have been implemented a sensor for the plug movement, vacuum, pressure, sheet temperature, tool position and forming air temperature. All these values have been recorded and gave us an improved understanding of the forming process.

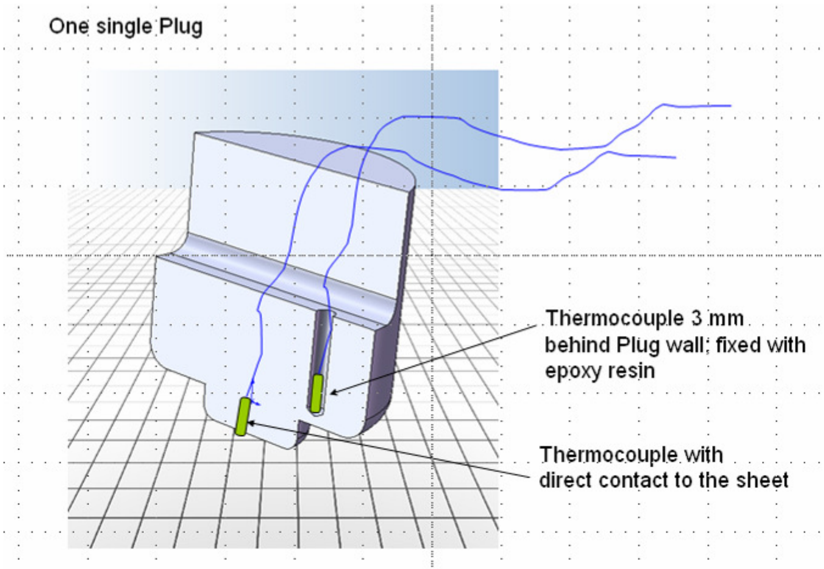


Figure 14: Drawing of a single plug with sensors inside

For the trials at Holfeld the tool was designed in close work with QUB. The last CAD draft is shown on the next figure:

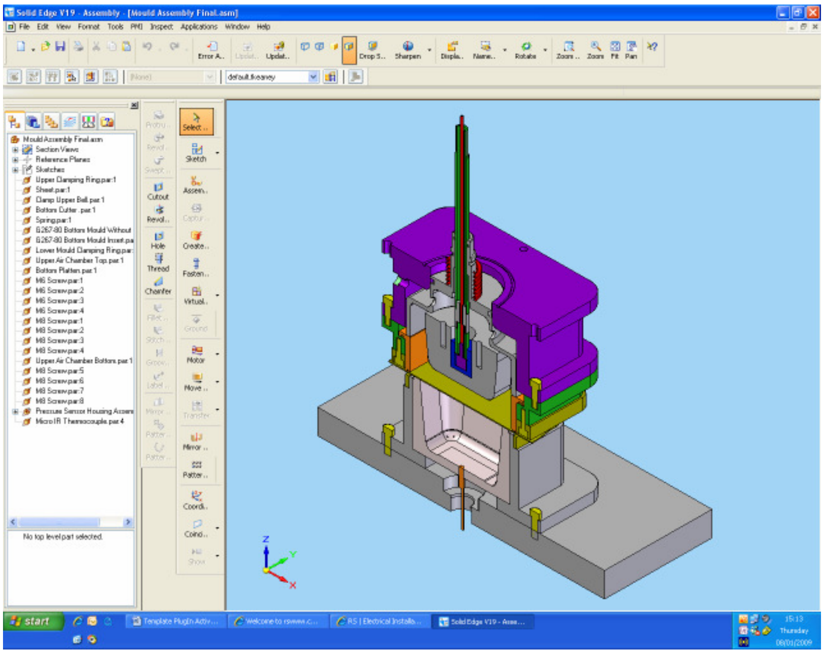


Figure 15: Final CAD Section View of the Tool Design

After finalising the laboratory test and defining the necessary test equipment the test tool was build up at Holfeld.

Figure 16: Upper Tool for Trials

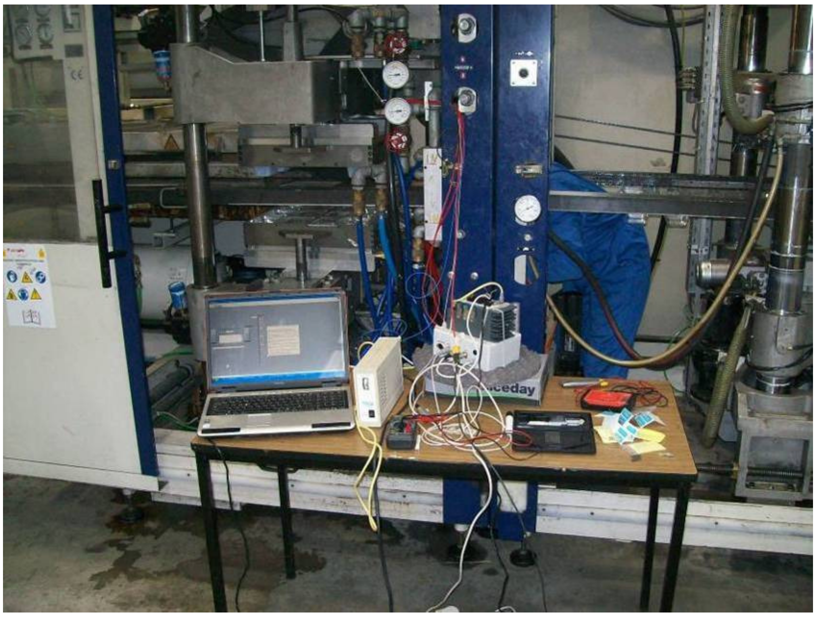


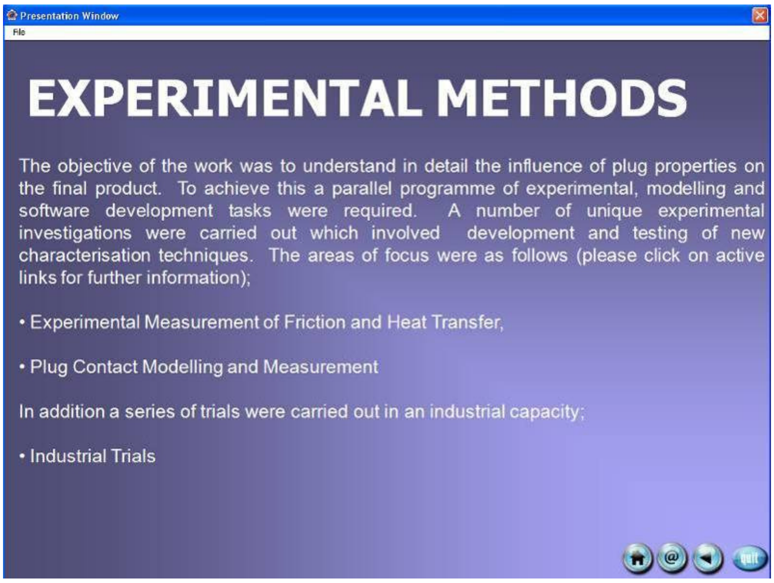
Figure 17: Data Logging System beside the Machine with Assistance from the Maintenance Department during Tool Fitting.

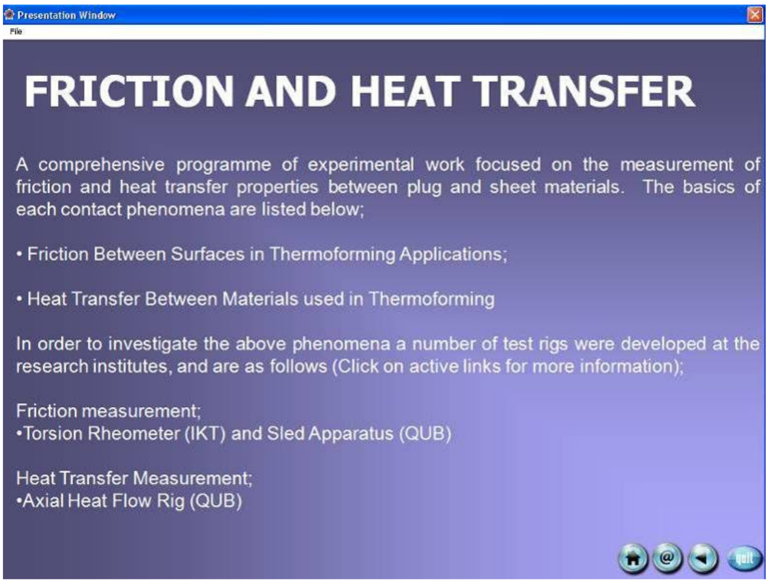
These results have been implemented into the simulation software to optimise the algorithm of the software. The software was set up with the appropriate material models and mould and plug geometries so that simulations of each of the thermoforming trials could be carried out. We compared the practical and simulation results and, where necessary, adjusted or implemented changes to the models. So milestone 7 was also completed successfully.

WP 7 Development of the Expert System

The technical data generated as a result of the literature searches and experimental programmes conducted in WPs 2, 3 & 4 were gathered together and have been presented as databases within the Expert System program. This is illustrated in the screenshot of the working database section shown below.

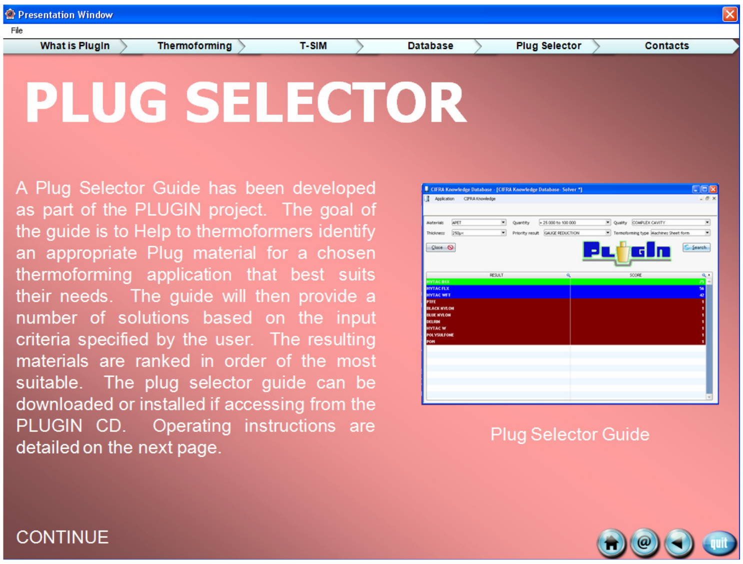
General information on the PlugIn project, the consortium members and the major outcomes from the various work packages have also been included in the database as shown in the screenshots below.





As well as the Plug Selector expert system, the final package contains a suite of databases covering the basic properties of available sheet and plug materials, detailed technical information on plug contact phenomena and testing techniques (WP2&3) and practical advice on thermoforming.

This task was completed throughout year 2 of the project and it largely involved the gathering together of the most important results from the work. The work package was lead by QUB with support by all members of the project team. Visits were made to CIFRA in France to discuss the plug selection guide from work package 1 and consultations were held in Belfast with staff from CGP on the main results from the experimental programmes (WPs 2, 3 & 4). A detailed study was undertaken of the software available for presentation of the PlugIn results. Demo versions of several software packages were obtained and evaluated and after detailed consultation with the consortium members it was decided to select the package Adobe Authorware 7 because of its ease of use and ability to provide a user friendly interface. Time was then spent learning to program with the software and a series of prototype programs were developed and made available to the consortium members for evaluation. Through feedback and testing the range and complexity of the program was gradually expanded. A version of the plug selector (WP1) was included in the Expert System and this is illustrated in the screenshot from the program shown below.



The accumulated reservoir of knowledge from work packages 1-6 and the simulation trials (above) will be sorted and evaluated to form rules regarding the selection and operation of plug materials for thermoforming. Through an iterative process of consultation and feedback with all of the SME partners, the rule base was refined to form the final expert system.
Virtual trials of the experiments completed in WP6 were completed using the T-Sim package by Accuform. The results showed good correlation with the experimental measurements and demonstrated the improved predictive capability of the software as a result of the project. For a number of cases the software provided new optimised tool geometries which were then implemented in production trials by the thermoforming companies (Jacob and Holfeld). These trials were carried out in the final few weeks of the project and have shown real improvements in production.
The validated simulation software developed under WP6 will be used to carry out virtual production trials, examining a much wider range of plug/sheet combinations and process settings than would be feasible in the companies given the available timescale. Each of the industrial thermoformers (Holfeld and Jacob) are able to access the T-Sim simulation package for this work and Accuform will provide technical support. Where possible the results have been compared to actual thermoforming tests (WP6), which were carried out by each of the industrial partners in tandem with the simulation work.

The final Expert system is implemented within a user-friendly web-based interface, which is password protected and accessible only by the partners. It includes links to all of the partners' websites and it will promote horizontal and vertical integration of their activities. The system is transparent and will genuinely enable each of the partners to equally share the results of the programme.
In this task feedback from the consortium members on the prototype expert systems was used to create a final working program. Particular attention was given to making the software as simple and easy to use as possible. Using the user friendly features of the Authorware package the expert system has been provided on a bootable and stand-alone CD. This has readily enabled its wide dissemination amongst the consortium members and it gives the consortium the option of making the software more widely available in the future. The same software has also been uploaded to the project web

page and it is assessable to registered users through a password. Milestone 8 could be achieved with a small delay of 2 months successfully.

WP 8 Dissemination

Several activities to disseminate the project and its results have been undertaken during the complete duration of the project. The activities are listed below:

Planned Dates	Type	Type of Audience	Countries addressed	Size of audience	Partner involved
	Web-site	general	all	N/A	Jacob, QUB
17.09.2007	Conference	Industry	USA	500	CGP
October 2007	Exhibition K-Show	Industry	Europe	>1.000	Accuform, CIFRA, CGP
November 2007	Project Flyer	General	Europe	N/A	Jacob
November 2007	Project Poster	general	Europe	N/A	Jacob
04.04.2008	6th European thermoforming Conference	Industry	Europe	> 1000	Jacob USTUTT
24.-30.04.2008	Exhibition “Interpack”	Industry	Europe	> 1.000	Cifra CGP Accuform
23.-25.04.2008	Paper “ESA Form”	Industry	Europe		QUB
24.06.2008	Paper + poster on PPS (Italy)	General	Europe	> 1.000	QUB
22.09.2008	Presentation at IKT	Research	Germany	200	USTTUT
20.-23.09.2008	18th thermoforming conference USA	Industry	USA	> 1.000	CGP
15.10.2008	Exhibition “FAKUMA”	Industry	Europe	> 1.000	USTUTT
17.-21.11.2008	Exhibition “Emballage” France	Industry	Europe	> 1.000	Cifra
24.-29.01.2009	Exhibition “Interplastica” Moscow	Industry	Europe	> 1.000	CGP
18.-19.03.2009	Presentation at IKT	Research	Germany	200	USTUTT
March 2009	Exhibition “Plast”, Italy	Industry	Italy	> 1.000	CGP

April 2009	Exhibition “Eurotec”, France	Industry	Europe	> 1.000	USTUTT CGP
June 2009	Exhibition “RussoPack”	Industry	Russia	> 1.000	CGP

All other activities are described in Deliverable D13 “Plan for using and disseminating knowledge”.

List of Deliverables

Deliverable no.	Deliverable name	Workpackage no.	Date due	Actual/Forecast delivery date	Estimated indicative person month	Used indicative person month	Lead contractor
D1	Website	8	January 2007	January 2007	1	1,5	Jacob
D2	Project report month 6	0	March 2007	March 2007	N/A	N/A	Jacob
D2	Project report month 12	0	September 2007	October 2007	N/A	N/A	Jacob
D2	Project report month 18	0	March 2008	September 2008	N/A	N/A	Jacob
D2	Project report month 24	0	September 2008	April 2009	N/A	N/A	Jacob
D3	Knowledge-based plug selection guide	1	March 2007	March 2007	19	19	Cifra
D4	Report on frictional properties	2	September 2007	October 2007	N/A	N/A	USTUTT
D5	Report on thermal properties	3	September 2007	June 2008	N/A	N/A	QUB
D6	Plan for using and disseminating knowledge - draft version	8	September 2007	October 2007	N/A	N/A	Jacob
D7	Report on plugging effects	4	March 2008	January 2009	N/A	N/A	CGP
D8	Models for sheet polymer materials and plugging	5	March 2008	January 2009	22	28	Accuform
D9	Instrumented plug system	6	June 2008	September 2008	7	10	Holfeld
D10	Knowledge of industrial thermoforming process	6	September 2008	January 2009	17	18	Holfeld
D11	Web-based expert system	7	September 2008	January 2009	9	14	QUB
D12	Scientific Papers	8	September 2008	October 2008	N/A	N/A	Jacob
D13	Plan for using and disseminating knowledge - final version	8	September 2008	April 2009	N/A	N/A	Jacob

List of Milestones

Milestone No	Milestone Name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
M1	Annual report	0 - Project Management	September 2007	October 2007	Jacob
M2	Define Scope of investigation	1 - Knowledge base acquisition	March 2007	March 2007	Cifra
M3	Friction relationships established	2 - Investigation of friction	September 2007	October 2007	USTUTT
M4	Heat flow relationships established	3 - Experimental measurement of heat transfer	September 2007	April 2008	QUB
M5	Effects of plug contact established	4 - Investigation of plug contact	March 2008	November 2008	CGP
M6	Development of plugging step simulation	5 - Modelling of plug contact	March 2008	November 2008	Accuform
M7	Practical plug operating conditions established	6 - Thermoforming trials	July 2008	November 2008	Holfeld
M8	User friendly plug selector expert system	7 - Expert system	September 2008	November 2008	QUB

Section 3 – Consortium management

There has been one change in the steering committee: New chairman was elected due to the departure of Mr. Henrik Albertsen. He was replaced by Mr. Marco Jungmeier from Jacob Kunststofftechnik GmbH.

Steering Committee:

Chairman: Mr. Marco Jungmeier
Representative: Mrs Christina Härter, USTUTT
Michel Py, CIFRA
Noel Tessier, CGP
Dr. Peter Martin, QUB
Dr. Karel Kouba, Accuform
Fergus McNamee, Holfeld
IPR Manager: Noel Tessier, CGP
Dissemination Manager: Marco Jungmeier, Jacob

Meetings

During the first 12 month 3 project meetings were organized by the partners on site:

- 10. and 11. October 2006: Kick Off at Jacob, Germany
- 18. and 19. April 2007: 6 Month meeting at CGP and CIFRA, France
- 18. and 19. October 2007: 12 month meeting at IKT, Germany
- 09. and 10. April 2008: 18 month meeting at QUB, Belfast
- 17. and 18. September 2008: 24 months meeting at Holfeld, Ireland

Also several intermediate Meetings were arranged:

- 27. June 2007: Project meeting Frankfurt, Germany
- 19. September 2007: Project meeting, Belfast, Northern Ireland
- 30.06. – 02.07.2008: Trials at Jacob incl. meeting with involved Partners
- 11. – 12.09.2008: Trials at Jacob incl. meeting with involved Partners
- 05. – 07.11.2008: Trials at Jacob incl. meeting with involved Partners
- 11. – 12.11.2008: Trials at Holfeld incl. meeting with involved Partners

Accuform is responsible for supply of simulation software in its current version, software training and support. The partners used the software within the project according to the work package descriptions. Accuform supplied the partners with updates as these became available during the project. Main actions have been:

a. Supply and distribution of software
b. Installation and start-up support
c. Generating and supply of hardware keys and software keys
d. Software training
e. Hotline support
f. Distributing of updated software

The personnel effort is not directly related to RTD activities, and neither to the co-ordination of the project. Therefore, it is part of the project management work package, but is not funded at 100%.

Section 4 – Other Issues

The collaboration of RTD performers like the Queens University of Belfast and the University of Stuttgart and the SMEs in this project was one of the most important issues to finalise “PlugIn” successfully.
All partners agreed that this was right from the beginning a “team-work feeling” (cit. technician of Jacob Kunststofftechnik). The support of the RTDs was 100% satisfactory. During the project several visits of RTDs at SMEs and vice versa led to a very close collaboration also beyond the PlugIn project. So different other problems the companies had could be discussed and solved with the people from the Universities.
Also in completely different business units contacts could be forged, which still are existing. A case in point is the support of the universities with material by the SMEs. As a return service the SMEs get material analysis such as microscopy inspection for free.