D6.4 - PicknPack report

Individual Prototypes

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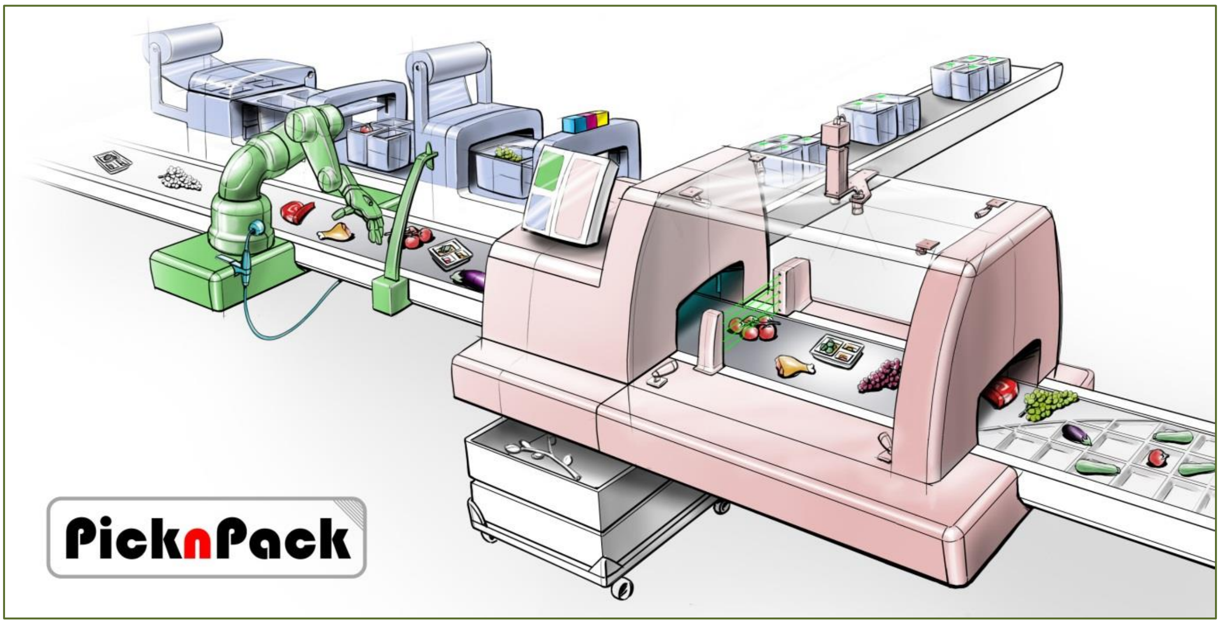
10/31/2013



Flexible robotic systems for automated adaptive packaging of fresh and processed food products

SEVENTH FRAMEWORK PROGRAMME

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Dissemination level		
PU	Public	X
PR	Restricted to other programme participants (including the EC Services)	
RE	Restricted to a group specified by the consortium (including the EC Services)	
CO	Confidential, only for members of the consortium (including the EC Services)	

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1 Introduction

This work package aims to develop an innovative adaptive packaging system able to efficiently produce food packaging in small batches of 1-1000 packed food products.

D6.4 is the documentation of following prototypes performed before month 21 (1 July 2014):

- Digital mould
- Sealing and cutting system
- Integrity system
- Flexible heating system
- Decoration system

2 Digital mould

WP6 has been working on several flexible mould systems:

2.1 Pin mould - In-line digital mould

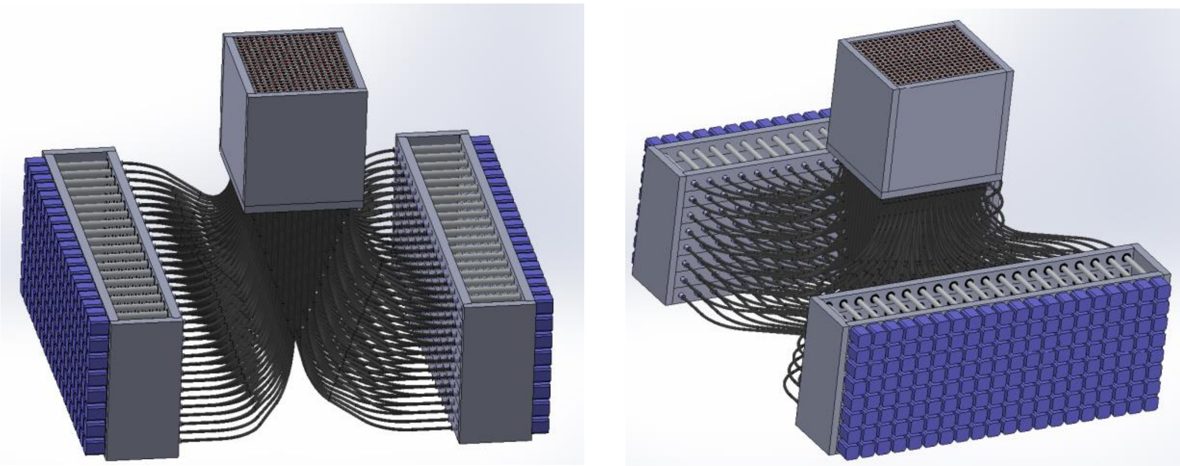


Figure 1 – Digital mould with many pins operated with cables and servo motors

The mould has a number of pins able to move up and down. We produced three fixed prototypes with different resolutions and tested the performance in a packaging machine. We noted resolution and quality is a trade-off between price and quality.

In a mould of 150x200 mm, we need following:

Resolution in mm	Number of pins
10 mm	300
6 mm	833
5 mm	1,200
4 mm	1,875
3 mm	3,333
2 mm	7,500

As we realised such a system will be expensive, we are working on another idea.

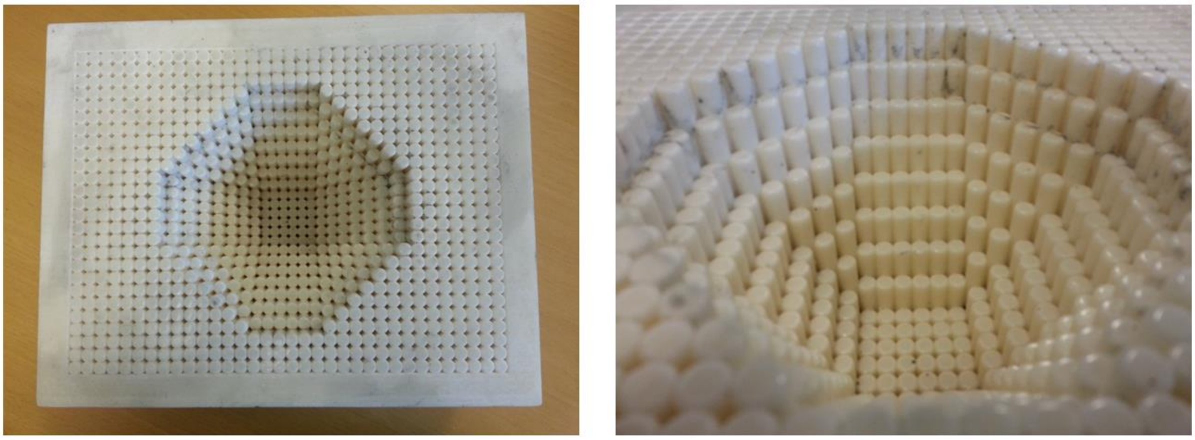


Figure 2 Mould with 5 mm pins

Figure 3 Tray produced in a mould with 5 mm pins

The quality of a tray made in a mould with 5 mm pins is not acceptable. In order to upgrade quality either the pins must be less and/or a flexible layer between the pins and the plastic shall result in a smooth surface.

2.2 Off-line digital mould

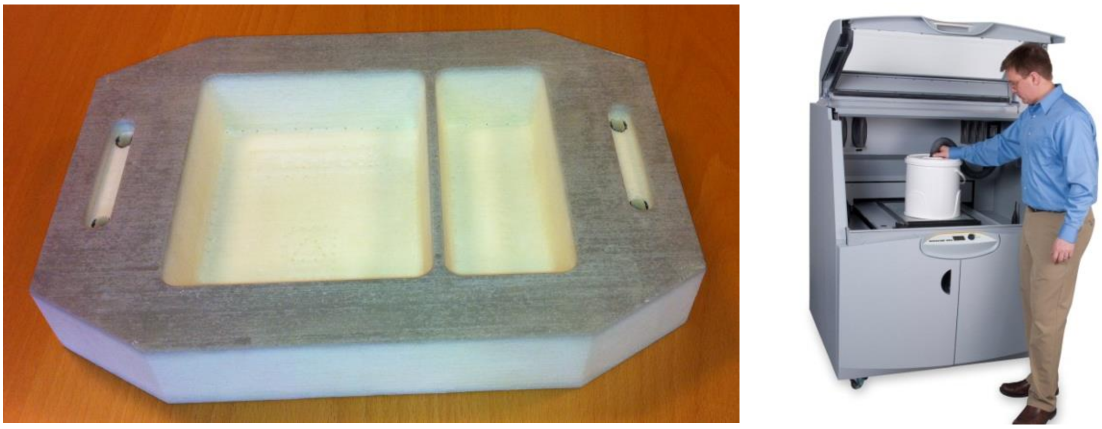


Figure 4 – Digital produced plaster moulds produced off-line

Based on a standard 3-D printer for prototypes you can produce moulds which are able to produce about 1-3,000 trays and with a surface treatment, which is also more smooth.

The moulds will in the off-line system be produced off-line and shall be mounted on the thermo-forming-machine before the production. We need to develop an extreme fast changing system.

Moulds can be implemented in a standard thermo-vacuum-forming machine.

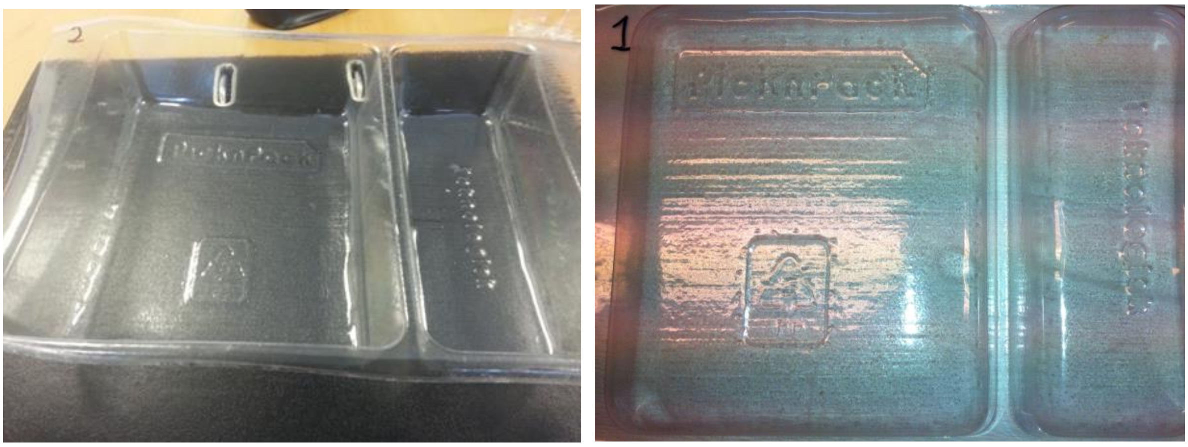


Figure 5 Tray made in a plaster mould from a 3-D printer

The plaster/concrete/ceramic/aluminium technology produces flexible moulds able to be used for more than 1,000 items in a very high quality.

Lead time for these technologies is 4-10 hours for 3-D plaster technology and 1-2 hours for CNC milling of concrete moulds. However, 3-D modelling is in a fast development these years and is expected to be more efficient, fast and inexpensive within a few years.

2.3 Brick mould system

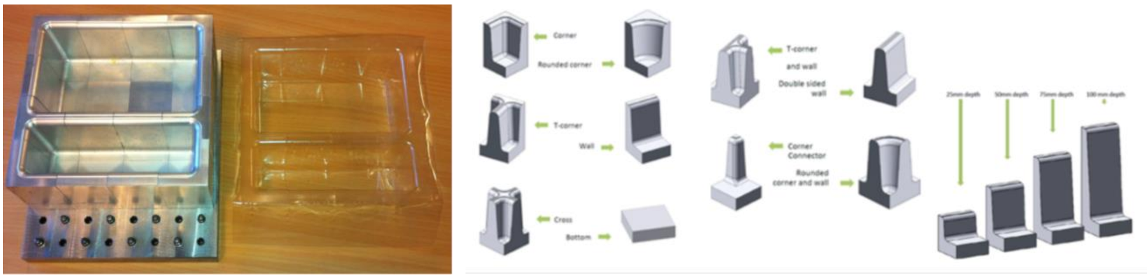


Figure 6 – Prototype of a brick mould

WP6 has already designed and produced a prototype of an innovative mould system. The system produces excellent trays as seen on the photo in figure 7. WP6 hope to create a fast system with only few minutes lead-time between design and production.

WP6 has selected to use the brick mould system in PicknPack as it stands out as the best system after many tests with many other prototypes. WP6 had some discussions about using the word digital mould for the brick mould system. It was decided to make this system digital as follows:

1. The design is done with bricks because this is the most natural way to work in the food industry
2. The design is scanned digital either using marking on the bricks or vision
3. The data from the mould is now digital and can be converted to inputs for all other processes in PicknPack.
4. As an extra option, WP6 is now evaluating if we are going to build a simple machine to build the mould out of digital data. Most likely WP6 will document such a solution but as this machine only has a little impact in demonstration, the machine is most likely not to be built.

After following interpretation of the word digital, we have decided that the brick mould system is a digital mould.

In order to demonstrate the digital nature of the Flexible Brick Mould solution, let us, first of all, refer to the basic definitions:

Digital *- relating to or using signals or information represented by discrete values (digits) of a physical quantity. (*Oxford American Dictionary*)*

Digitize *- Convert (pictures or sound) into a digital form that can be processed by a computer. (*Oxford American Dictionary*)*

The Table below presents physical quantities that characterized the colour image digitized into digital bitmap computer files. These quantities are put in a direct correspondence with the quantities of the Flexible Brick Mould digitized into set of bricks, exactly as a colour image is digitized into a set of pixels.

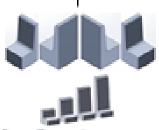
Color image (RGB)– digital bitmap file	Flexible Brick Mold – digital mold implementation
Pixels and their digitized parameters	Bricks and their digitized parameters
1. X position → 2. Y position ↑ 3. R (red color) ● 4. G (green color) ● 5. B (blue color) ●	1. X position → 2. Y position ↑ 3. Orientation around axis  4. Brick height 5. Brick shape 

Figure 7 – Digital nature of the flexible brick mould

Since the digital nature of a computer bitmap file is beyond any doubt, it is possible to conclude that the Flexible Brick Mould is digitised or simply is a digital object.

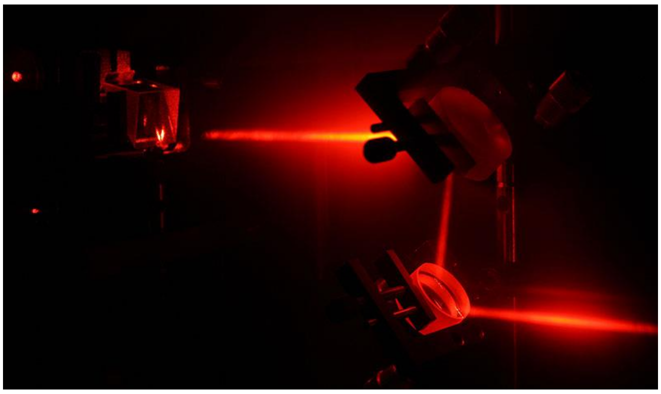
Conclusions

As WP6 evaluate the Flexible Brick Mould as a digital solution, WP6 has decided to focus the development on the Flexible Brick Mould system, as this system fulfil the requirements of the food industry best.

WP6 has given up working more with the off-line digital mould system, as these systems are not very innovative nor fulfil the requirements. However, WP6 is still evaluating if the pin mould solution is also going to be demonstrated. If WP6 select to demonstrate the pin mould system this will be done either next to the demonstration site or partly in the in-line mould of the demonstration unit.

3 Flexible sealing and cutting

The laser welder and cutter will be placed in the end of the packaging line after the trays are filled and after the top film is applied. The top and the under film are mechanical locked together at the same level under the laser. The laser will veld and cut by a controllable mirror system.



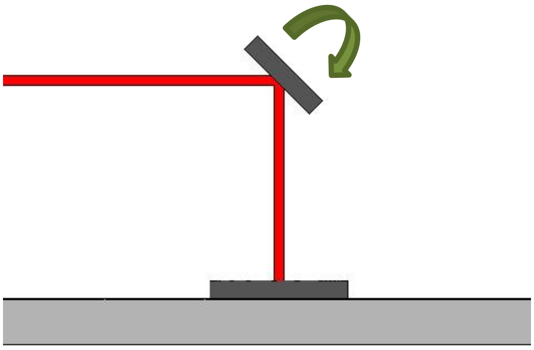


Figure 8 – The laser with controllable mirror system

The laser must be able to follow this stop-go situation and process as follows:

1. Welding the two films together demand that the movement is stopped
2. Perforation of the packaging for MAP can be done both in stop and go
3. Cutting the trays out from the films can be done both in stop and in go after the top film is cut

The cutting system has a demand, that cutting points have to have a distance between top and bottom films. The mould for the tray sides need a little ditch/groove to create this distance.

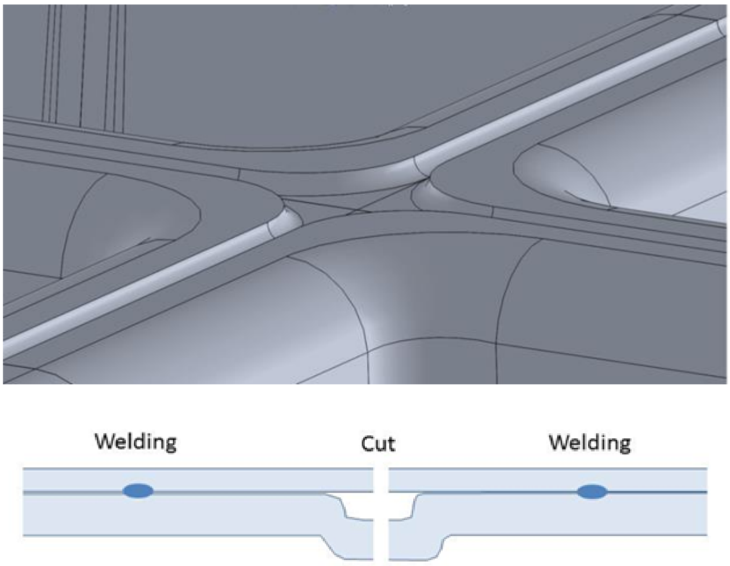


Figure 9 – Ditches or grooves in brick moulds create a distance for cutting

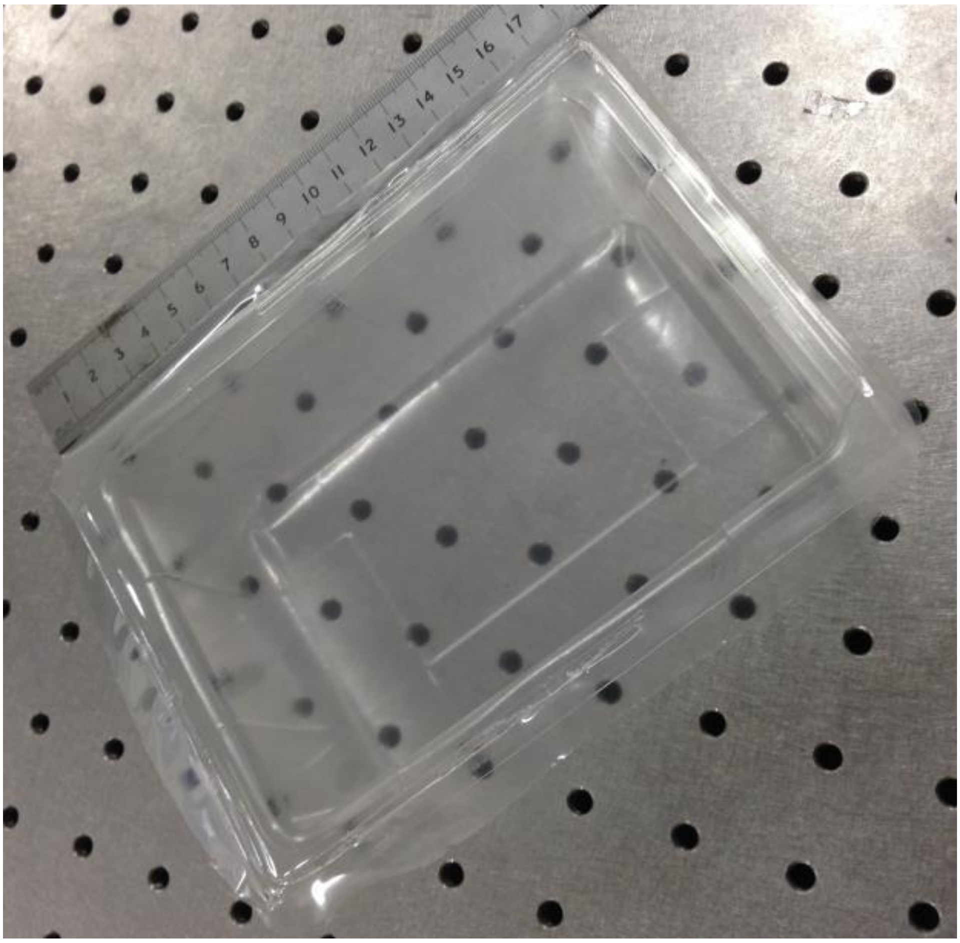


Figure 10 – Tray made in the brick mould that is laser welded and cut

Trays made on the brick mould were tested on a prototype build by University of Lincoln with success.

The experiences from these tests indicate a problem with having time for both sealing and cutting in the stop time. It is important that the under and over web is perfectly indexed under sealing which need a stop. If the over web is cut under sealing it will be possible to cut under the creeping movement.

The experiments also indicate that the sealing process will be the bottleneck to reduce the stop time.

4 Integrity system

The integrity checking system is based on a hyper spectral imaging set-up. Two different detectors were used, being a VIS-NIR system (400-1000 nm) and a SWIR system (1000-2500 nm). Tests were performed on different package sizes in order to study image quality and potential issues with reflection. Illumination, which is provided using classical halogen sources, was optimized using ray tracing software so to minimize reflection issues, and to make illumination homogenous. Figures 11 and 22 show the set-up and a typical image of an empty package at a given wavelength (900 nm).

Measurements show that imaging is promising, but future tests on the final laser seal should now be performed to calculate accuracies. Seen the fact that laser seals will be small [smaller than the conductive seals we have used so far], resolution of the system might be a bottleneck, and will be investigated.

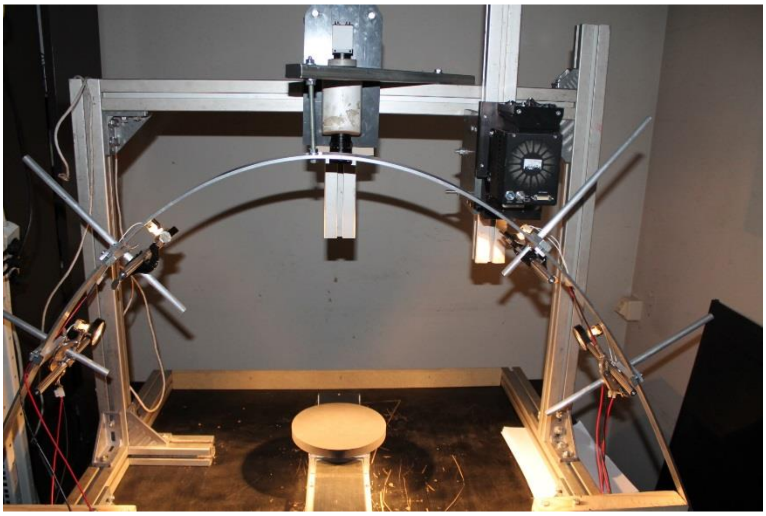


Figure 11 - Hyper spectral set-up used for the measurements.

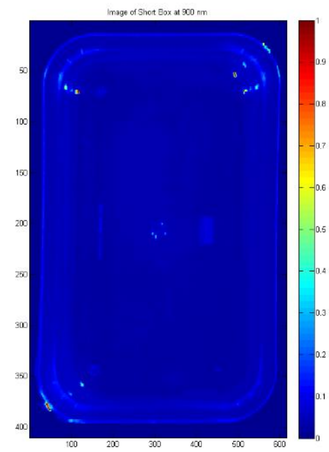


Figure 12 - Image of an empty package at 900 nm.

5 Flexible heating system

5.1 Technical introduction

This text for flexible heating system is based on PicknPack report: *Laboratory study of inkjet printed electro-conductive elements of active packaging for microwaveable ready meals*.

Thin metallic reflectors and susceptors of microwave electromagnetic radiation (or simply microwaves) are inalienable elements of modern active packaging solutions for microwaveable foods. The effects of reflection and susception of microwaves in thin metal objects are controlled by their electrical conductivity (or resistance), thickness, and radiation frequency. Obviously, the mutual relations are as follows:

- The higher the frequency, the better the reflection and the worse the susception
- The thicker the sheet or the film of the metal, the better the reflection and the worse the susception
- The higher the conductivity, the better the reflection and the worse the susception

Thus, for a fixed frequency, the criteria of a thin metal layer transformation to the total reflector or the optimal susceptor (=optimal absorber of electromagnetic energy) can be expressed in terms of both *thickness* and the so-called *surface (sheet) electrical resistance*. This last is the resistance-to-thickness ratio for this layer that is measured in Ohms/square or Ω/□). These criteria are of course physically equivalent, but implemented differentially on manufacture and application of reflectors and susceptors for active microwave packaging:

Usage of the thickness criterion is based upon comparison of the layer thickness with the so-called *skin depth*. The skin depth is the depth below the surface of the conductor at which the eddy-current density caused by alternating electromagnetic field falls to 1/e (about 0.37) of its value at the surface. The skin depth depends on the resistance and frequency (the higher the resistance, the larger the skin depth; however, the higher the frequency, the smaller the skin depth). The skin depths of some bulk metals at 2.45 GHz is as follows:

- Silver (smallest of all materials) – 0.33 µm
- Aluminium – 0.86 µm
- Stainless steel (304) – 4.3 µm
- Titanium – 3.3 µm

Obviously, silver and aluminium are the best candidates for implementation of active packaging since they allow higher flexibility of the layer. Whereas cost-effectiveness dictates the usage of aluminium. Thus, in order to become a total reflector, the layer thickness must exceed 2.7 of the skin depth, or approximately triple skin depth. The layer of bulk aluminium must therefore be approximately 3-µm-thick to become a total reflector of 2.45 GHz microwaves, while the silver layer thickness needs to be just 1 μm. Obviously, the thickness of the susceptor must be much less than the skin depth. Experiments show that typical thickness of aluminium susceptor layer providing for 50 % absorption is of the order of 1 nm.

5.2 Laboratory studies

The only metallic inks that are currently available commercially and allow processing under conditions, which are compatible with polymer films on which the metal has to be printed, are silver inks. Thus, the deposited material is a porous silver film formed on the plastic film or tray after sintering of the inks. Its electrical conductivity is significantly different from the conductivity of the bulk silver and depends on many factors, which are difficult to control, for example, temperature and roughness of the sealing film. Therefore, the conductivity of the printed and sintered coating should be measured in order to control its capability to reflect 2.45-GHz microwaves.

The depositions made for proof-of-concept studies of the PicknPack concept for packaging of microwaveable ready meals were carried out using 200-μm-thick polyethylene-terephthalate (PET) substrate films, which were kept at the process temperature of 60° C. In order to reach the necessary conductivity/thickness of the deposited silver layer, the printing was carried out in several passes of the printing head (actually, from 1 to 9 passes). The printing resolution varied from 120 to 360 dpi. The inks were sintered at 150° C during approx. 30 min.

Figure 13 - Inkjet printed silver coating on PET film installed in the experimental cell for the validation of its reflective power in a microwave oven

<u>The coating that demonstrated ideal reflective behaviour in the 'microwave oven' tests was deposited for 9 passes with 360 dpi resolution.</u> The water inside the cell covered with this sample remained cold after at least 10 min. of microwaving, and the electrical breakdown did not occur. For

comparison, the water in the cell without coated film on the top reached the boiling temperature after 10 min.

The sample that already demonstrated somewhat absorptive (resistive) behaviour in the microwave oven (i.e. it is not a total reflector), was fabricated for 6 passes with the same resolution, on the same substrate, and using the same sintering procedure. Its sheet resistance was measured to be 0.200 ± 0.05 Ω/□ and the thickness of approximately 3.5 μm. This sample pictured after the 10 min 'microwave test' is shown in Figure 13. The rippling of the PET substrate dew to initial thermal sub-melting caused by the joule heating of the silver layer can be easily seen in this picture.

Figure 14 - The sample with the silver coating printed for 6 passes with 360 dpi resolution.

5.3 Deposition of susceptors

Since the implementation of inkjet printed continuous metal microwave susceptor with the sheet resistance of 200-500 Ω/□ is not feasible, another solution was proposed and used. In contrast to the continuous metal coating susceptors, which are pre-heated by joule heat losses of radiofrequency eddy currents, the printed susceptors are heated by the radiofrequency displacement currents caused in a distributed capacitor. These distributed capacitors are formed by relatively small conductive metallic 'islands' printed on a dielectric substrate, e.g. on a polymer film or a paper sheet. These conductive islands may be either totally or partially reflective with regard to 2.45 GHz microwave radiation. One of the possible distributed capacitor patterns is shown in Figure 14.

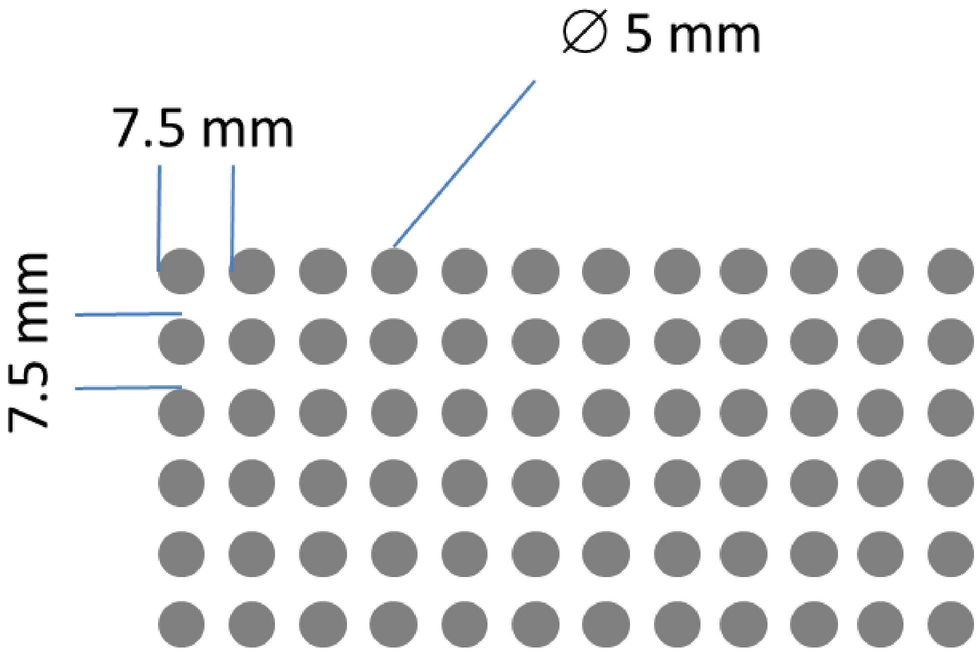


Figure 15 - Pattern of totally reflective circular islands allowing heating up to 120-150°C.

However, the susceptor effect was also achieved in our experiments using the low-resolution one-pass inkjet printing of silver. In this case, the deposited silver dots and the PET substrate formed the distributed capacitor.

5.4 Experimental validation of susceptors

The susceptors have been validated in a very straightforward manner: After 1 min. of microwaving, the distribution of temperature resulted from absorption of microwave energy has been imaged by a thermovision camera Testo 875. This does not allow full characterization, but gives the possibility to make sure that the susceptor effect is observed. Anyhow, the development of the inkjet printed susceptor technology is not finished yet. We hope to find a better method for in-line characterization of the working temperature and efficiency of the susceptor.

The thermal images of the distributed susceptors right after 1 min. of microwaving are shown in figure 16.

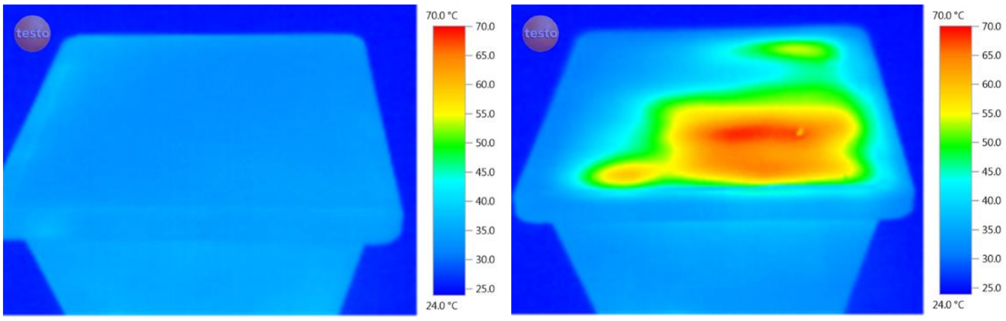


Figure 16 - The thermal images of a plastic tray: left picture – the tray is open, right picture – the tray is covered by a PET film with a distributed inkjet printed silver susceptor deposited for one pass with the resolution of 120 dpi.

The susceptor shown in figure 17 is an actual sample of a pattern of totally reflective islands. It is based on the structure shown in Figure 6. So far, these patterns have only been made of aluminium and deposited on different substrates by means of CVD technique at the Tribological Center of DTI. However, there is absolutely nothing restricting inkjet printing implementation of the same pattern. DTI and XAAR plan to carry out some depositions and validation experiments with these susceptor structures in the near future.

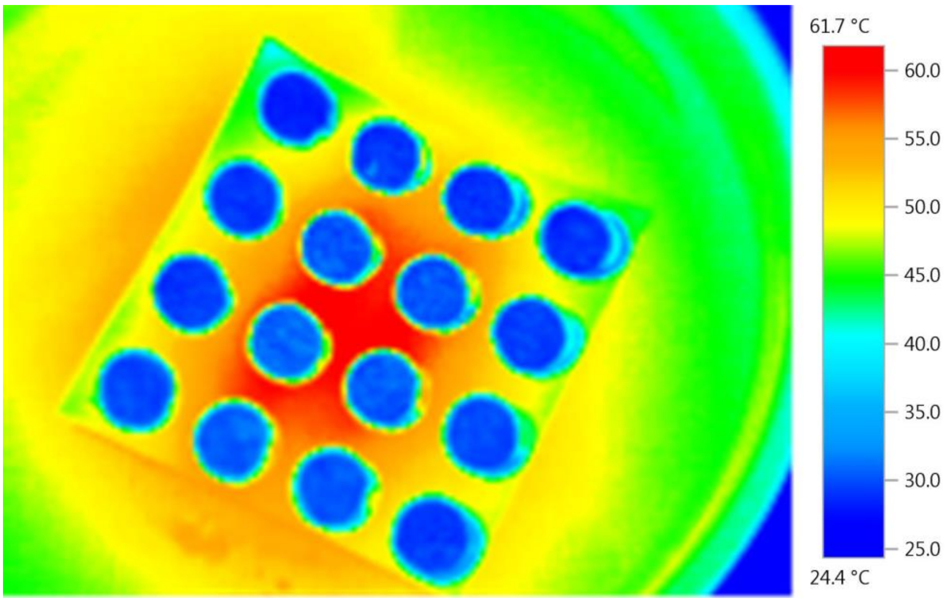


Figure 17 - The thermal images of a printed susceptor formed by a paper substrate and a totally reflective islands of aluminium film. The metal pattern remains cold while the substrate is heated up by the radiofrequency electrical displacement currents caused by microwave electromagnetic field.

5.5 Conclusions

- The inkjet printed total microwave reflector was for the first time fabricated and validated in this study.
- The successful proof-of-concept experiments of inkjet printing of microwave susceptor has been carried out.
- The future work is to be done in order to develop inkjet printed flexible susceptors viable for application in PicknPack project for packaging of microwaveable ready meals.

As a conclusion for the flexible heating systems, WP6 has, together with the Project Board, decided to proceed with the research and make space on the line to apply these systems later in the process as WP6 do not believe to have an industrial system ready within the time frame of 2014. As a natural conclusion the Project Board and WP6 has decided to print with two different colours on the top web.

For these reasons, PicknPack do not expect to demonstrate the flexible heating systems in-line. PicknPack will demonstrate these technologies off-line as an integrated part of the demonstration event.

6 Flexible decoration

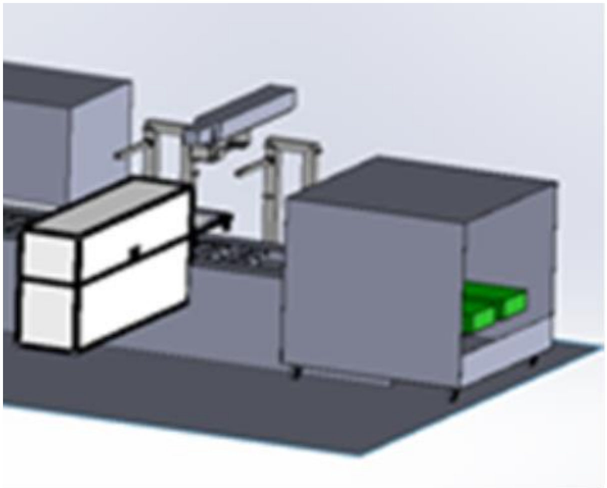


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Figure 18 – Printer build together with the laser welding and cutting

WP6 has done several successful tests decorating plastic films in different colours.

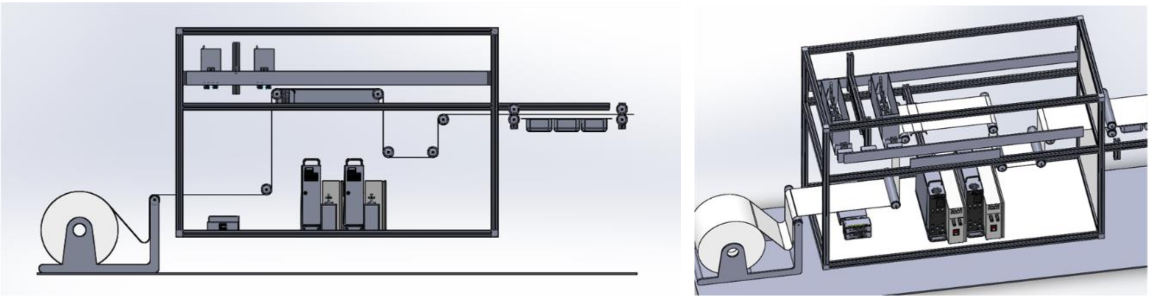

Figure 19 – Two colour jet-ink printer

It has been decided to decorate in two colours for the demonstration unit, which will give an excellent impression of the opportunities in flexible in-line decoration. Extra colours can be added at extra costs as later users select. WP6 has discussed the wish to add more colours on the printer. The printer design is made so it is possible to add several extra colours. As the print equipment for four/five-colour decoration in the full 300 mm web width is too expensive for our limited budget WP6 has selected to demonstrate in two colours in a very high quality.

The printing system is designed in a way that individual information and decorations for batch sizes down to single units are printed onto the top-film, before it is sealed onto the tray. Work has also been performed to identify suitable low-migration UV-curable inks for this process, as it is a crucial part of the process that no ink components migrate into the food products. The inkjet print head selected for this process is the Xaar 1002 print head model, which allows to print in a grey-level-mode at 360 dpi, resulting in high apparent resolution and image quality. A unique feature of these print heads is the continuous ink recirculation past the back of the nozzles during jetting, which means that air bubbles or unwanted particles are carried away, resulting in highest printing reliability. These features make the Xaar 1002 the most suitable print head for this type of single-pass printing as employed in PicknPack, where it is important that the printed information like text and barcodes does not contain any defects that make it unreadable.

Beside this approach direct on the packaging line, DTI has decided also to experiment with another solution for a printer. DTI will try to rebuild an existing colour office printer with four colours to be able to print shaped and bended cardboard to be converted to sales boxes. DTI hope such a system can also be used for web printing of both plastic or paper based materials. Production speeds for such a design will be perfect for the ready meal industry, but in the low end for other business areas.

Figure 20 – Different samples printed with Xaar ink-jet technology

7 Deviations from DoW

WP6 has up to now no deviations from DoW. See following evaluations based on DoW 1.2 progress beyond the state-of-the-art.

1.2.9. Digital mould *The most commonly used packaging platforms for food trays are either thermoplastic materials or moulded paper. Both packaging forms are shaped in moulds. These moulds are* *Bottlenecks for flexible package production as the moulds are relatively expensive and demand a lead-time of several days to be produced and adjusted. Even once these moulds are produced, it takes some time to switch from one mould to another. The typical switch time plus adjustment to the next production batch is 1-8 hours. Flexible mould technology is the solution proposed in this project and will allow the production of batches of only 1-100 units per type of package. More specifically, digital mould technology will be used in the* *PicknPack concept. The aim is to create a digital mould for either thermoforming polymers or moulded paper. This digital mould can be changed from one design to another within seconds without any change of the packaging converting machine. Such a technology will be just as flexible as the robots, which manipulate the food components into a final product.*
• WP6 hope that the brick mould system will be able to start production only 5-10 minutes after the beginning of the design process. If this is, the case WP6 deliver more than expected in lead-time. • In addition, mould shifts shall be done in seconds, which is also better than expected. • The system is perfect for bathes of 1-100 units. • The brick mould system is a digital solution see chapter 2.6.3 under task 6.2 Brick mould system. • The pin mould system is also digital will minimum be demonstrated off-line.

1.2.10. Flexible packaging system *Food products are often sealed into a specific controlled environment in order to maintain the best possible shelf life. Such a protective environment is the optimal combination of temperature, humidity, oxygen, carbon dioxide, nitrogen and other gasses. Typical food packaging lines either flush atmospheric air out of a packaging bag made of plastic films or flush the optimal air into the*

tray before sealing with a top film. Both these technologies suffer the problem that the product is exposed to atmospheric air and that that will also be locked into "pockets" in the food product. The advantage with the PicknPack system is that the entire operation can take place in a designed environment, which protects the food products being packed. Even the short time inside the PicknPack environment gives the advantage that the food components adjust to the modified atmosphere. This will as an extra benefit also increase the shelf life of the products. The sealing system shall be designed to take place as the last step before the product leaves the protected environment of PicknPack. The sealing system shall include both a sealing system and a cutting system to make the retail package ready for presentation and sale.
The text clearly define MAP created in a closed room with no humans looking directly on the packaging line. For the in-line demonstration activities, PicknPack has selected NOT to produce under these MAP conditions demanding all operations done in a sealed environment with access for humans. PicknPack will create an off-line demonstration of these conditions in order to make it possible to demonstrate for humans.

1.2.11. Flexible packaging integrity system *As mentioned above, modified atmosphere packaging is often used in the food industry to guarantee the shelf life. It is evident that any flaws during the flexible sealing process that cause weak or defective seals should be detected before the package reaches the consumer. KUL has built a track record in developing seal integrity systems which can be seen not only from the patent that was granted on this topic, but also from the number of different world-class food companies now using the technology. However, the current systems face several drawbacks requiring research into novel technologies. Available systems are mainly based on camera vision systems, being only suited for transparent material, and on electronic sniffer systems that are only useable for specified tracer gases. A flexible solution should answer different needs, such as ease of adaptation to small batches and related geometry changes, as well as operating irrespective of the modified atmosphere used in the considered process. This will be the main focus in PicknPack where a system based on hyperspectral vision will be devised.*
This is what PicknPack will demonstrate in-line.

1.2.12. Flexible heating system

Many food products are heated by consumers in the packaging. The heating processes can include baking, boiling/heating in water, and microwave heating among others. Baking in the oven and heating/boiling in hot water is the main method, which places demands on the packaging material properties. Preparation in microwave ovens is a method increasingly used for heating various ready meals. Traditionally microwave heating is a boiling process using a closed packaging made of a plastic film transparent to the microwaves. But also, other microwave heating technologies are available. Susceptor technology in the packaging material can absorb all the energy so that the packaging becomes very hot and can act as either an oven or, with oil between the susceptor and food product, can fry the food.

Susceptors can be created on the package, which are semi-transparent to microwaves. The food can also be shielded from the microwaves with a non-transparent material added to the packaging. These materials can be either different metals or carbons. The aim is the development of a method for the application of these semi-transparent or fully reflecting microwave materials onto packaging using advanced ink-jet printers. The purpose of this is to develop a fully flexible method for creating flexible heating systems in the package. Such a flexible heating system will allow the energy to be allocated in a completely flexible manner to different components of the food products. If PicknPack selects specific food components, the flexible heating system shall be distributed over the packaging in order to obtain the optimal result for the ready meal.

With the innovative and promising results on both printed reflectors and susceptors PicknPack will be able to demonstrate these technologies off-line as an integrated part of the demonstration event.

WP6 still need to perform some research in order to develop a commercial system for a cost fitting the food industry. PicknPack hope to find such more commercial methods within 1-2 years.

1.2.13. Flexible decoration *Nowadays, food is typically packed in a pre-printed plastic film or a pre-printed carton box.* *The printing process is done by the supplier of the packaging material. This results in a lead-time from ordering the decoration to the supply of the pre-printed packaging film, which ranges from a few weeks to half year. Another problem in the existing decoration system today is that the size of the production batches has to be at least several thousands. In order to overcome the need for smaller batches many food producers use a general design for basic packaging supplemented with a label in a poorer quality, but with a lead-time of only 1-5 days. If the packaging has a complex shape it is difficult to decorate these parts of the packaging. Food producers will in these situations typically only decorate the flat parts of the packaging. The aim of PicknPack is to provide the flexibility to produce batches of only 1-* *100 units before the next decoration change and to be able to decorate also complex shapes of food packaging. This would represent a huge step beyond the state of the art. The idea in* *PicknPack is to directly decorate the primary packaging material on each product with a custom design without delay down to a batch size of one unit. If this will be possible, even tailor made products will look professional and costs for additional labelling can be saved. In order to reach this goal PicknPack will develop a high-resolution package printer directly on the packaging line able to decorate packaging materials such as plastics and paper/carton.*
• The flexible decoration system will be demonstrated in-line in two colours on the top film. • We hope to demonstrate with equipment a four-colour printer off-line. • Printing of complex shapes of packaging will be demonstrated off-line. The printer used for in-line demonstration is able to decorate in a full digital way and batch sizes down to single units at the required process speed, but has limited performance in terms of colours and decorating the sides of the package. A printing system that would be capable of doing everything would be technically possible to build, but too complex and expensive for the scope of the project, especially as PicknPack does not have the budget for many print heads and an extra robot.