FINAL PUBLISHABLE SUMMARY

Grant Agreement number: 298647

Project acronym: TDM-Seals

Project title: Cost-effective low-friction SEALS by Texturing During Moulding technology

Funding Scheme: FP7-SME-2012-2

PROJECT COORDINATOR: Instituto Tecnológico de Aragón

PARTNERS:

BRITISH PLASTICS FEDERATION
PLASTIPOLIS
ASSOCOMAPLAST
SWEDISH PLASTICS INDUSTRY ASSOCIATION
DMX SAS
MIJU S.A
BARBIERI A. & C. S.N.C
TECNOLOGIAS AVANZADAS INSPIRALIA
LEIBNIZ UNIVERSITÄT OF HANNOVER

PROJECT DURATION: From 01/10/2012 to 30/09/2015

EXECUTIVE SUMMARY

In the sector of plastic and rubber seals there is a growing demand for high performance dynamic seals that should be able to operate with no leakage under high pressure, have extended lifetime and lower energy consumption levels. Friction is one of the aspects more intrinsically related to the seal performance, as it generates heat, accelerates wear and causes premature damage and leakage, shortening their lifetime and increasing the energy consumption of components.

Surface texturing can significantly reduce the friction of lubricated seals. However, the high potential of surface texturing is hindered by the fact that this treatment is still far from being suitable for real-life production processes. Its major limitation is that texturing is applied as a post-treatment, which has a strong effect on the market feasibility of these solutions.

The TDM-SEALS consortium has developed a novel design and production process for the fabrication of low-friction plastic and rubber seals, at competitive prices, based on texturing during moulding. The method consists of three main steps:

1. Design of the optimum texture pattern that achieves low friction through a novel methodology that combines experimental techniques with a simulation tool kit that includes friction (viscous, adhesion and hysteresis) and fatigue prediction.
2. Application of the texture on the mould by means of technologies that allow a good definition of the pattern on its surface and an adequate transfer of the pattern to the seal.
3. Application of a coating that reduces in more than 30% the demoulding forces with respect to the uncoated mould. TDM-SEALS has obtained textured coated surfaces with demoulding forces that are similar to those of the surface without coating or texturing. To quantify demoulding forces, a test rig that replicates the processing of the rubber has been designed and developed.

TDM-SEALS has demonstrated the results by manufacturing and testing different textured seal prototypes -from simple D-rings to more complex piston seals- with different materials: NBR and TPU. Friction reduction levels between 20% and 50% over the whole velocity range (1-300 mm/s) have been obtained for a textured D-ring and between 20-45% for a textured TPU piston seal.

Additionally, a step-by-step strategy has been designed in order to allow SMEs to apply the developed technologies in an orderly fashion and develop an efficient seal from the very beginning.

It has been calculated that, five years after introducing the TDM-SEALS technology, an SME could obtain a benefit of around 360.000 € for a simple seal and 480.000 € for a complex seal. The total profit could reach 1.8 M€ selling just 5 models of simple seals. The Net Present Value (NPV) associated to the investment considering a discount rate of 25% over a period of 5 years is 156.000 € for a simple seal and 194.000 € for a complex seal. This high positive value indicates that the investment can be undertaken with low risk.

The TDM-Seals Project (Grant Agreement 298647) is supported by the European Commission through the Programme Research for SME Associations

PROJECT CONTEXT AND MAIN OBJECTIVES

In the sector of plastic and rubber seals there is a growing demand for high performance, zero-leak dynamic seals that should be able to operate with no leakage under high pressure, be more robust and reliable, with extended lifetime and with lower energy consumption levels. Friction is one of the aspects more intrinsically related to the seal performance, as it generates heat, accelerates wear and causes premature damage and leakage, shortening their lifetime and increasing the energy consumption of components.

Surface texturing can significantly reduce the friction of lubricated seals. Surface texturing is the application of a microtopography in the form of microdimples or grooves to the surface of a seal. The resulting micro-texture on the seal surface dramatically reduces its friction without affecting its sealing properties. However, the high potential of the use of surface texturing for the reduction of friction in seals is hindered by the fact that this treatment is still far from being suitable for real-life production processes. Its major limitation is that texturing is applied as a post-treatment, which has a strong effect on the market feasibility of these solutions since it implies more complex and increased cost fabrication processes. Therefore, there is the need to develop an innovative process for surface texturing of seals compatible with low cost manufacturing processes.

The TDM-SEALS project aims to develop a novel production process for the fabrication of low-friction plastic and rubber seals, at competitive prices. We propose using surface texturing of the components during the moulding, to achieve a reduction in the seal dynamic friction of >20%. Furthermore, the production process for surface textured seals has been optimised by reducing the production-cycle time related to the de-moulding difficulties. To achieve this aim a novel ceramic coating for the moulds has been developed.

The TDM-Seals Project (Grant Agreement 298647) is supported by the European Commission through the Programme Research for SME Associations

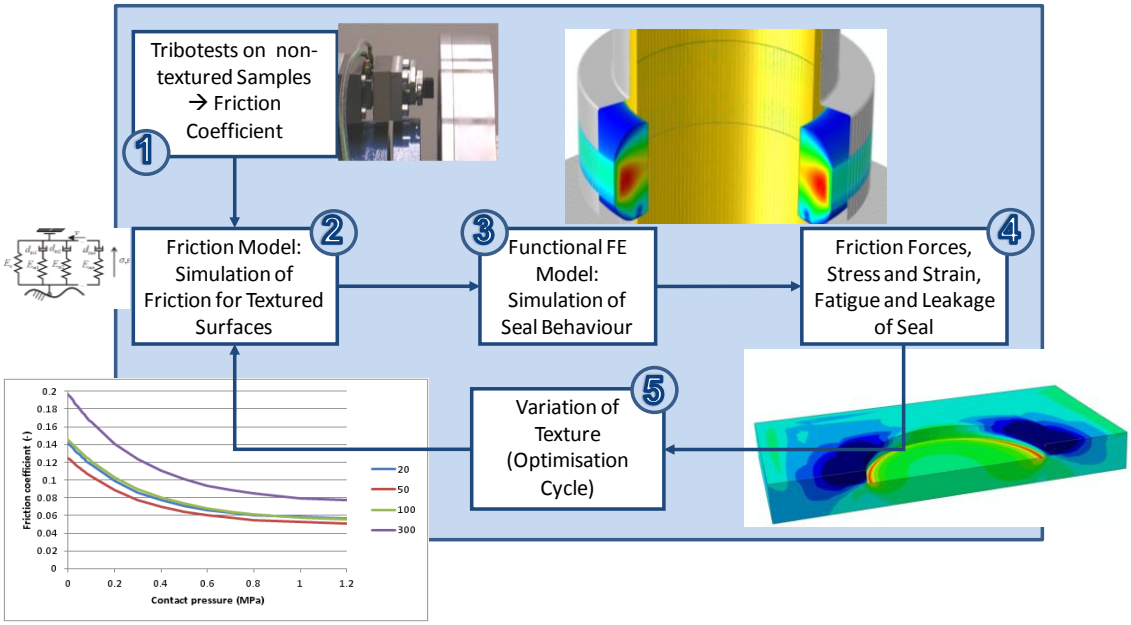
MAIN SCIENTIFIC AND TECHNOLOGICAL RESULTS

TDM-SEALS is a cost effective method for designing and manufacturing low friction seals by means of texturing during moulding.

This method consists of three main steps:

1. Design of the optimum texture pattern that achieves low friction with the lowest possible increase of demoulding forces
2. Application of the texturing patterns on the mould
3. Selection and application of a coating for facilitating the demoulding

To design a texture pattern that reduces dynamic friction of seals, TDM-SEALS has developed a methodology that combines experimental and simulation techniques and that allows designers to arrive at an optimised texture by means of an iterative optimisation process.

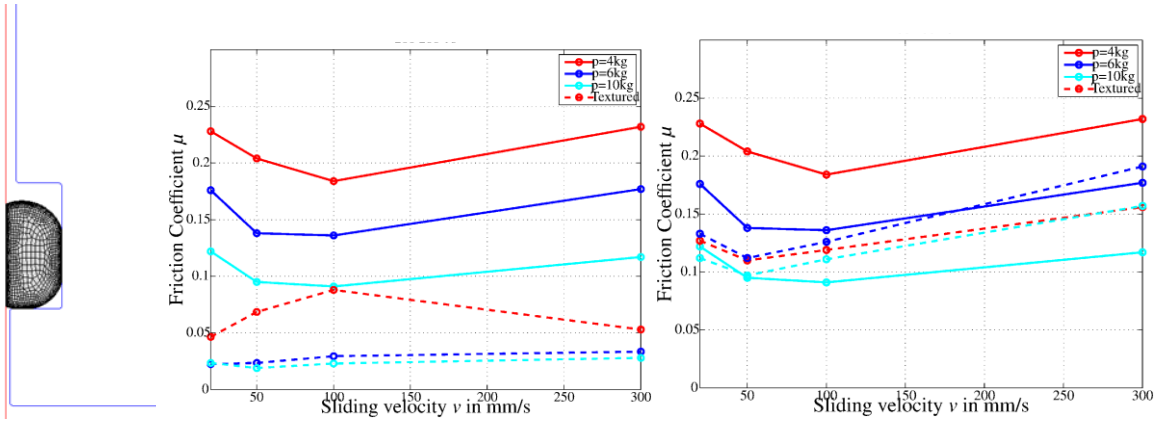


Methodology of the simulation approach

The simulation tool kit that has been developed includes:

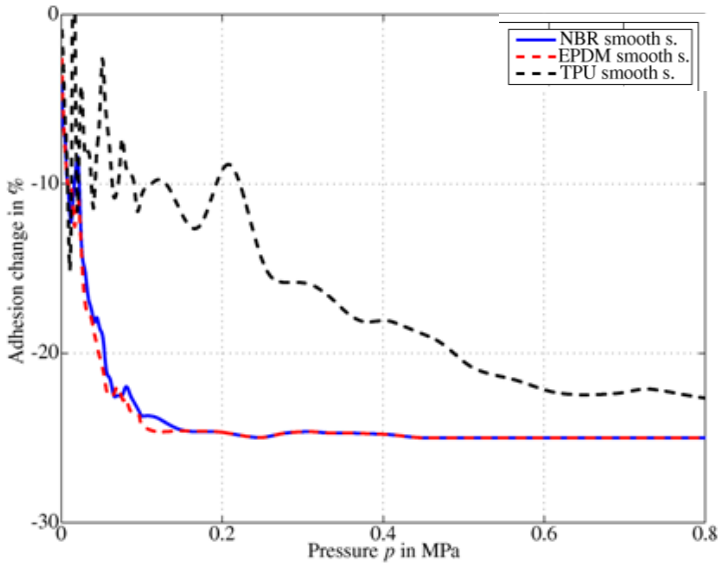
- A viscous friction model based on the Reynolds equation that takes into account the pressure distribution, fluid film height and the seal deformation, that has been validated with tribometer tests. The results of this model can be fed into a FE simulation model of the seal in order to perform functional simulations and estimate the friction reduction. These functional FE models have been validated by comparing their results with experimental friction forces measured on a D-ring seal.

The TDM-Seals Project (Grant Agreement 298647) is supported by the European Commission through the Programme Research for SME Associations



FE model of a D-ring showing reduction in friction forces for two different textures

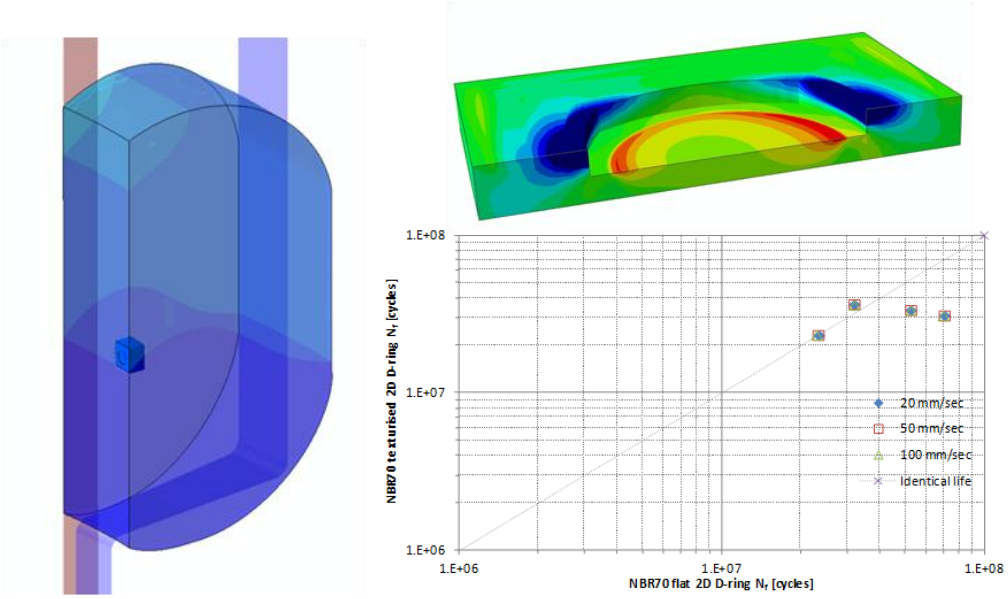
- A simulation approach to estimate the influence of the texture on the adhesion component of friction, which takes into account the texture characteristics, the contact pressure and the variation of the contact area at the roughness length scale, as well as the roughness of the countersurface.



Adhesion friction variation for a texture covering a certain % of the nominal contact area

- A friction hysteresis friction model including the viscoelastic properties of the seal material and the counter surface roughness
- A fatigue model that includes a macromechanical model of the seal as well as a local micromechanical model of a dimple to analyse the local deformation fields of the texture features. The result of the fatigue model is a life expectancy measured in loading cycles and allows designers to ensure that the texture pattern will not have detrimental effects on the fatigue life of the seal.

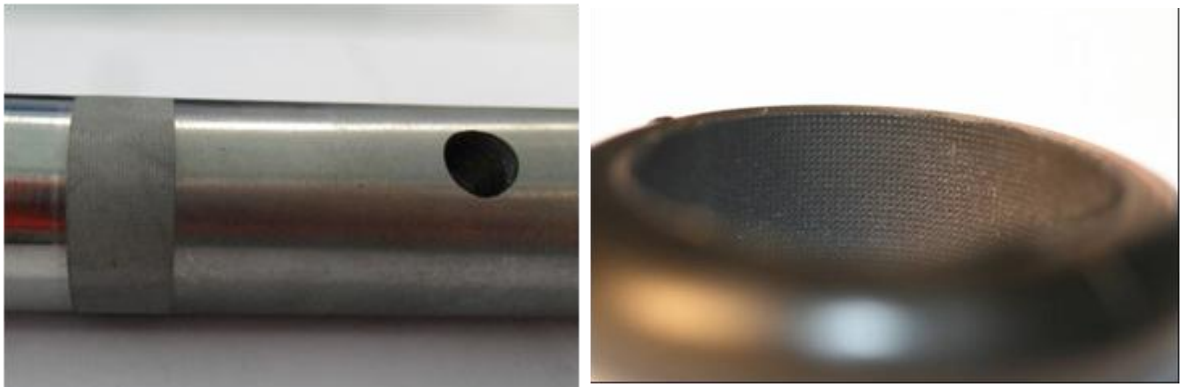
The TDM-Seals Project (Grant Agreement 298647) is supported by the European Commission through the Programme Research for SME Associations



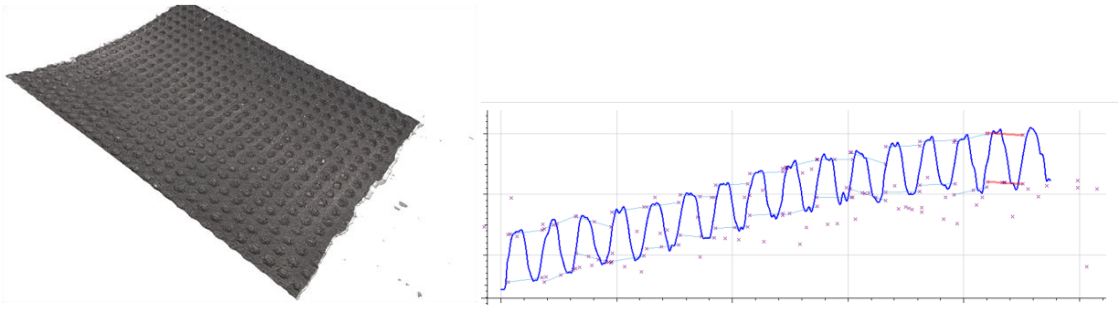
Macro and micro fatigue models and life expectancy estimation

Once the characteristics of the sealing application and its operational requirements have been specified, the design methodology can be applied in order to obtain a series of candidate texture patterns.

The second part of the method is the engraving of the texture on the mould. TDM-SEALS has explored different technologies for obtaining a textured mould with a good definition of the pattern on its surface and an adequate transfer of the pattern to the seal. Different photolithography based techniques, as well as laser based techniques have been assessed. Texture patterns on the mould and the seal surface have been thoroughly evaluated with a microscope in order to determine the texturing procedure that provides the best texture transfer. Finally, a procedure with the conclusions and recommendations for mould texturing has been elaborated.

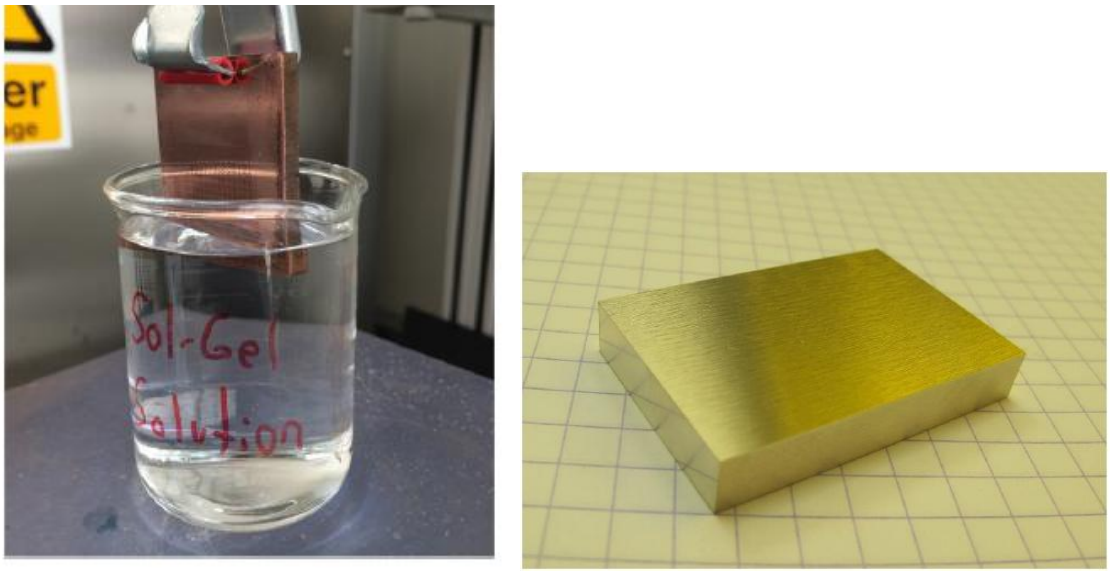


Textured mould and textured EPDM D-ring produced by Texturing-during-Moulding



Detail of the texture on the seal surface and microscope results

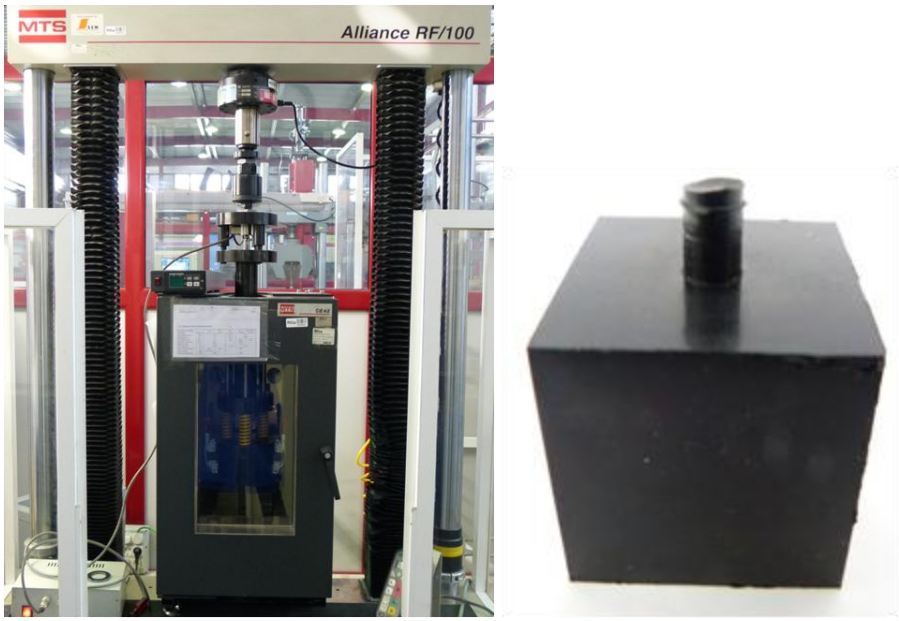
The last part of our method addresses the demoulding procedure. One of the objectives of TDM-SEALS is that the demoulding process using surface textured moulds is comparable to the process with non-textured moulds, so that it does not constitute a barrier for the adoption of surface textured moulds. The envisaged solution is to apply a coating to the mould in order to facilitate the demoulding of the textured seal.



Sol Gel – based and PVD-based coatings have been developed and assessed

But how can the efficacy of a coating be quantified? Measurement of demoulding forces is not a common practice in the rubber industry, although the demoulding process is one of the critical aspects in the processing of polymers and can be critical when using textured surfaces. In TDM-SEALS we have designed and developed a test rig that replicates the processing of the rubber as similarly as possible to the real fabrication process of seals, and measures the forces needed to demould the rubber sample from the mould. Not only coatings, but also different mould surfaces, textures and rubber materials can be evaluated. Using this test-rig, we have been able to evaluate the increase of demoulding forces due to the texturing, allowing us to detect patterns that might make the demoulding too difficult and select coatings that compensate the increase of demoulding forces of the texturing.

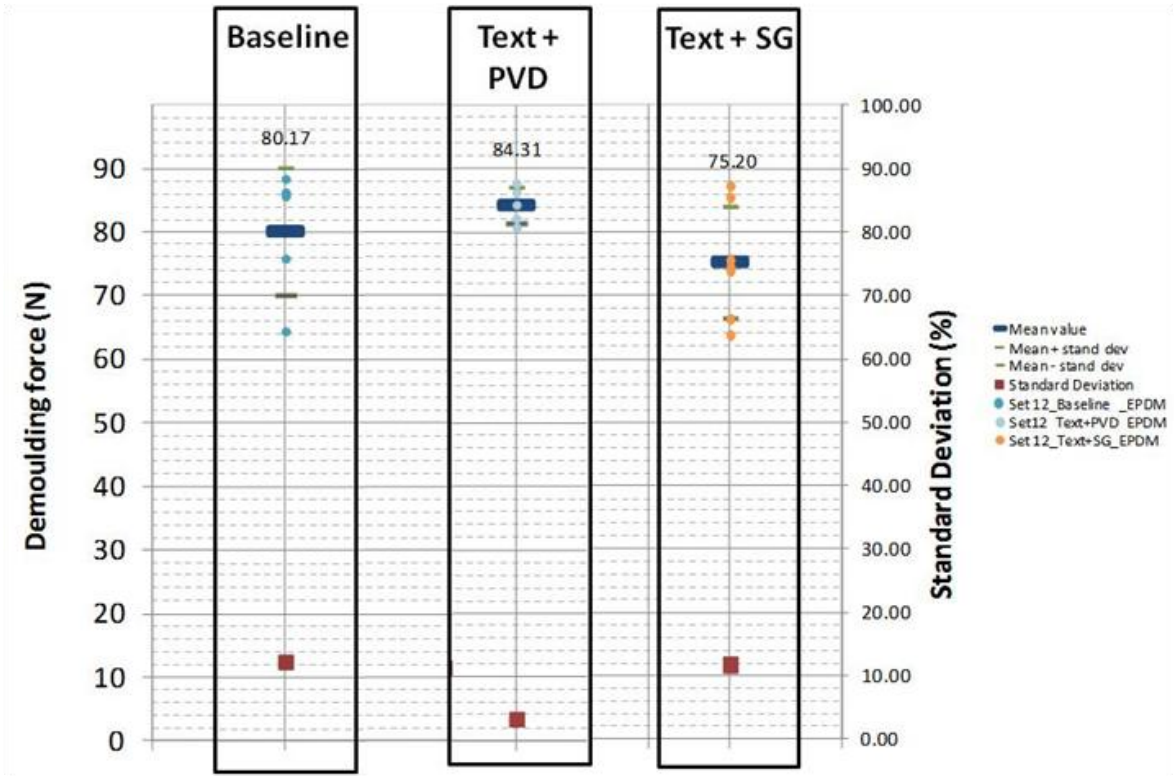
The TDM-Seals Project (Grant Agreement 298647) is supported by the European Commission through the Programme Research for SME Associations



Test rig for measurement of demoulding forces and processed sample

PVD (*Physical Vapor Deposition*) and Sol-Gel based coatings have been developed and evaluated using this device. A series of optimum coatings that decrease the adhesion between mould and elastomer have been found. Different situations, depending on the surface characteristics (flat/textured) and the rubber material (NBR, EPDM, ...) require different coatings. TDM-SEALS has found optimum coatings for these different situations.

In particular, we have found coatings that reduce in more than 30% the demoulding forces with respect to the uncoated mould. In some cases, the demoulding forces of the textured coated sample are almost similar to those of the surface without coating or texturing.

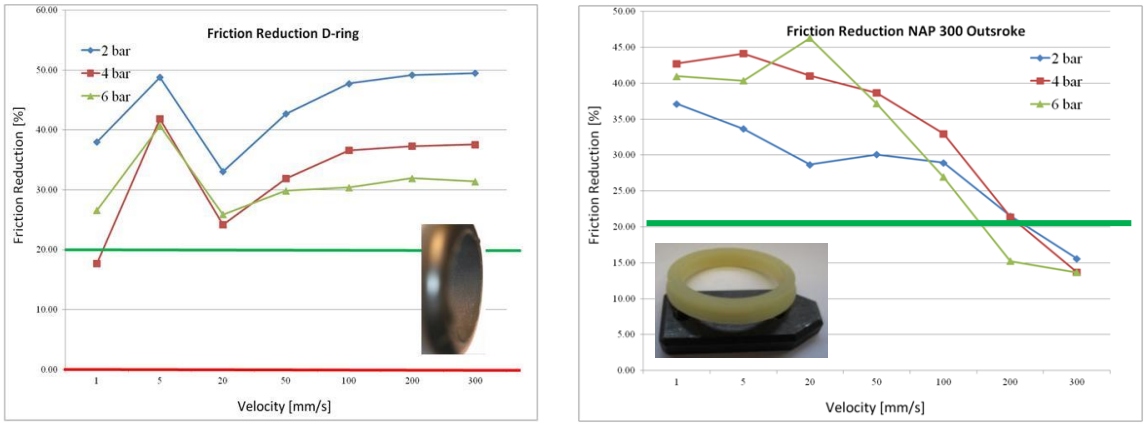


Demoulding test rig results

The TDM-Seals Project (Grant Agreement 298647) is supported by the European Commission through the Programme Research for SME Associations

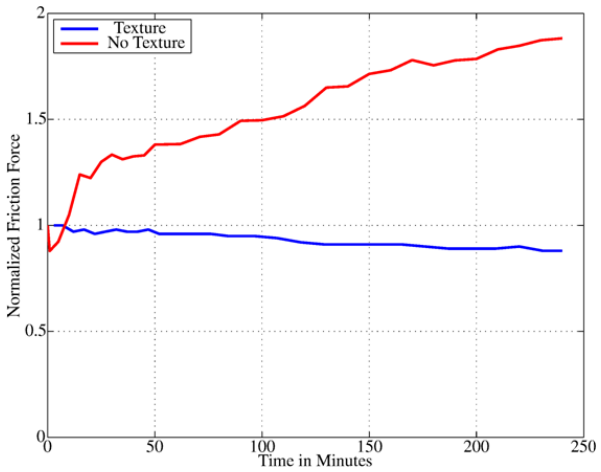
Thus, TDM-SEALS has developed a series of coatings that facilitate the demoulding both in flat and textured mould surfaces. The application of these coatings is essential to compensate the demoulding difficulties induced by the texture. Some of these coatings were evaluated on real moulds (injecting 100.000 parts), showing a very significant improvement of the demoulding quality, cleanliness and injection time (20% less) for three different rubber materials.

The ultimate proof of concept was the manufacturing of different seal samples (D-rings and piston seals) with different materials (NBR and TPU), textured with the most promising patterns. Friction testing of D-rings showed friction reduction between 20% and 50% over the whole velocity range (1-300 mm/s) for one of the patterns, 10%-50% in the range 50-300 mm/s for a second pattern and 0-40% in the 100-300 mm/s velocity range for a third pattern. A TPU piston seal yielded friction reduction above 20% (up to 45%) for all operation conditions.



Fricion reduction for a textured D-ring (left) and a TPU piston seal (right)

Moreover, a wear test showed how the friction force increases over time for a standard seal sample, while it remains constant –even slightly decreasing- for a textured seal, due to the lubrication storage capacity of the texture.

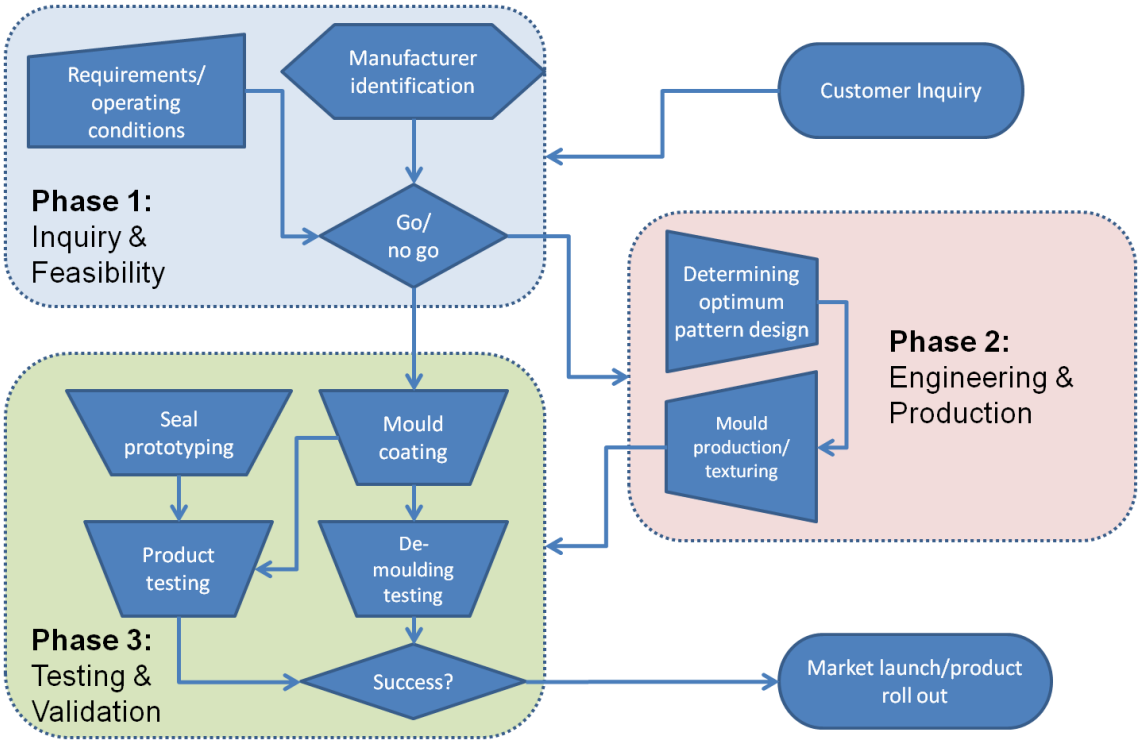


Long time friction test

As a final check, the fatigue model was applied, analysing the local deformation fields of the texture features and predicting a life expectancy of the same order as that of non-textured seals.

The TDM-Seals Project (Grant Agreement 298647) is supported by the European Commission through the Programme Research for SME Associations

Thus, TDM-SEALS has developed a series of technologies that will allow SMEs to develop low friction, high performance seals. The next logical question that an SME might ask is: how can we take advantage of all these tools in an orderly fashion and develop an efficient seal from the very beginning? To guide SMEs that might be in that situation, TDM-SEALS has devised an iterative step-by-step strategy that should be followed:



Flow chart: Step-by-step guide for TDM production process

In summary, the main foreground generated by the project is:

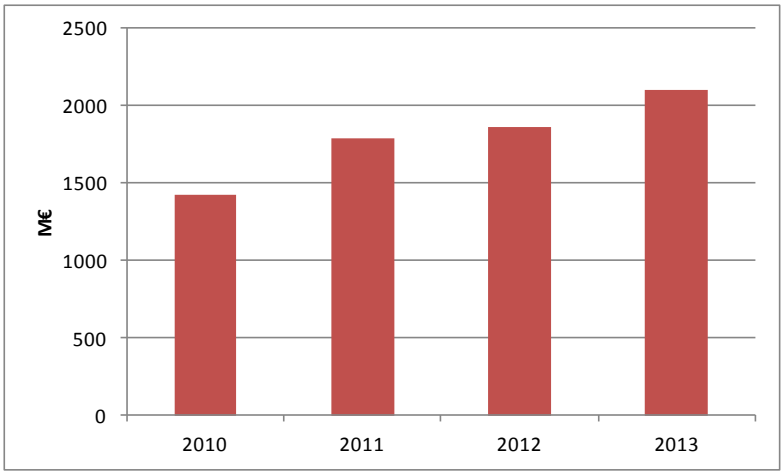
1. A Texturing-During-Moulding production process for low friction seals
2. Coatings for moulds that facilitate the demoulding
3. D-ring prototypes made of NBR with texture patterns that reduce friction above 20%
4. A TPU piston seal with a texture pattern that yields friction reduction above 20%
5. Several texture patterns that yield a significant friction reduction in button samples
6. A methodology that combines experimental and simulation techniques to derive an optimised texture
7. A validated friction model comprising three relevant friction mechanisms
8. A validated fatigue model including a macromechanical model of the seal and a local micromechanical model of the texture
9. A test rig for the evaluation of demoulding forces

POTENTIAL IMPACT AND USE

All these results will be used and exploited by the SME associations that are the main beneficiaries of the project. The proofs of concept in the form of real products will immensely facilitate the exploitation of TDM technology towards other customers and products.

The solutions for the production of low friction seals will have as major client sector the users of hydraulic and pneumatic equipments, which are used in turn in a wide variety of industrial sectors: transport (automotive, aerospace, railways, elevators), home appliances, industrial machinery, agricultural industry, earth moving and mining industries, etc.

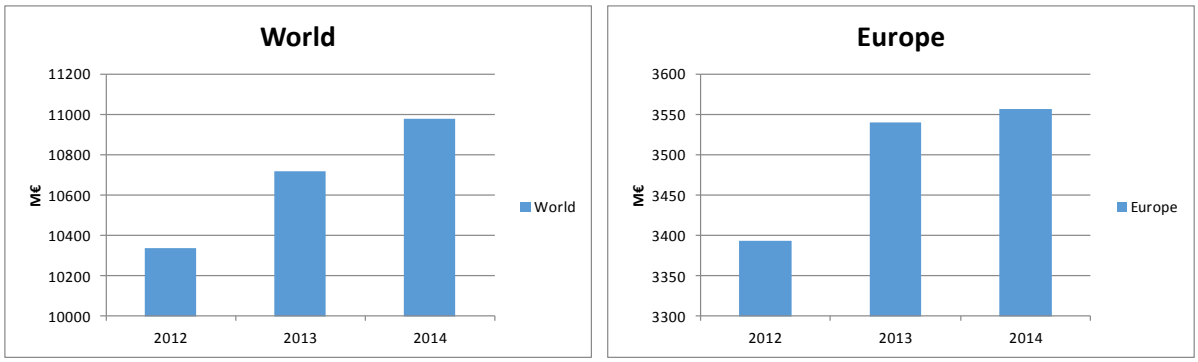
The main market segments are the market of plastic and rubber sealing components. According to the UN COMTRADE database, the European exports of mechanical seals and seals of vulcanised rubber reached 2100 M€ in 2013, with an increase of 13% with respect to 2012. The increase rates in 2012 and 2011 were 4% and 25% respectively. Applying a conservative annual growth rate of 5%, the European market size in 2016 will be 2300 M€, and considering that about 10% could be dynamic seals in which low friction is important, the target market in 2016 would be 230 M€. With an estimated 7% market penetration of low friction seals in year 5 after the project, an accumulated sales revenue in year 5 after project end of 32 M€ could be obtained, of which 6.5-9.5 M€ would be net profit.



Gaskets, washers, and other seals of vulcanised rubber– exports from EU-28

Another target market is the sector of mould manufacturers. The use of anti-sticking coatings is not limited to the production of low-friction seals, but has the potential to be used in the production of other types of plastic and rubber products in which demoulding is an important part of the process. According to the UN COMTRADE database, the current worldwide global exports of moulds for plastic and rubber can be estimated in 11000 M€ in 2014, with the European exports being 3550 M€. The figures below show the global exporting figures, with the worldwide figures increasing in 2014 at 2.4% with respect to the previous year, and the European exports remaining more stagnant, with a 0.4% increase with respect to 2013. Assuming a very conservative 1% yearly growth rate, and that only 10% of the moulds could correspond to applications where coating and/or texturing would be profitable, the market size for moulds in 2016 would be 326 M€.

The TDM-Seals Project (Grant Agreement 298647) is supported by the European Commission through the Programme Research for SME Associations

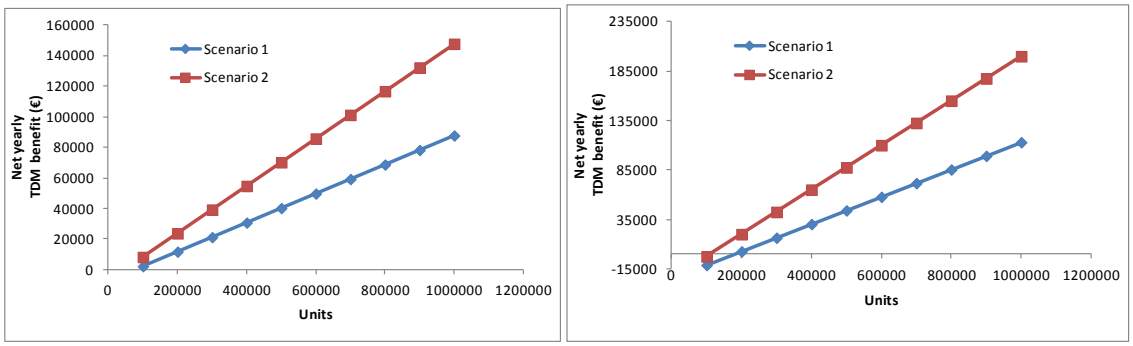


Moulds for rubber and plastics – list of exports

Considering that coated moulds will achieve an average 4% market penetration in year 5 after the project end, an accumulated sales revenue in year 5 after project finalisation of 26 M€ is estimated, with a net profit of 6.5 M€.

At the end of the project, a detailed analysis of the economic feasibility and benefits associated to the commercialisation of low-friction seals has been performed, focused on the automotive market (with typical annual productions of dynamic seals between 100000-1000000 units per type of seal). The analysis takes into account current average prices of dynamic seals, current annual revenues and benefits, the estimated increase in price for a high-performance seal, and the accumulated costs of introducing the TDM-SEALS technology (texture design, mould texturing and mould coating). This analysis shows the following potential impact:

- The application of an easy-to-demould coating conveys an important reduction of the mould cleaning time and frequency. After TDM-SEALS, a reduction of 30-50% in down times related to mould cleaning is expected, which leads to an increase in productivity between 5% and 25%.
- A conservative 5-year business plan, considering an steady sales increase from 100.000 units in year 1 to 1.000.000 units in year 5, and a certain price margin decrease between year 1 and year 5, shows total benefits of 360.000 € for a simple seal and 480.000 € for a complex seal. Taking into account that an SME can produce between 5 and 20 different models of dynamic seals, the total profit could reach 1.8 M€ selling just 5 models of simple seals.
- An interesting indicator is the Net Present Value (NPV), defined as the net sum of present values of incoming and outgoing cash flows associated to an investment over a period of time. The NPV is an indicator of how much value an investment or project adds to the firm. A discount rate to adjust for risk, opportunity cost, or other factors is estimated at 25% (15% is the usual rate for high TRL technologies in national pre-launch phase, 25% is the usual rate for validated technologies, and 50% is the usual rate for technologies under development).
- The Net Present Value (NPV) associated to this investment considering a discount rate of 25% over a period of 5 years is 156.000 € for a simple seal and 194.000 € for a complex seal. This high positive value indicates that the investment can be undertaken with low risk.
- We have also estimated the net benefit during one year as a function of the number of units and the possible scenarios of productivity increase and selling price increase. This has allowed us to estimate, the payback amount (number of units needed to pay for the investment associated to the TDM-SEALS technology) and the production volume below which the investment is not worth considering:



Estimated yearly benefit for simple o-ring seals (left) and more complex piston seals (right) under two scenarios (scenario I – low increase in productivity and price; scenario II – high increase in productivity and price)

By offering textured and/or coated moulds, mould manufacturing SMEs will also be able to expand their offer. It must also be taken into account that mould manufacturers could sell not only coated and textured moulds for dynamic seals, but also easy-to-demould moulds for any type of plastic or rubber component. It is expected that during the initial years after the project end, the mould making SMEs will formalize agreements with texturing and coating companies. Afterwards, the mould makers can consider executing the corresponding investments and directly apply these coating and texturing processes in their facilities.

During the initial period, mould manufacturers will charge the total cost of manufacturing the mould to the purchasing company plus a reasonable commercial margin. The increase in revenue associated to the sales of high-performance moulds will be associated to the number of coated and textured-coated moulds sold per year. The annual production of moulds of a typical SME varies significantly and it is very difficult to obtain a specific number from mould makers. A conservative 5-year plan estimates a total profit would be around 400.000 €, of which 200.000 € would come from the margins applied on the texturing and coating services. With no initial investment needed, the accumulated profit will just depend on the number of moulds that are sold.

CONSORTIUM MEMBERS

PROJECT COORDINATOR – MAIN PROJECT CONTACT			
ITAINNOVA INSTITUTO TECNOLÓGICO DE ARAGÓN	**INSTITUTO TECNOLÓGICO DE ARAGÓN**	**SPAIN**	Dr. José R. Valdés jrvaldes@itainnova.es
SME ASSOCIATIONS			
BPF	**THE BRITISH PLASTICS FEDERATION**	**UK**	Mr. Robert Price rprice@bpf.co.uk
Plastipolis PLASTICS INDUSTRY COMPETITIVENESS CLUSTER	**PLASTIPOLIS**	**FRANCE**	Mr. Maudez Ledantec maudez.ledantec@plastipolis.fr
SPIF	**SVENSK PLASTINDUSTRI FÖRENING**	**SWEDEN**	Mr. Leif Nilsson leif.nilsson@arlaplast.com
Assocomaplast ITALIAN PLASTICS AND RUBBER PROCESSING MACHINERY AND MOULDS MANUFACTURERS' ASSOCIATION	**ASSOCOMAPLAST**	**ITALY**	Mr. Girolamo D'Agostino g.dagostino@assocomaplast.org
SMEs			
DMX	**DMX**	**FRANCE**	Mr. Jaques Lafa lafa@dmx.fr
miju	**MIJU**	**SPAIN**	Mr. Roberto Maurel rom@miju.es
BARBIERI RUBBER	**BARBIERI RUBBER**	**ITALY**	Mr. Alberto Barbieri alberto@barbierirubber.it
RESEARCH AND TECHNOLOGY DEVELOPERS			
Leibniz Universität Hannover	**IDS- LEIBNIZ UNIV. HANNOVER**	**GERMANY**	Dr. Matthias Wangenheim wangenheim@ids.uni-hannover.de
inspiralia	**TECNOLOGÍAS AVANZADAS INSPIRALIA**	**SPAIN**	Dr. Tomás Rodríguez tomas.rodriguez@inspiralia.com

Project website address: http://www.tdm-seals.eu/

The TDM-Seals Project (Grant Agreement 298647) is supported by the European Commission through the Programme Research for SME Associations