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Advanced polyurethane based systems for continuously produced pre-insulated pipes

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Abstract

Modern production techniques are being developed to allow cost savings for the production of pre-insulated pipes. The continuous pipe moulding process is one of the relatively new advanced production techniques. The inner medium pipe is continuously fed into a moulding section, together with a polyurethane foam mixture that is applied onto a film. An outer protective casing pipe is subsequently applied on the polyurethane insulation layer. Compared to the conventional discontinuous pipe filling technique, the continuous process allows a reduction of the foam filling density and a reduction of the casing pipe thickness that can result in substantial cost savings for the pipe manufacturer. The continuous pipe moulding technique is used for the production of both rigid and flexible pre-insulated pipes.

Compared to discontinuous pipe filling the continuous pipe filling process requires a change of foam reactivity, viscosity build-up and cure characteristics which made the development of new polyol systems for rigid pre-insulated pipes necessary. Modified rigid polyurethane systems with inherently low flow-ability but superior thermal resistance were developed.

Significant performance improvements were achieved with the introduction of a new generation of semi-flexible foam systems. A careful balance of short and long chain polyether polyols allows a combination of high flexibility with increased thermal resistance. A main disadvantage, the fast separation tendency of the polyols, could be overcome and storage stable systems were developed.

Introduction

A number of different production techniques can be used for the production of pre-insulated pipes. One can distinguish between two types of techniques, the discontinuous and the continuous production technique. Although the initial investment in continuous production techniques is higher, it allows cost savings due to a reduction of foam filling density and a reduced thickness of the high density polyethylene casing pipes.

Continuous pipe manufacturing techniques made the development of new polyurethane systems necessary, both for rigid and for flexible systems. We have developed polyurethane systems for this technique which provide an increased thermal resistance of the foam combined with added advantages in processing. Systems for the manufacture of flexible as well as for rigid pipes will be described.

Experimental

Materials

A series of experimental polyether polyols was produced and reacted with polymeric MDI, for example Suprasec 5005. The usual ancillary chemicals and physical blowing agents such as HCFC-141b and pentane were used.

Property measurements

Pre-insulated pipes and foam samples that were produced were left for at least 24 hours to cure before cutting and carrying out mechanical tests. The test methods applied are described in the European Standard EN 253, drawn up by the Technical Committee CEN/TC 107 "Pre-fabricated district heating pipe systems" [1]. Other specific test standards are indicated in the tables. The foam softening temperatures were measured on a Perkin Elmer TMA7 Thermal Analysis System in penetration mode using a heating rate of 10°C per minute.

Polyurethane systems for the continuous moulding technique were developed, which provide an

increased thermal resistance

combined with added advantages in processing

Discontinuous production techniques

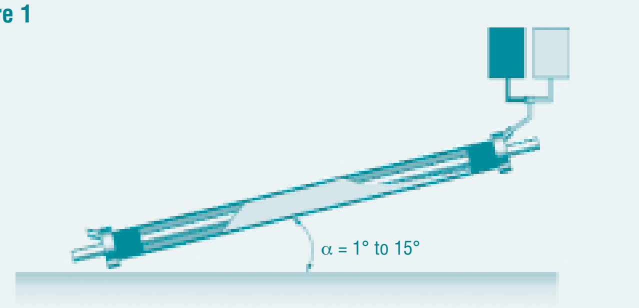
The various discontinuous production techniques, being the horizontal filling technique, the pour-and-rise technique and the top filling technique, differ mainly in orientation of the pipe and the place of the foam injection. The top filling technique is the most widely used discontinuous filling technique. A more detailed overview can be found in the literature [2].

In order to fill the annular space between service pipe and casing pipe over lengths up to 16 metres, the polyurethane formulation must have excellent flow properties to obtain an even and homogeneous density and property distribution along the pipe. Because of the long flow paths of the foam along the pipe, a relatively high degree of foam overpack is required to fill long pipes satisfactorily. A sufficiently thick casing pipe is required to withstand the pressure induced by the foam expansion. To meet a certain minimum core density of the foam everywhere in the pipe, a sufficiently high overall density needs to be applied. This requires a high pipe filling density and therefore involves excess polyurethane foam to be injected.

Discontinuous filling techniques do not require a high capital investment and are reasonably flexible, which allows a large number of different pipe dimensions to be produced without major changes to the set-up. However, the high pipe filling densities and the thick HDPE casing pipes increase the raw material costs for the pipe manufacturer.

Principle of top filling technique

Figure 1



Discontinuous techniques

do not require a **high capital investment**

and are **reasonably flexible**

Continuous production techniques

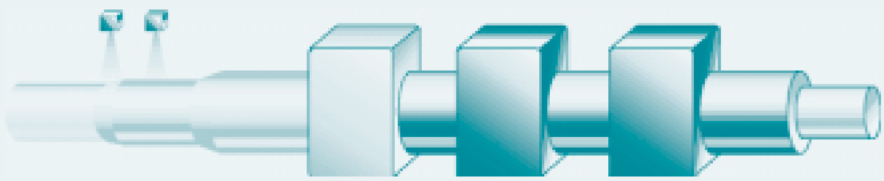
Obvious possibilities to lower costs are the reduction of the foam overpack as well as the filling density and a thickness reduction of the casing pipe. This however, requires different pipe production techniques and adapted polyurethane foam systems. Continuous pipe production techniques consist of two stages. In the first stage, the foam is applied on the inner pipe. In the second stage, the casing pipe is extruded or wound around the pre-shaped foam. Continuous techniques allow a fast and consistent production of a large number of pipes of the same dimension, at comparatively low variable costs.

Continuous spray technique

In the continuous spray technique the reacting foam mixture is sprayed on the outside of a rotating pipe. The foam has to react quickly so that the foam adheres well to the pipe surface and does not spin off. Various layers of foam may be applied from different spray heads to obtain the required insulation thickness. A uniform foam is created over an extremely short flow path. Large and long pipes can be insulated using smaller foaming machines. Applied foam densities can be lower, the HDPE casing pipe can be thinner and hence material savings are possible.

Principle of continuous spray line

Figure 2



The foam surface is not completely smooth. In practice, the spray technique is only suited for big diameter pipes. Losses caused by overspray restrict this technique to bigger diameter pipes where the waste generation is limited.

Continuous pour technique

The pour technique is similar to the spray technique. The main difference is that the foaming mixture is not sprayed but poured onto a rotating pipe. This technique reduces waste and is more environmentally friendly. The pour technique can also be used for smaller diameters. A major difficulty to overcome is the uneven foam surface that requires a careful design of the foam laydown device. We have started the development of foam formulations that could be applied with this technique.

Continuous moulding technique

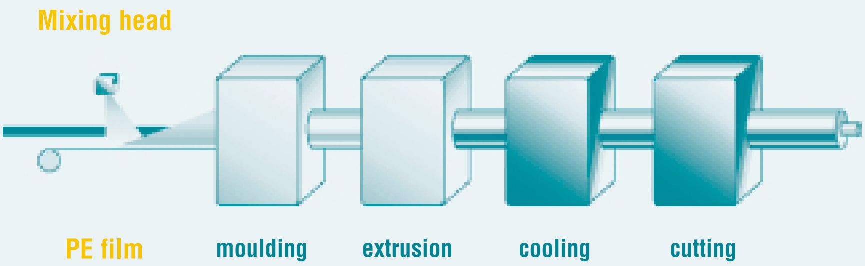
A very elegant solution and a relatively new advanced technique is the continuous pipe moulding process. The principle is shown in Figure 3. Firstly, a foam dispensing machine continuously pours the foaming mixture onto a Corona treated polyethylene film, above which the inner service pipe is positioned. The pipe and the film are continuously fed into the circular moulding section and guided to stay at equal distance to each other, see also Figure 4. The film is first folded into a semi-cylindrical shape and is then closed at the top just before it enters into a moulding section. The reacting foam mixture is expanding in the space between the film and the pipe. Hardly any foam overpack is applied.

The moulding section preferably consists of moving half shells to reduce the friction between the moulds and the foam. On average it is approximately nine meters long to allow a sufficient cure of the foam. At the end of the moulding section the foam must have the required mechanical strength and the pipe can be pulled through an extrusion head where the high density polyethylene casing is extruded around it. The pipe composite is then cooled down and cut by a sawing device into pipes of the required length.

The continuous production technique allows a consistent pipe production due to continuous foaming. The method can be substantially automated. The foam system used does not require very good flow characteristics as no flow along the

Continuous moulding technique

Figure 3



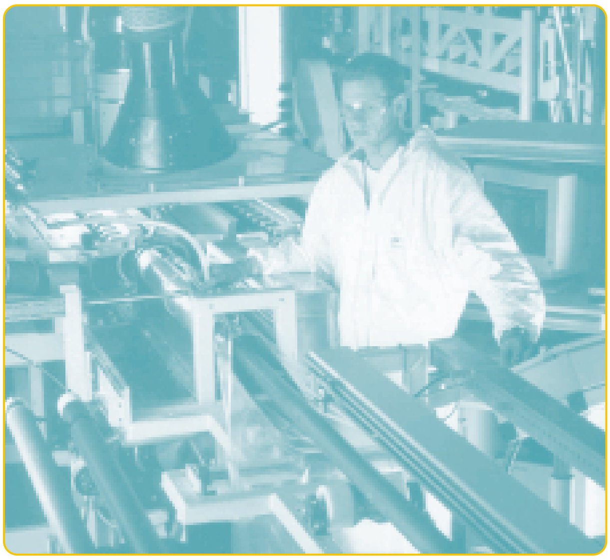
pipe is necessary. Because of the good distribution of the foam, the filling density can be reduced considerably. Also the thickness of the HDPE casing pipe can be reduced significantly, in particular for larger diameters, as it does not have to withstand a high pressure resulting from the foam expansion.

A special variation of this technique is the use of a steel foil, together with a polyethylene film, onto which the foam is applied. The steel foil functions as a casing pipe and is welded after it has left the mould section. At the next stage, the casing pipe can be corrugated providing an increased radial compressive strength which is important if high load bearing requirements need to be fulfilled.

Table 1. Comparison of discontinuous and continuous pipe filling techniques

Discontinuous	Continuous
Advantages – easy set-up – convential hardware – large range of pipe dimensions – technically less demanding **Disadvantages** – high foam overpack required – even property distribution difficult – labour intensive	**Advantages** – lower foam density – thinner HDPE casing – even distribution of foam properties – automated manufacturing **Disadvantages** – skilled operators required – limited flexibility – complex hardware

Figure 4. A small scale continuous moulding line



The continuous moulding technique is used for the production of small and medium size diameter pipes up to a pipe diameter of approximately 20-25cm. For larger pipe diameters, the required high foam reactivity makes it difficult for the foam to completely flow around the inner pipe.

In Table 1 a comparison of continuous and discontinuous manufacturing technique is given. The continuous processing technique requires a higher initial capital investment into hardware than a discontinuous technique and it further needs skilled operators. However, the reduced foam filling density, the thinner HDPE casing and the automated manufacturing can result in substantial cost savings for a pipe manufacturer in terms of raw material and labour costs, which justify the initial higher investment costs. However, any changes in pipe diameter and insulation thickness involve long set-up times which makes this technique particularly suited for large producers who manufacture large quantities of pipes with the same outer diameter.

The continuous moulding technique can be used for flexible and rigid pre-insulated pipes. Different service pipes, i.e. made with cross-linked polyethylene, polybutylene, aluminium, copper or steel can be employed. Because of the importance of this technique, we have invested in a small scale continuous moulding machine in order to enable us to develop and optimise foam systems for this manufacturing technique.

Our moulding line is equipped with a 4 component low pressure mixing head. Besides polyol and isocyanate, the catalyst is added separately which facilitates the co-ordination and fine-tuning of the line speed and foam reactivity. There is a possibility for a fourth component to be added separately which can be a blowing agent, i.e. to adapt the foam rise profile. The equipment is fully computer controlled. Important parameters like temperature and the flow of the components, the heating of the conveyor and the line speed can be controlled through a process visualisation programme.

Advanced rigid foam systems for rigid pre-insulated pipes

For the production of rigid pre-insulated pipes which are e.g. used in district heating and buried in the ground, the polyurethane foam must fulfil heavy requirements. For a high insulation efficiency a low foam thermal conductivity is of paramount importance to avoid heat loss during the transport of hot water. A high long-term heat resistance is necessary as district heating networks operate with service temperatures up to 130°C, occasionally with peaks up to 140°C.

High mechanical properties, i.e. compressive strength, are required to enable the foam to withstand high loads, i.e. during transportation of the pipe or when the pipe composite is laid in the ground. A good adhesion of the foam to the inner and outer pipes is vital to ensure the long term performance of the pipe composite. A high shear strength is required to avoid detachment during the thermal expansion and contraction of the medium pipe, resulting from the temperature variations of the transported water. The minimum properties a foam must fulfil are outlined in the European quality norm EN 253 [1].

The required reactivity of a foam system applied with a continuous technique is considerably higher compared with a foam system applied with a discontinuous production technique. A sufficiently fast build-up of mechanical strength during the moulding residence time is necessary to avoid post-expansion of the foam after it has left the mould section. However, increasing the reactivity must not have a negative effect on the long-term thermal stability of the foam. A very high level of amine based catalysts may lead to accelerated foam decomposition reactions at elevated temperatures and therefore reduce the long-term thermal stability.

Earlier studies in our laboratories have shown that an increase of the foam aromaticity, either by increase of the isocyanate level or by the addition of an aromatic polyether polyol, can improve considerably the thermal resistance of a polyurethane foam. An increased isocyanate level together with a carefully selected catalyst combination allowed a rapid build up of mechanical foam strength to suppress a post expansion of the foam after the mould section and provided improved mechanical and thermal foam properties.

Table 2 shows properties of a fully water blown system, Daltofoam TE44213, for the production of straight pipes with a continuous manufacturing technique. The foam requirements according to the European standard for pre-insulated pipes to be used in district heating, EN 253, are fulfilled.

Reformulating of this system into a water/pentane dual blown system was not straightforward. The reaction of water with isocyanate generates a high level of polyurea moieties in the foam. These structures are known to provide a high thermal resistance. For the pentane blown system however, the reduction of the water level led to a reduction of polyurea moieties which consequently reduced the thermal stability and mechanical properties of the foam. To compensate for this, the foam aromaticity was further increased via the addition of an aromatic polyether polyol. It was found that thermal and mechanical properties of rigid foams can be improved if a polyether polyol based on a diphenylol alkane precursor is used [3]. Table 3 shows the properties of a pentane blown system, Daltofoam TE34204. Again, the EN 253 norms are well fulfilled.

With the continuous moulding technique these systems can be applied at a reduced pipe filling density of 60-65 g/l (free rise). As a comparison, 80-100 g/l filling density is required for discontinuous pipe filling to achieve a similar core density. This accounts for a reduction of approximately 25% of foam material and therefore results in substantial cost savings for the raw material. Further cost savings result from a thickness reduction of the HDPE casing pipe which is extruded around the foam. In general, the percentage of cost savings for HDPE is similar to the savings obtainable for the polyurethane foam.

A consequence of the lower foam density is a somewhat reduced compressive strength and shear strength. However, the values obtained are still well above the required quality norm. A high calculated continuous lifetime of 147°C for the water blown system and 145°C for the pentane blown system is obtained over a period of 30 years continuous service.

The continuous moulding technique allows

cost savings for the raw materials

Table 2. Properties of a water blown rigid foam for continuous pipe production

Property	Unit	Test method [1]	Typical values	Requirement acc. to EN 253 [1]
Average cell size	mm	5.3.2.1	<0.5	<0.5
Closed cell content	%	5.3.2.2	93	>88
Foam density	g/l	5.3.3	70	>60
Compressive strength	MPa	5.3.4	0.47	>0.3
Water absorption	% vol	5.3.5	3.1	<10
Shear strength before ageing				
axial at 23°C	MPa	5.4.2.1	0.17	>0.12
axial at 140°C	MPa	5.4.2.2	0.16	>0.08
tangential at 23°C	MPa	5.4.3	0.43	>0.20
Thermal conductivity	Wm.K	5.4.5	0.029	<0.033
Calculated continuous lifetime temperature, 30 years	°C	5.4.4	147	>120

Table 3. Properties of a pentane blown rigid foam for continuous pipe production

Property	Unit	Test method [1]	Typical values	Requirement acc. to EN 253 [1]
Average cell size	mm	5.3.2.1	<0.5	<0.5
Closed cell content	%	5.3.2.2	94	>88
Foam density	g/l	5.3.3	61	>60
Compressive strength	MPa	5.3.4	0.41	>0.3
Water absorption	% vol	5.3.5	3.7	<10
Shear strength before ageing				
axial at 23°C	MPa	5.4.2.1	0.21	>0.12
axial at 140°C	MPa	5.4.2.2	0.13	>0.08
tangential at 23°C	MPa	5.4.3	0.38	>0.20
Thermal conductivity	Wm.K	5.4.5	0.027	<0.033
Calculated continuous lifetime temperature, 30 years	°C	5.4.4	145	>120

Advanced semi-flexible foam systems for flexible pre-insulated pipes

The continuous moulding technique is perfectly suited for the production of flexible pipes as this technique imposes no restrictions on the length of the pipe produced. Flexible pipes are produced in lengths of hundreds of meters and coiled up after production. Flexible pipes are pipe in pipe systems with service pipes produced of i.e. thin-walled steel, soft annealed copper, cross-linked polyethylene (PEX), polybutylene or aluminium. Forward and return flow service pipes can be fitted into a shared casing pipe.

The casing pipe can be steel, high or low density polyethylene. Corrugated service and casing pipes are sometimes employed which enhance the flexibility and help to retain the adhesion between foam and pipe during and after the bending of the pipe.

Flexible pipes are being used more and more frequently because of the ease of handling. Installation is very simple, i.e. house connections can be made without major preliminary planning since obstacles can be bypassed simply by bending the pipe. Flexible pipes can be laid continuously and hence fewer joints are required which avoids the time consuming welding of the service pipes with the subsequent joint filling. This results in a higher laying speed and hence contributes to cost reduction. The trench profile for flexible pipes is usually narrower and the flexibility of the pipe allows alleviation of cost-escalating route situations. Therefore excavation costs are lower, in particular for smaller pipe diameters.

An important outlet for flexible pipes is district heating, in particular in the secondary district heating network, i.e. for house connections. Other applications include drinking and waste water pipes in industry and agriculture, refrigeration plants, swimming pools and many other special fields.

Requirements for a semi-flexible polyurethane foam

To allow the coiling-up of the pipes after production without loss of adhesion between foam and pipes, a high degree of foam flexibility is necessary. However, the foam should also provide good mechanical properties and a high thermal resistance. For temperatures below 95°C where PEX pipes are normally used, a permanent heat resistance of the foam of 95°C is sufficient. However, for service temperatures up to approximately 130°C, where a metal inner pipe such as copper or steel is used, the foam system must provide an increased heat resistance.

High flexibility and high thermal resistance are antagonistic properties: a high flexibility usually requires a low cross-link density whereas a high thermal resistance asks, besides other features, for an increased cross-link density. Nonetheless, we have found that a special combination of short and long chain polyether polyols permit foams which combine high thermal resistance with high flexibility.

Table 4 shows properties of water/pentane dual blown foam systems, where rigid foams were flexibilised through the addition of a long chain polyether polyol. The flexibility could be increased by increasing levels of the long chain polyol, however, at the same time, the heat resistance dropped considerably. Short and long chain polyol were compatible and well miscible.

Table 4. Properties obtained with miscible combinations of short and long chain polyols

Property	Unit	Test method	1	2	3	4	5
OH-value	mg KOH/g	calculated	450	405	365	325	280
Reactivity, cream/fibre time	s	SMS 2318	15/45	15/47	14/46	15/47	15/47
Softening temperature, initial	°C	TMA	127	115	101	84	70
after 24 hours at 130°C	°C	TMA	137	129	112	99	83
Flexibility	mm	DIN 53423	8	12	15	18	20
Compressive strength	kPA	ASTM 1621	340	280	279	181	208

Table 5. Properties obtained with immiscible combinations of short and long chain polyols

Property	Unit	Test method	6	7	8	9	10
OH-value	mg KOH/g	calculated	450	405	365	325	280
Reactivity, cream/fibre time	s	SMS 2318	14/38	13/37	14/38	14/38	12/39
Softening temperature, initial	°C	TMA	140	143	135	132	126
after 24 hours at 130°C	°C	TMA	141	146	147	142	138
Flexibility	mm	DIN 53423	12	11	13	15	21
Compressive strength	kPA	ASTM 1621	331	274	245	181	161

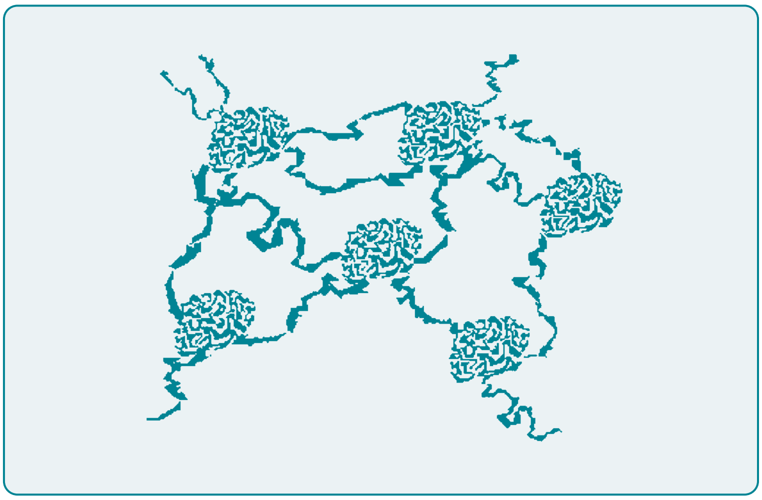
Table 5 shows properties of foams made with a combination of a short and a long chain polyol which were not compatible. The foams were also water/pentane dual blown. The OH-value of the polyol blends, foam network parameters like cross-link density and aromaticity and the iso-index are equal to the formulations in Table 4. Also reactivities and free rise densities are similar. The incompatibility on a macro-molecular state was seen by the separation tendency of the polyols during storage.

These formulations provide high softening temperatures together with high flexibility. Flexibility and softening temperature can be influenced via the ratio of short chain to long chain polyether polyol. Increasing the level of the long chain polyol gives an increased flexibility, however, the softening temperature is still high. Increasing the level of the short chain polyol provides an increase in softening temperature but still offers a high degree of flexibility. The variation of the ratio of short chain to long chain polyol allows composition of tailor-made foam systems for given sets of requirements.

This development work resulted in the market introduction of polyether polyols for the production, in a continuous process, of semi-flexible foam systems for the insulation of pipes, i.e. Daltofoam TE44216.

We think that a dual network consisting of hard domains which are interconnected with long, flexible chains is the reason for this behaviour. The rigid domains formed by the short chain polyol are presumed to provide the high softening temperature, the long chains resulting from the flexible polyol are presumed to interconnect the rigid domains and thereby provide the flexibility.

Figure 5. Possible structure of a semi-flexible foam



A drawback of this approach was the separation tendency of short and long chain polyol. Storage stable systems were not possible and machine modification, such as an additional day tank equipped with a stirrer to ensure thorough mixing of the components prior to use, to restore the correct blend composition, were required. Further, two storage tanks were necessary. However, the improvements in foam end properties clearly outweighed this drawback so that our customers have invested into these machine modifications.

Although the market acceptance of these semi-flexible systems was high, it was an obvious research target to overcome this separation tendency. Recently we succeeded in developing a new generation of semi-flexible foam systems that overcame the separation tendency and permitted storage stable systems.

With this new generation of semi-flexible foam systems, the combination of high flexibility and high thermal resistance is retained. The foam properties obtained with this new polyether polyol, i.e. the flexibility and the heat resistance, are comparable with the properties obtained with the non-miscible semi-flexible systems. In Table 6 typical key properties of a fully water blown semi-flexible foam are outlined:

Table 6. Comparison of a water-blown miscible and non-miscible system

Property	Unit	Test method	Daltofoam TE44200	Daltofoam TE44216
Blend stability	–	visual	stable	separates
Ratio polyol/isocyanate	pbw	–	1.08	1.00
Reactivity		SMS 2318		
cream time	s		11	11
fibre time	s		31	31
Free rise density	g/l	ISO845	59	60
Flexibility	mm	DIN53423	>15	>15
Softening temperature, initial	°C	TMA	>130	>135
Compressive strength	kPa	ASTM 1621	180-220	180-220

With a specific semi-flexible system, the softening temperature can be further increased through increasing the isocyanate-index. The flexibility is only marginally affected.

Table 7. Effect of isocyanate-index on mechanical properties

Property	Unit	Test method	1	2
Reactivity		SMS 2318		
cream time	s		8	8
fibre time	s		22	22
Isocyanate index			105	115
Softening temperature, initial	°C	TMA	136	142
Flexibility	mm	DIN53423	17.5	16.5
Flexural strength	kPa	ASTM 1623	370	350
Compressive strength	kPa	ASTM 1621	260	280

Modifying the isocyanate index is a very easy way for a pipe manufacturer to adapt foam properties slightly to particular requirements. Obviously, by changing the ratio of short and long chain polyol, larger variations in foam properties are possible.

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Biographies

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Jürgen Kellner received an MS degree in Chemistry from the University of Regensburg and a PhD in Organometallic Chemistry from the Technical University of Munich. He joined Shell Chemicals in 1989 and held various positions in research and market development in the field of epoxy resin. In 1996 he took up a position in the Chemical Research Centre of Shell in Louvain-la-Neuve, Belgium as a Senior Research Chemist in Rigid Polyurethane. He is project leader for the applicational research and development activities and technical service for rigid polyurethane foam insulated pipes.

Patrick Morton
Patrick Morton is by education an engineer in industrial chemistry. He received his diploma in 1990 and joined the Chemical Research Centre of Shell in Louvain-la-Neuve. He worked in the lamination and domestic appliances area. He is now a senior technical specialist in the field of rigid polyurethane pipe insulation.

Philippe Zarka
Philippe Zarka did his studies as a chemist at the High Technical Institute – Brugge in Belgium. He joined the Chemical Research Centre of Shell in Louvain-la-Neuve in 1990. He worked in the domestic appliances area and currently exercises a function as associate technical specialist in the rigid polyurethane pipe insulation field.

The authors joined Huntsman Polyurethanes in 1999 following a strategic alliance in the area of rigid polyurethanes between Shell Chemicals and Huntsman Polyurethanes.

The new generation of semi-flexible foam systems

combine high flexibility

and high thermal resistance

and overcome the seperation tendancy