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Mid-Term Report

Technical Report No: 3

Period of Reference: 01/07/2007 – 31/12/2008

Technical Group: TSG8

JoinTec

-

Innovative and competitive new joining technology for steel pipes using adhesive bonding

Contract Number: RFSR-CT-2007-00035

Contractors:
Universitaet Paderborn "UPB"
Salzgitter Mannesmann Forschung GmbH "SZMF"
Gaz de France SA "GDF"
Sika Danmark AS "SIKADK"
Centro Sviluppo Materiali SPA "CSM"
Salzgitter Mannesmann Line Pipe GmbH "MLP"
Arbeitsgemeinschaft fuer Waerme und Heizkraftwirtschaft e.V. - AGFW- "AGFWEV"
Bohlen & Doyen Polska Sp. Z o.o. - „BOHLENDP“

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Completion Date:	30/06/2010

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I. TABLE OF CONTENTS

II. ABSTRACT

The loads, expected to affect the pipes during laying and service and the resulting stresses in the joint were calculated to act as input for the adhesive development and joint design. With a FE-model first simulations of the qualitative stress progress in the joint were performed using different joint geometries.

As a joint geometry, a simple overlapped joint using a steel sleeve, was elaborated in detail. The gap of the pipes to be bonded is adjusted by using steel wedges, which are driven between the pipes and the sleeve. It is sealed with heat shrinking material, preventing an adhesive leakage. Adhesive application was elaborated and feasibility tests were performed. The adhesive is injected into the gap using a pressurised air driven cartridge system. A complete filling of the gap will be assumed, if the adhesive leaks from an upper borehole. Tests were performed to proof this assumption using different adhesives. As a result of first adhesive characterisation and tests, an adhesive was chosen which will be modified to fit the needs resulting from pipe bonding. Strength tests with adhesively bonded pipes were performed at UPB and SZMF using small-scale-pipes. Additionally, process defects were incorporated during pipe bonding to indicate the weaknesses of the developed joining concept. For choosing a surface pre-treatment, different surface states were benchmarked using peel tests and determinations of contact angle. As a pre-treatment, an epoxy coating was chosen. First tests concerning an accelerated curing were performed and influences of the heat input of the mechanical properties of the adhesive were verified.

SIKADK performed tests with modified PU156 to show the possibilities in changing the strength and the elongation of the adhesive and how this adhesive could be modified to match the requirements for pipe bonding. Two alternatives for adhesive application on construction sites and for full-scale testing were discussed and evaluated.

For non-destructive analysing a testing device was purchased and tested. Specimens with reference defects were used for this task. Different ultrasound inspection techniques were reviewed and rated. Work on repair procedure started. Defects were incorporated in simple overlapped specimens to determine the influences of these defects on the mechanical properties of bonded joints. Basing on these defects, a repair procedure was developed and tested.

A FE-model was set up and calculations concerning the stress distribution were performed.

The elaborated testing sequence for the full-scale tests features cyclic loadings as well as external damages to display realistic exposures in pipe life-cycle.

III. MID-TERM SUMMARY - PART I – MANAGEMENT AND CO-ORDINATION ASPECTS

III.1 Mid-term Project Overview

CATEGORY OF RESEARCH:	Steel
TECHNICAL GROUP:	TGS8
REFERENCE PERIOD:	01/07/2007 – 31/12/2008

CONTRACT N°:	RFSR-CT-2007-00035
PROJECT N°:	RFSR-CR-07-035
TITLE:	JoinTec – Innovative and competitive new joining technology for steel pipes using adhesive bonding
CONTRACTOR(S):	- Universitaet Paderborn “UPB” - Salzgitter Mannesmann Forschung GmbH “SZMF” - Gaz de France SA “GDF” - Sika Danmark AS “SIKADK” - Centro Sviluppo Materiali SPA “CSM” - Salzgitter Mannesmann Line Pipe GmbH ”MLP” - Arbeitsgemeinschaft fuer Waerme und Heizkraftwirtschaft e.V. - AGFW- “AGFWEV" - Bohlen & Doyen Polska Sp. Z o. o. “BOHLENDP”
COMMENCEMENT DATE:	01/07/2007
COMPLETION DATE:	30/06/2010
NEW COMPLETION DATE:	n/a
WORK UNDERTAKEN:	- elaboration of joining concept - screening of adhesives - choice of adhesive - characterisation of proposed adhesives - work on curing procedure - work on application method - work on repair procedure - development of non destructive testing method - planning of full-scale tests - work on FE-Model - test of reliability of proposed joining concept
MAIN RESULTS:	- load and design specifications - choice of joint design - choice of adhesive - partial characterisation of proposed adhesive - proofed feasibility of proposed joint design - partial characterisation of mechanical properties of joint design - choice of application method

	- choice of surface pre-treatment - principle for accelerated curing - choice / test of non destructive testing method - elaboration of full-scale testing program - concept for FEM calculation model - repair procedure for bonded steel pipes
FUTURE WORK TO BE UNDERTAKEN:	- final characterisation of proposed adhesive - start of full scale testing - determination of mechanical strength of small pipes under dynamic loads and climate influences - determination of curing parameters for accelerated curing - pipe laying tests on pilot plant
ON SCHEDULE (*YES /NO)*:	No
PROBLEMS ENCOUNTERED:	- Due to the insolvency of Bohlen and Doyen Polska Z. o. o. the accomplishing of the pipe laying tests is endangered. - Adhesive development delays.
CORRECTION – ACTIONS	- University of Paderborn will overtake responsibility for pipe laying tests. The tests will be done by a subcontractor on behalf of University of Paderborn. Pipes will be bonded by University of Paderborn and Salzgitter Mannesmann Forschung. - As the adhesive development delays it was decided to use PU156 for further tests. The tests on simplified joints will be done with this adhesive, too, as well as the full scale tests and the pipe laying tests. The adhesive to be developed will be available at the end of the project and qualified using tests on the adhesive bulk and simplified joints. Additionally, specifications of future adhesives for pipe bonding will be elaborated.

BUDGET INFORMATION PER PARTNER:	- Universitaet Paderborn “UPB” Budget: **490.548 €** - Salzgitter Mannesmann Forschung GmbH “SZMF” Budget: **425.693 €** - Gaz de France SA “GDF” Budget: **9.211 €** - Sika Danmark AS “SIKADK” Budget: **128.975 €** - Bohlen und Doyen Polska Spolka Z Orgraniczona Odplwiedzialnoscia “BOHLENDP” Budget: **111.838 €** - Centro Sviluppo Materiali SPA “CSM” Budget: **280.000 €** - Salzgitter Mannesmann Line Pipe GmbH ”MLP” Budget: **92.650 €** - Arbeitsgemeinschaft fuer Waerme und Heizkraftwirt-schaft e.V. - AGFW- “AGFWEV" Budget: **9.720 €**
COST OF THIS PERIOD (EURO): *	**532.224,32**
TOTAL COST TO DATE (EURO): *	**532.224,32**
TOTAL BUDGET (EURO) :	**1.548.635**
PUBLICATIONS – PATENTS :	n/a

III.2 Programme Bar Chart

Figure 1 shows the progress of the JoinTec project at the end of the third reporting period.

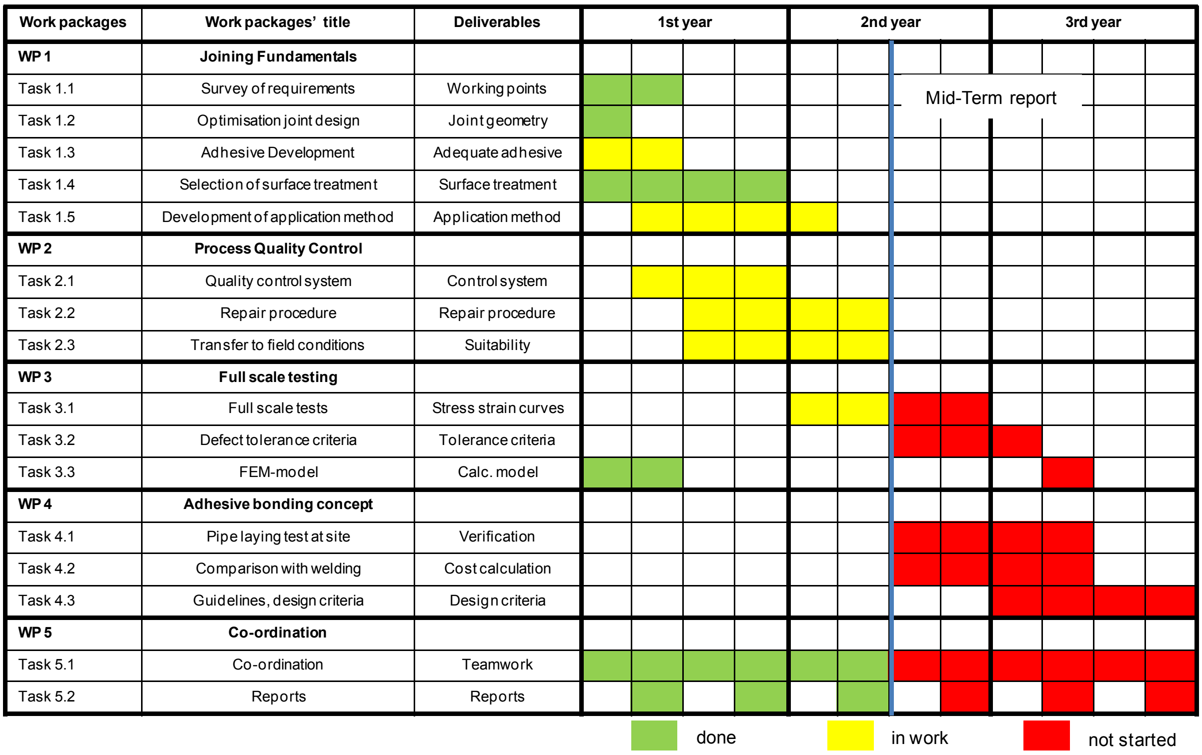


Figure 1: programme bar chart

III.3 Management and Co-ordination

For co-ordination aspects the project team held meetings every half year to present the research work done in the relevant period and to discuss the results obtained in an interdisciplinary environment. These meetings took place in Paderborn, Frankfurt, Hamm and Rome. Due to the complexity of the contents of the project, it was decided in Hamm to perform co-ordination meetings of several days duration to cope with all objectives of the relevant period. This procedure can be reviewed as successful because of the more deeply discussions and the positive influences in building a team. Sub-group meetings were performed under participation of the project partners and the co-ordinator for discussing topics in detail.

Due to the insolvency of Bohlen & Doyen Polska, great efforts were made to replace this project partner by an equal substitute. This substitute could have been the German Bohlen & Doyen Bauunternehmung. Negotiations were entered to find a solution how the working points of Bohlen & Doyen Polska can be accomplished with a reduced budget. Eventual this solution failed because of reservations of the European Commission concerning Bohlen & Doyen Bauunternehmung. Due to this fact the project team decided to perform the pipe laying tests with the support of consulting engineers on a pilot plant. As this approach got the agreement of the European Commission, it has to be detailed and fixed in the project proposal. Therefore, project partners identified consulting engineers and pilot plants for these purposes.

Due to delays in developing an adhesive for pipe bonding, the adhesive, which seems most suitable after the screening, will be used for further tests. These tests will help to characterise the adhesive concerning the lap-shear strength, the behaviour under dynamic loads like cyclic loads and crash loads. Changing mechanical properties of the adhesive under the influence of aging will be evaluated as well. All tests on big pipes will be performed using the proposed adhesive as well. As soon as the new adhesive is available, test to characterise it will be performed. These tests will give the indication if the new developed adhesive will fit on the needs of pipe bonding.

IV. MID-TERM SUMMARY - PART II - SCIENTIFIC AND TECHNICAL PROGRESS

IV.1. INTRODUCTION

Joining techniques such as welding, brazing, riveting and screwing are used by industry all over the world on a daily basis. As a result of the very successful developments in recent years a further method of joining is becoming more and more important and is already a key technology in many areas: adhesive bonding.

The main innovative value of this research work is the introduction of pace developments in adhesive bonding technology of recent years into the steel pipe industry by means of an interdisciplinary European team work between leading companies and research facilities from the steel and the adhesive industry. The joining concept will be based on the present pipeline requirements including operation and maintenance processes.

A main objective is the development of an efficient, integrated and easy-to-use joining technique for adhesive bonding of steel pipes. In addition, guidelines, design calculation methods and non-destructive testing methods including a repair concept for adhesively bonded steel pipes have to be prepared. To guarantee the transferability of the elaborated bonding concept, pipe laying tests, using the developed technology will be performed including the appliance of a non-destructive quality control, which is under development. In addition, cost calculations and cost comparisons to conventional joining technologies will be performed to prove the economical benefit of adhesive bonding for pipe-joining.

The report at hand treats with the research work done in the first half of the JoinTec project. It consists of the research work of the following working packages:

Work package 1: Joining Fundamentals
Work package 2: Process Quality Control
Work package 3: Full scale testing
Work package 5. Management and co-ordination

IV.2. TECHNICAL IMPLEMENTATION REPORT

IV.2.1. WORK PACKAGE 1: JOINING FUNDAMENTALS

IV.2.1.1. Task 1.1 Survey of Requirements

The application for pipe joints using adhesive bonding is the transport of water, heat and natural gas. Depending on this, the pipes to be used are chosen and the loads occurring while pipe laying and pipe service were calculated and are described in the following chapter. This leads to the technical boundary conditions which define the tasks and working points to be worked on in this project. The next chapters present the results of the research work done.

Design Loads

Generally, two load cases have to be considered in designing pipelines, namely loads during operating conditions and loads resulting from laying. Further we consider two pipe geometries for future investigations that have to be performed within the project. Salzgitter Mannesmann Line Pipe GmbH provides the geometries:

- D_a x t = 168.3 x 7.0 mm for the transport of water and
- D_a x t = 508.0 x 8.8 mm for the transport of water, heat and gas.

Thus, we can calculate the loads for the different loading conditions and pipe geometries as follows below.

Loads during Operating Conditions

The leading force under operating conditions is the internal pressure which leads to a circumferential stress σ_φ and an axial stress $\sigma_x = 0.5\sigma_\varphi$ in the pipe. Considering a pressure of $p < 16$ bar, respectively $p < 40$ bar we gain the axial normal force given in Table 1 and depending on the internal operating pressure p. For a conservative approximation of pressures and forces in the test phase of the bonding, the test loads are scaled by the factor 1.5. This is reasonable to cover the scattering and to ensure the quality of the expected structural resistance.

Table 1: Loads during Operating Conditions

Pipe Geometry Da x t	Load Case 1: Internal Pressure			
	Internal Pressure		Resulting Axial Force	
168.3 mm x 7.0 mm	$p_{operating}$ [bar]	16	$N_{x,operating}$ [kN]	34
	p_{test} [bar]	24	$N_{x,test}$ [kN]	51
508.0 mm x 8.8 mm	$p_{operating}$ [bar]	40	$N_{x,operating}$ [kN]	797
	p_{test} [bar]	60	$N_{x,test}$ [kN]	1195

Loads resulting from laying

On the construction site the pipeline is welded, so that some hundred meters or almost kilometres of pipeline result. While lifting the pipeline with a side boom into the trench, moments and axial forces arise due to bending of the pipeline. The resulting forces are summarized in Table 2.

Table 2: Loads resulting from laying

Pipe Geometry Da x t	Load Case 2: Laying			
	Bending Moment		Axial Force	
168.3 mm x 7.0 mm	M_{laying} [kN m]	38,8	$N_{x,laying}$ [kN]	745
	M_{test} [kN m]	58	$N_{x,test}$ [kN]	1118
508.0 mm x 8.8 mm	M_{laying} [kN m]	476,3	$N_{x,laying}$ [kN]	2900
	M_{test} [kN m]	714	$N_{x,test}$ [kN]	4350

Design Stresses in the Adhesive

Shear Stresses resulting from Pipe Laying

We can calculate the normal bending stresses in the pipe by the beam theory with $\sigma_x(z_i)=M/EI*z_i$. Herein *M* is the bending Moment, *E* Young's modulus, *I* the moment of inertia and z_i the distance to the centre as shown in Figure 2. To evaluate the shear stresses in the adhesively bonded joint on the outside area of the pipe we calculate an equivalent resulting force $R_i = \sigma_x(z_i)*A_i$ that acts on a respective incremental area A_i of the cross section of the pipe. With this resulting force we compute the shear stresses on the incremental surface area A_{glue} by $\tau(z_i)=R_i/A_{glue}$ within a numerical simulation.

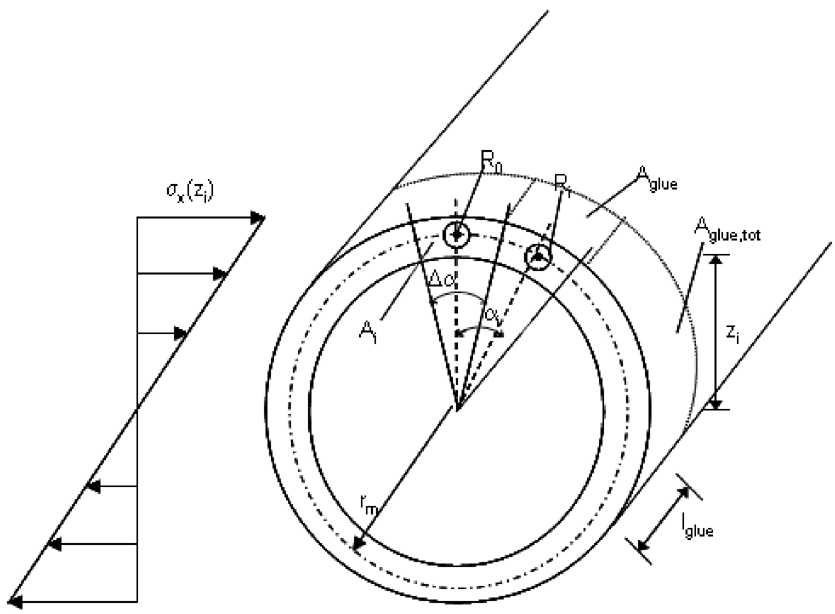


Figure 2: Incremental geometry and forces on the cross section of a pipe

The more incremental steps we choose, the more our solution converges to the real solution. Here we achieve convergence using 200 steps which means an incremental angel of α = *0.45*°. The solution is verified by comparing the bending moment with the sum of the incremental bending moments computed by $M_i=z_i*R_i$, which leads to an error of less than 1%.

In our case the maximum shear stresses yield from the test loads in the case of laying given in Table 2.

We superimpose the shear stresses from bending with the shear stresses obtained from the axial force mapped on the whole circumferential surface area $A_{glue,tot}$. These stresses are constant over the whole cross section and are calculated by the simple mapping $\tau_N = N_x / A_{glue,tot}$. In Table 3 the maximum shear stresses that can occur due to bending, normal force and in total are summarized.

Table 3: Maximum shear stresses in glued joint

Pipe Geometry Da x t	max. shear stresses			
		τ (z.i) [MPa mm]	τ_N [MPa mm]	τ_{tot}(z.i) [MPa mm]
168.3 mm x 7.0 mm		1900	2115	4015
508.0 mm x 8.8 mm		2433	2726	5159

The shear stresses are given in MPa·mm, which means that the stresses depend on the length of the sleeves. We can calculate the true stresses according to one half of the sleeve length. This means, for the 168.3 x 7.0 mm pipe, τ_{tot}(z.i) = 4015 MPa mm and a sleeve length of l_{sleeve}= *600 mm:*

$$\tau = \frac{\tau_{tot}(z_i)}{l_{sleeve}/2} = \frac{4015}{300} = 13.38 MPa \quad (1)$$

Remark: Due to the equilibrium conditions we have to take into account only one half of the sleeve length. The above calculations do not consider the stress concentrations in the transition point from steel pipe to adhesive. The calculations are based on the assumption of a constant stress distribution in the adhesive. As the loads are chosen quite conservative, the calculation should be sufficient for the test phase of the project.

Thus, we can fit the length of the sleeves and the shear stresses in the adhesive to each other. By reformulating (1) we can directly compute the sleeve length with a given maximum shear stress capacity of the adhesive. Here we assume to the latest information a max shear stress capacity $\tau_{glue,max}$ = 15.0 MPa of the PU156 due to the information of UPB and SIKADK. The following total sleeve lengths for the joints are computed respectively, see Table 4:

Table 4: Required sleeve lengths in glued joint

Pipe Geometry Da x t	sleeve length			
		$\tau_{glue,max}$ [MPa mm]	$l_{sl,comp.}$ [mm]	l_{sleeve} [mm]
168.3 mm x 7.0 mm		15	535	550
508.0 mm x 8.8 mm		15	688	700

IV.2.1.2. Task 1.2: Choice of Joint Design

Adhesive bonding requires bonding surfaces in a sufficient expanse. Keeping this in mind it is difficult to use butt-joints, because only small bonding surfaces can be realised. Therefore, alternative joint geometries have to be examined to achieve maximum bond strength with a

minimum of complexity for joining and adhesive application. This is important to meet the quality requirements for joining pipes under conditions at construction sites.
As a first step, formal principles of joint design were identified (Figure 3). With these joint designs a utility analysis was performed reviewing the advantages and disadvantages of the different joint designs.

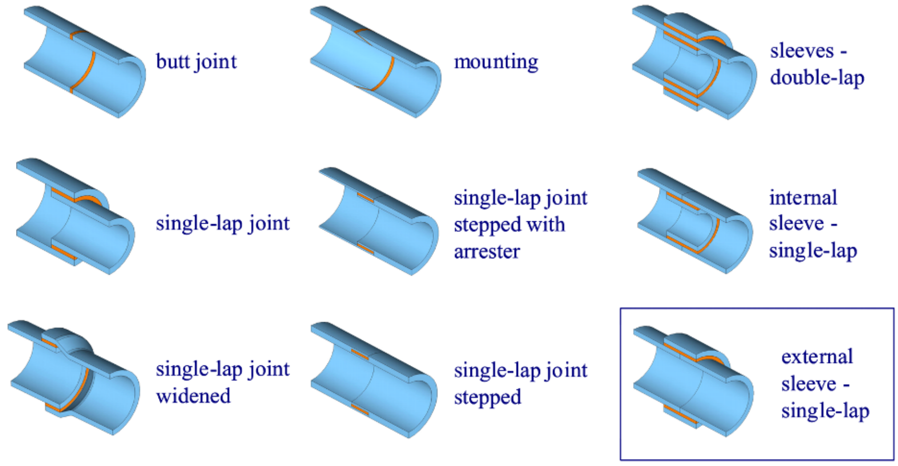


Figure 3: formal principles of joint design

Identified criteria for this benchmarking were: production expenditure, utilisation of material, strength of the adhesive joint, flow obstruction and joining at construction site. These criteria were weighted and analysed. First indications for the strength of the adhesive joint have been determined using finite-element-simulations. As a result, the utility analyses pointed out that the joint geometry using a single-overlapped external sleeve is most suitable. On this basis, a joining concept was elaborated, which is introduced in Figure 4, Figure 5 and Figure 6.
After sliding the sleeve over a fixed pipe, the ends of the non bonded pipes are positioned to each other. To align the pipes, an internal centring device is used. The pipes are locked into position using hydraulic clamps (Figure 4).

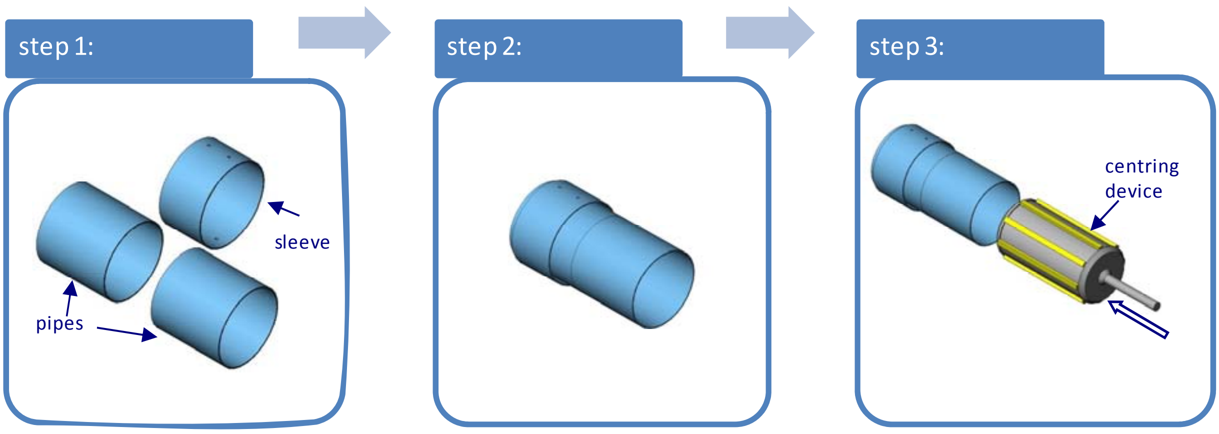


Figure 4: Concept for pipe joining using adhesive bonding (step 1 - 3)

To avoid contact between the adhesive and the transported medium, a sealing material is applied to the gap between the pipes. To adjust a defined bond line, steel wedges are driven into the gap between the steel pipes and the sleeve. To prevent an adhesive leakage out of the gap, the ends of the pipes are sealed with heat shrinking material, which is actually used to inhibit corrosion of welds (Figure 5).

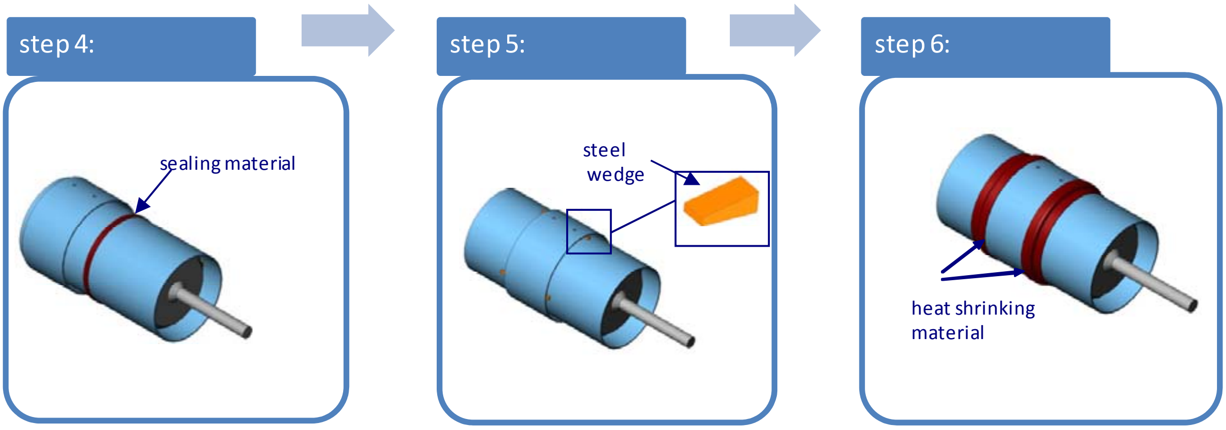


Figure 5: Concept for pipe joining using adhesive bonding (step 4 - 6)

The adhesive is injected through holes into the gap until it leaks out of the upper boreholes. That guarantees a complete gap-filling. After curing the adhesive, the centring device can be removed. Finally, the pipes are bonded adhesively. The cut-away view shows all relevant attributes of the joint geometry (Figure 6).

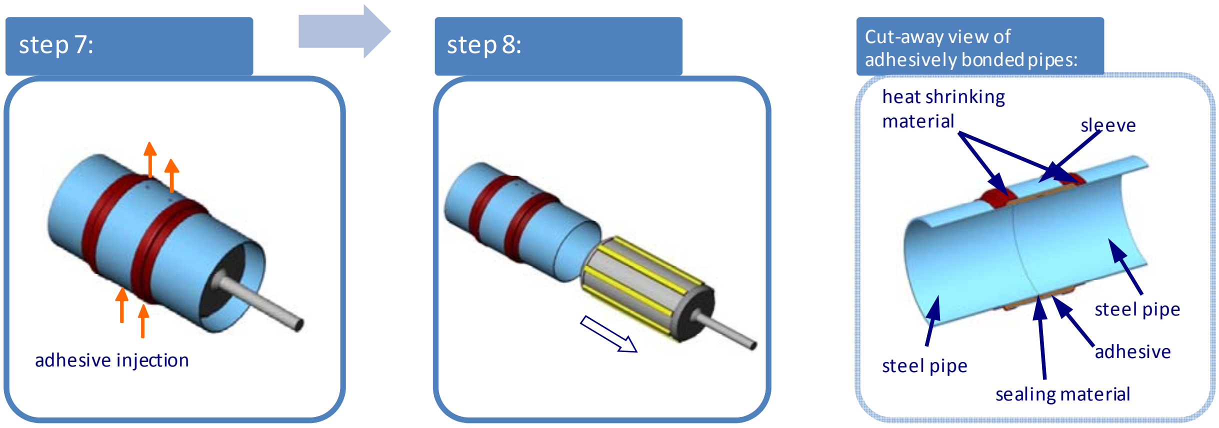


Figure 6: Concept for pipe joining using adhesive bonding (step 7 & 8)

To show the feasibility of the pipe bonding concept, small-scale-pipes made of S355 with a diameter of D = 50 mm and a wall thickness of t = 3 mm were adhesively bonded. The sleeves used were made of acrylic glass (Figure 7).

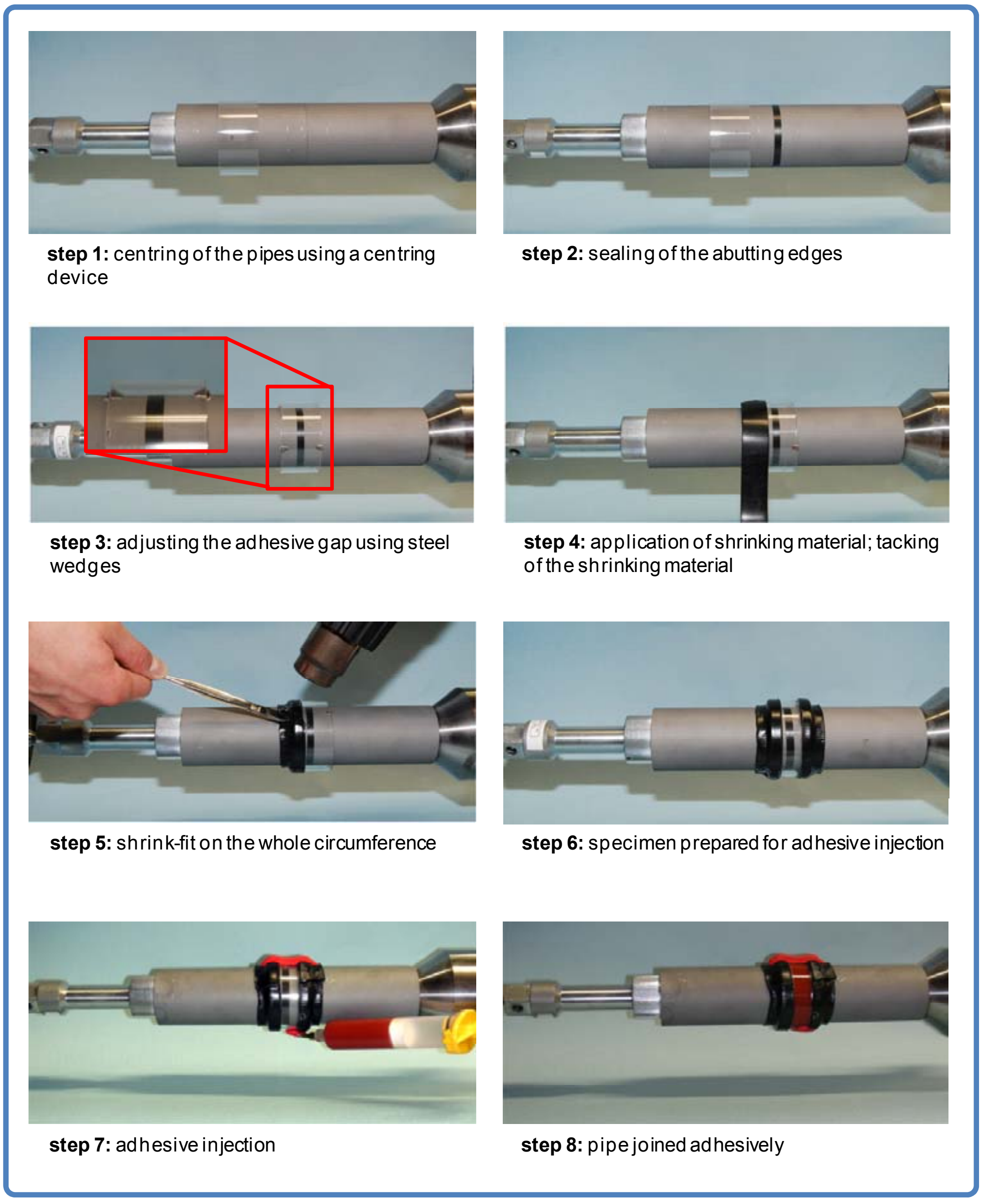


Figure 7: proof of feasibility of bonding concept for steel pipes

The tests show the feasibility of bonding pipes using the presented joining concept.

Further research work was undertaken to proof the complete filling of the gap using injection as application method. For this purpose, sleeves made of acrylic glass were used. The influences in using the adhesives PU154, PU155 and PU156 were tested just as well as the influences of using different filling pressures and different positions of the injection in- and outlets. After filling the gap and curing of the adhesive, the specimens were cut into sections for detecting failures in the bond line. Results using adhesive PU154 and filling pressures of 1 bar show that trapped air can be found on the whole circumference of the pipe. The thickness of the glue line can be characterised as constant (Figure 8).

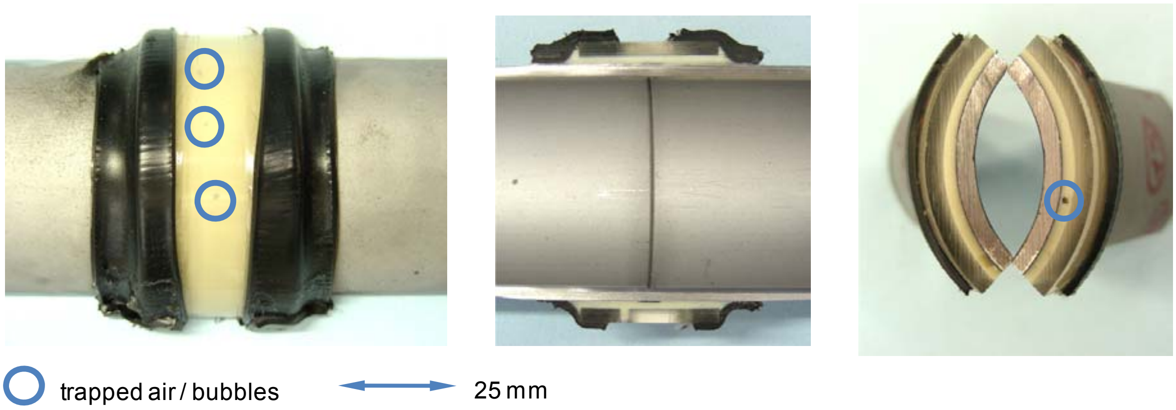


Figure 8: Filling of the gap. Adhesive: PU154; Viscosity: pasty; Filling pressure: 1 bar

Gap filling using PU156 with a viscosity of 3200 mPa*s and the same filling pressure as used by processing PU154 is much better. There was no trapped air found on the whole circumference. The glue line is also constant, what can be related to the use of the steel wedges. Using this adhesive, trapped air could only be detected at the transition between the sleeve and the shrinking material. This kind of air-trapping is rather uncritical, because this area has only a slight to no influence on the strength of the joint (Figure 9).

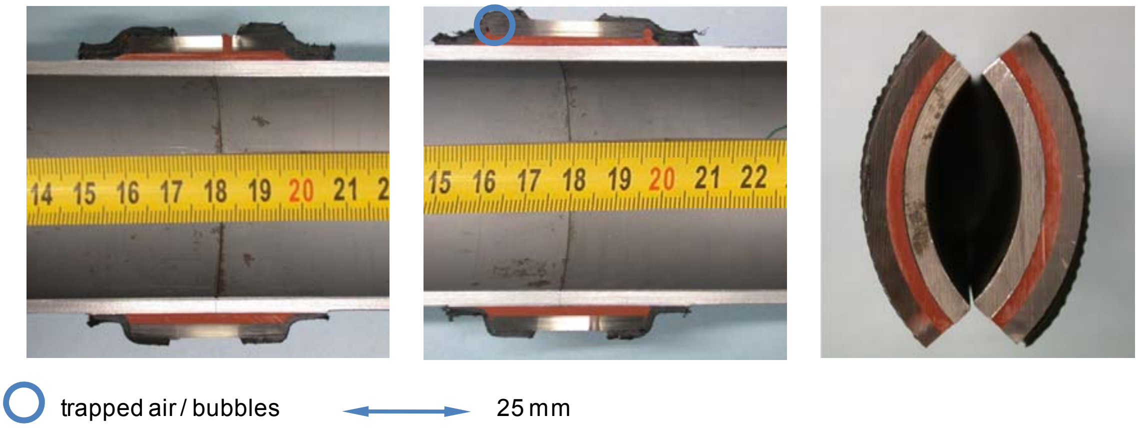
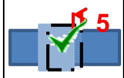
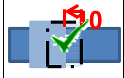
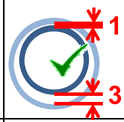
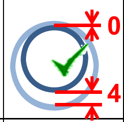
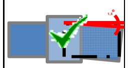


Figure 9: Filling of the gap. Adhesive: PU156; Viscosity: 3200 MPa*s; Filling pressure: 1 bar

It could be shown that best results in processing could be reached using PU156. For this reason, following tests were performed using these parameters.

To identify the strengths and weaknesses of the developed joining process, defined processing failures were incorporated during the joining process as they are shown in Table 5.

Table 5: Processing defects

defect	parameter	modification			
		mod.	status	mod.	status
Horizontal misalignment of the sleeve	Horizontal position of the sleeve	5 mm		10 mm	
Lateral misalignment of the sleeve	Lateral position of the sleeve	1 mm		2 mm	
Angular misalignment of the sleeve	Angle of the sleeve	5,7°	to be performed	7,6°	
Angular misalignment of the pipe	Angle of the pipe	1,5°		3°	to be performed

Results show that not every processing defect, related to misalignments of the used sleeves or pipes, leads to decreased resistance to tensile forces of the joint (Figure 10).

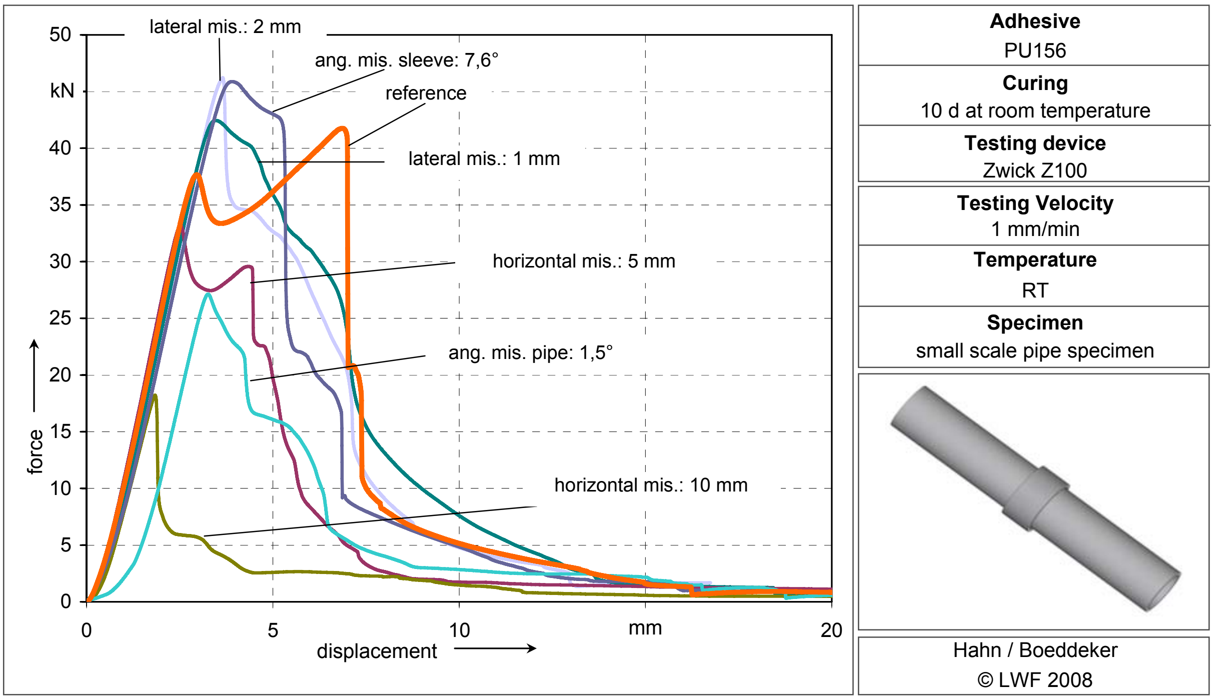
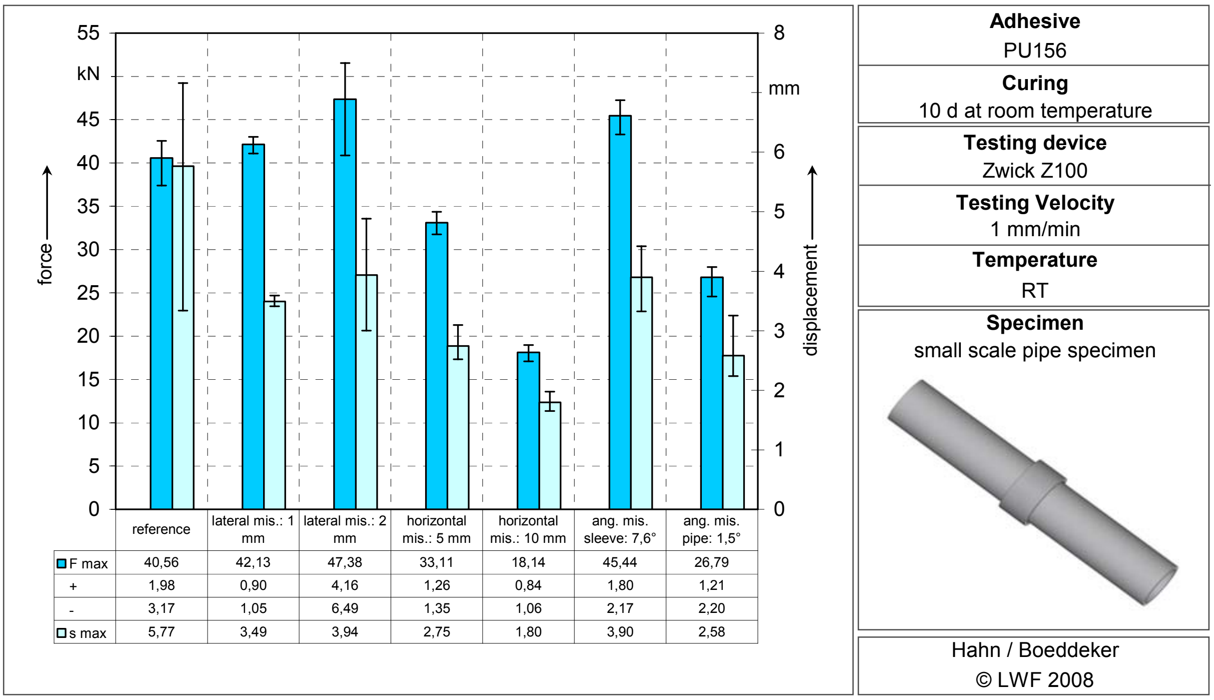


Figure 10: force-displacement curves of pipe specimens misaligned during assembling process

Lateral misalignments of 1 mm and 2 mm of the pipes effect an enhancement of the maximum forces combined with decreased displacement. The effect of the maximized forces can be explained through a partially minimized adhesive gap. The loss of strength which occurs through a maximized adhesive gap on the opposite is not as distinctive as the gain of strength related to the minimized gap. This effect can also be seen in the results of the shear-stress shear-strain tests. Contrariwise, the mechanical properties of the bonded small pipe specimens decrease rapidly when misaligning the sleeve horizontal. This behaviour is strongly depending on the reduction of the bond area. Figure 11 shows a comparison of the results of the tests using misaligned pipes. It can be stated out that not every processing defect will lead to a critical failure which may effect a demolition of the bonded pipes under loads. From this achievement, guidelines for pipe joining using adhesive bonding can be derived. The results found will also help to define defect tolerance criteria as they will be of importance in task 3.2.



	reference	lateral mis.: 1 mm	lateral mis.: 2 mm	horizontal mis.: 5 mm	horizontal mis.: 10 mm	ang. mis. sleeve: 7,6°	ang. mis. pipe: 1,5°
F max	40,56	42,13	47,38	33,11	18,14	45,44	26,79
+	1,98	0,90	4,16	1,26	0,84	1,80	1,21
-	3,17	1,05	6,49	1,35	1,06	2,17	2,20
s max	5,77	3,49	3,94	2,75	1,80	3,90	2,58

Figure 11: strength of specimens with defined processing defects

As a result, it can be stated that the proposed joining concept is robust against failures made in the assembling process, because using the steel wedges for centring the sleeve prevents misalignments by itself. In the same way the use of a centring device for aligning inhibits the pipes from any misalignments. Horizontal misalignments of the sleeve are critical defects which can easily prevented by marking the positions of the sleeve on the pipes.

Handling of a steel sleeve may cause problems on construction sites. Due to the bulky geometry handling is hindered. For simplifying the handling of the sleeves on the construction sites, a shift of the sleeve's material from steel to plastics seems suitable to reduce weight. A sleeve was developed, which integrates the function of sealing the joint from adhesive leakage and preventing corrosion of the sleeve by using PEHD as material. Sealing of the joint is realised using gaskets. Due to the special geometry, wedges for centring the pipes and the sleeve are not necessary. Thus, aligning and preparing the pipes for pipe joining should be accelerated. The concept of the proposed modified sleeve geometry can be found in
Figure 12.

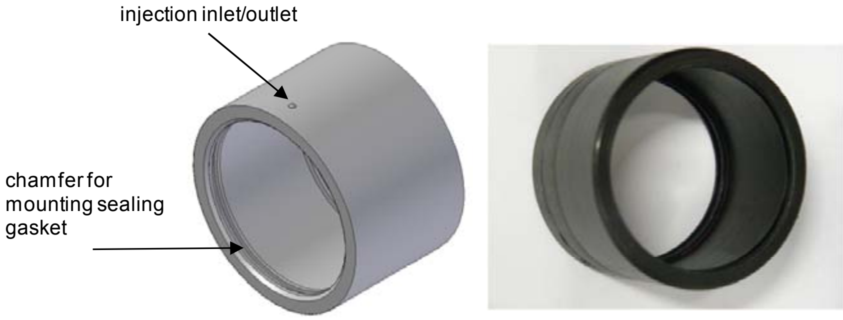


Figure 12: Proposed sleeve geometry using PEHD as sleeve material

For preparing the joint, the sleeve is pulled over the aligned pipes and centred in the middle of the abutting edges. Sealing the sleeve with shrinking material is not necessary due to the integrated gaskets. The adhesive application is done in the same way as known from the above presented joining concept.

Strength tests were made using this joint geometry (Figure 13). Results show that only 15 kN

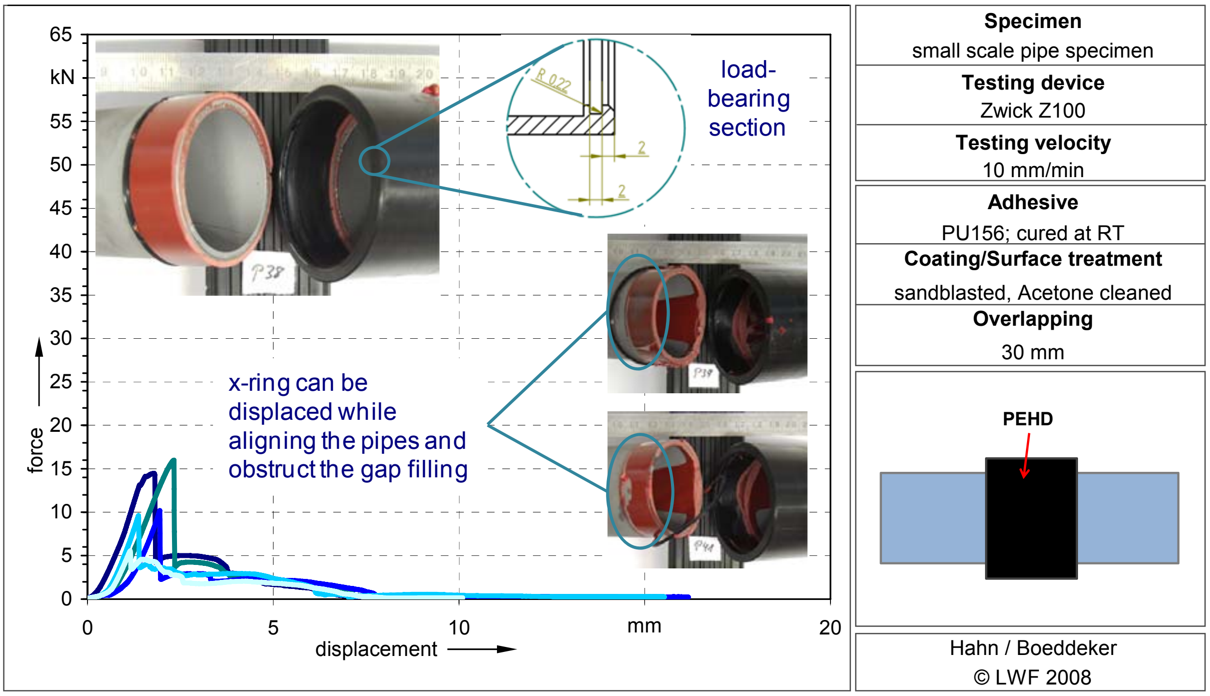


Figure 13: Strength tests of bonded pipes using sleeves made of PEHD

of bond strength can be reached. This comparably low value can be explained by analysing the appearance of fracture. The failure can be characterised as an adhesive failure, whereas this failure is not related to an incomplete wetting of the sleeves' surface, because the brush marks of the sleeves' surface can be detected as subdued relief at the cured adhesive.

Additionally, the pipes were not leak-proof. Due to the x-ring gaskets, which should prevent an adhesive leakage and which slipped off their position while aligning the pipes, the adhesive was able to flow out the sleeve.

To conclude, the proposed sleeve made of PEHD was not able to compete with the sleeve made of steel. Pipe preparation with these sleeves may be faster than using steel sleeves, but their mechanical properties and reliability can not reach the properties of the steel sleeves. Therefore, no further tests will be made using this geometry.

Next steps

As next steps dynamic strength tests of small scale pipe specimens will be performed. Tests with aged pipe specimens (VDA 621-415 and P-VW 1200) will be performed afterwards. These tests will be made using uncoated and coated pipes. As alternative sleeve material, tests with glass-fibre reinforced plastic will be performed. Additionally, tests with stress optimised bond lines will be carried out.

IV.2.1.3. Task 1.3: Development of an Adequate Adhesive

Initial Screening

When this project was started an initial screening to find a suitable adhesive was performed at Sika Danmark A/S (SIKADK). This screening was related to a very simple adhesion test for four of the strongest structural adhesives in SIKADK's product portfolio. It was chosen only to focus on 2-component polyurethane (2C-PUR). The four chosen candidates were PU154, PU155, PU156 and a trial product labelled 06-060-42.

The simple adhesion test was made to evaluate if an adhesive on the shelf could be used or if a new one should be developed from scratch.

The adhesion test was performed by mixing the base part with the curing agent and placing an amount of 50 g adhesive on a surface. When the adhesive had cured, the adhesion was tested by evaluating how hard it is to remove it from the surface. The result of this test can be seen in the Figure 14.

Figure 14: Evaluation of four adhesives the top one is PU-155, then PU-154 the red one is PU156 and the last one is 06-060-42 on epoxy coated surface and un-treated steel respectively

From this analysis it was clear that only PU156 performs well on both surfaces. As the adhesion showed good properties towards both surfaces it was chosen to modify the tensile properties of PU156.

Conclusion

PU156 is by far the best adhesive for this application among the ones which was tested. This adhesive will be used as reference for analyses at co-contractors and will at SIKADK be used as base for the improvements of the adhesive.

Tensile properties

To modify the tensile properties of PU156 it is necessary to adjust the formulation of the adhesive. Therefore, 40 different modifications were made and tested with respect to the tensile properties. Curing speed and changed adhesion to the surfaces was not taken into account for the tensile properties. The only focus was on elongation and strength at room temperature (23°C; RT) and at 60°C with a relative humidity of 50 %. The main objective was to increase the strength at 60°C as well as a higher elongation at RT.

The systems were mixed in three different series regarding the type of changes. The first series of modifications was based on the same raw-materials but in different ratios to see the changes affected from the raw-materials in the system. All tensile tests are performed on an Instron 5567 tensile testing machine according to the ISO 527-2 standard pulled at 2 mm/min.

First, the tensile properties of PU156 were to be tested to have the reference values which are listed in Table 6.

Table 6: Tensile properties of the reference adhesive PU156 at RT

Property	**PU156**
Tensile strength at max. load (TSx) [MPa]	18
Elongation at break (%elongb) [%]	4
E.modulus [MPa]	2240

The objective making the modified systems was to obtain a significant higher elongation without loosing strength. The first ten systems were analyzed for elongation above 15 % at room temperature. The results are listed in Table 7.

Table 7: Tensile properties of the 10 first modifications of PU156

Modification	1	2	3	4	5	6	7	8	9	10	std
TSx [MPa]	6	25	9	6	22	8	16	18	20	9	18
%Elongb [%]	26	1,5	46	29	1	56	7	3	3	29	4
E-modulus [MPa]	N.A	2470	N.A	N.A	2500	N.A	N.A	1170	1590	N.A	2240

std. = PU156

As it can be seen, several modifications fulfil the requirements with respect to elongation and they still show a relative high tensile strength. If temperatures will raise up to 60°C, the strength of the adhesives may probably sink to a value, which means that the requirements will not be met.

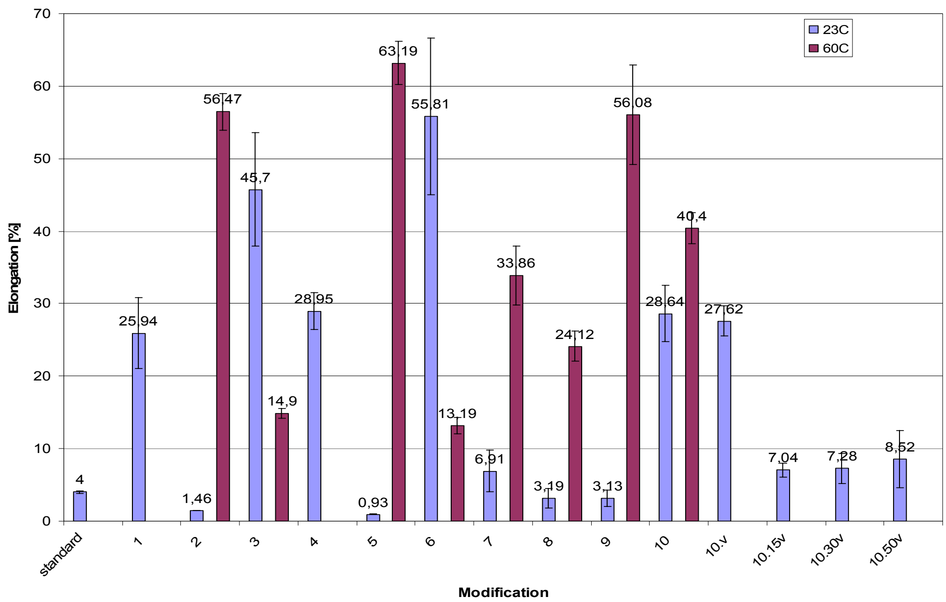


Figure 15: Elongation of tensile specimens at different temperature for the first modifications of PU156

For most of the systems the elongation was increased due to a more flexible adhesive, but this value was not as interesting at this temperature as the strength which is depicted in Figure 16.

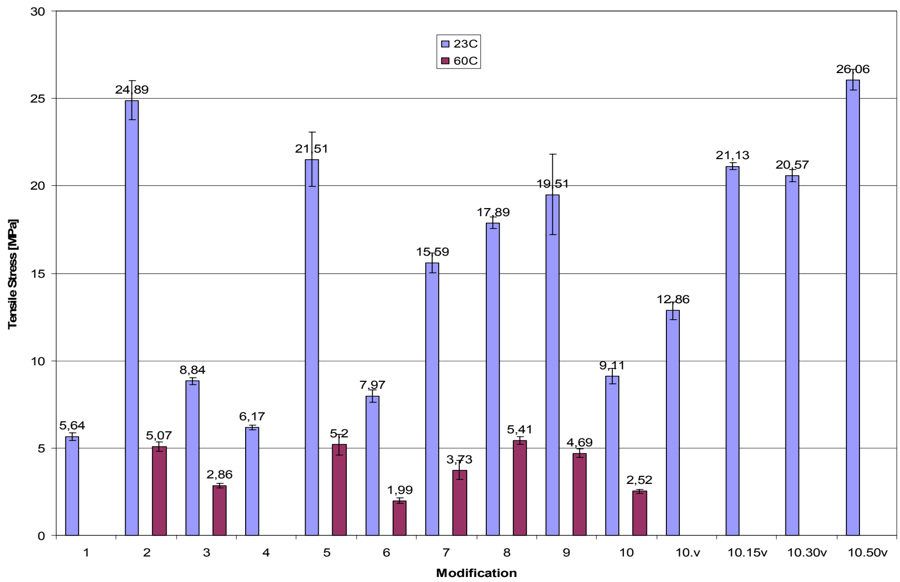


Figure 16: Tensile strengths of tensile specimens at different temperature for the first modifications of PU156

Results show, the strength decreases significantly and none of the systems showed the high strengths as it was the objective to get. However, the strength and flexibility could be increased by treating the adhesives with vacuum to get rid of trapped air - and to add a bit of cross-linking agent to increase the strength at high temperatures. The values of these modified modification made for system 10 are listed in Table 8.

Table 8: Modified systems of modification 10, v equals vacuum, c is cross-linking agent and the percentage added

Modification	10v	10,c1v	10c3v	10c5V	10	std
TSx [MPa]	13	21	21	26	9	18
%Elongb [%]	28	7	7	8	29	4
E-modulus [MPa]	N.A	N.A	N.A	N.A	N.A	2240

std. = PU156

As it can be seen, applying vacuum will increase the strength significant and yet have a high flexibility.

From this round of modified adhesives the mechanical properties are not completely out of reach, but still, more can be done, and therefore about 20 adhesive systems were mixed. Mixing these systems not only ratio has been changed but also the chemical composition. The main objectives are the same high flexibility at room temperature and high strength at 60°C.

The tensile results for most of these systems are depicted in Figure 17. A total of 20 different systems were mixed in this round, but due to too fast reaction or other problems with the mixture, only 6 systems were tested for their tensile properties.

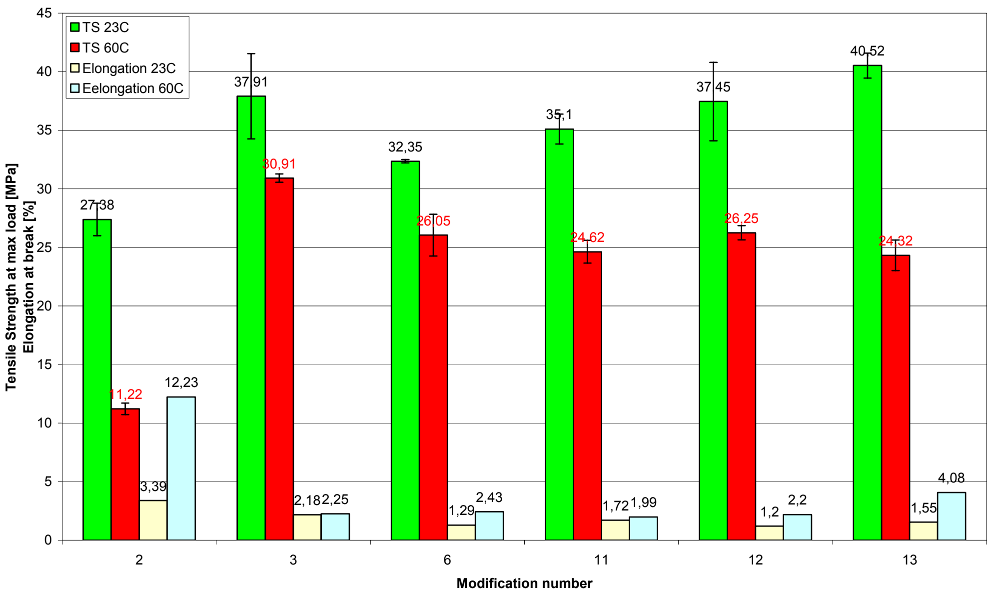


Figure 17: Tensile properties of the modifications made in the second round

The six different systems in Figure 17 show high strengths at elevated temperatures but only system 2 showed enough flexibility and was therefore chosen for further analyses. The main objectives regarding strength and flexibility were almost achieved with this adhesive system. Analysis regarding torsional strength and adhesion to the different materials will be performed for this material and compared to the original PU156.

A third round regarding the development of a new adhesive was made based on a clean paper. Only colour and some minor components were reused from PU156 - to see if an all-new adhesive would do the work. A total of eight systems were mixed in this experiment and the results from the tensile tests are depicted in Figure 18.

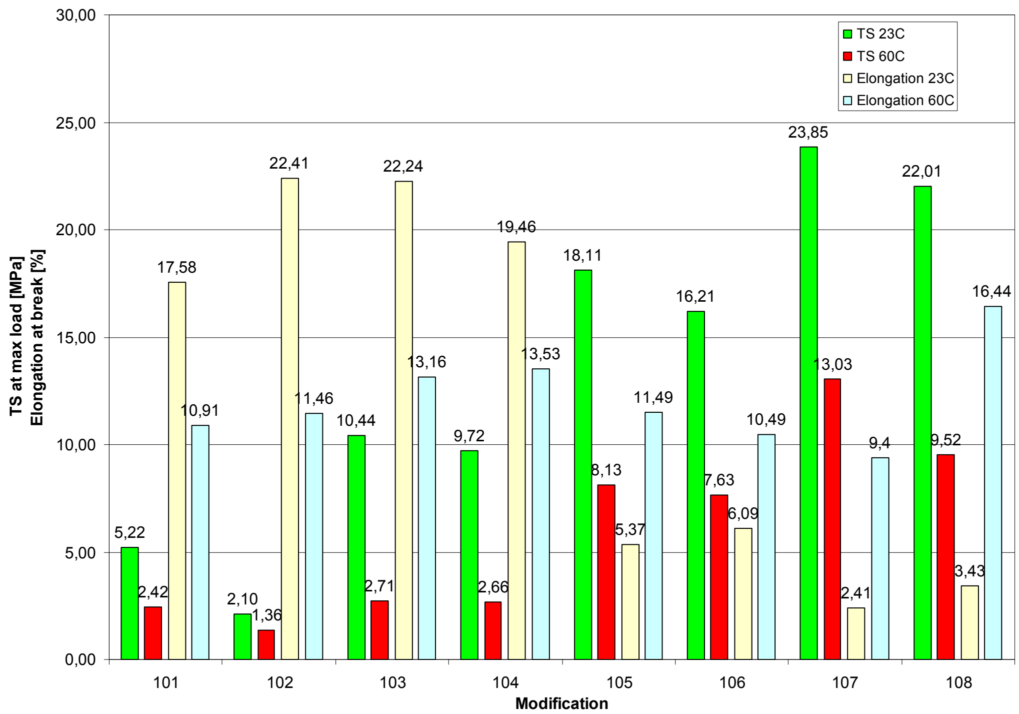


Figure 18: Tensile properties of the eight systems in the third formulation round

The systems 106, 107 and 108 showed tensile properties fulfilling the requirements for the adhesive and further analyses are made for these adhesives as well.

Conclusion

A total of 50 adhesives were mixed, but only five to six adhesives showed tensile properties fulfilling the initial requirements. The PU156 was used as a reference, and it was the purpose to improve its properties meanwhile more detailed analyses to the reference was made at the other contractors. The adhesives worth focusing on regarding adhesion and other analyses will be made for the systems PU156 (reference), modification 10,v (round 1 (called PU-1.10v)), Modification 2 from round 2 (PU-2.2) and the three systems 106, 107 and 108 from third developing round (PU-3.106, PU-3.107 and PU-3.108). These systems fulfilled the requirements regarding the tensile properties with respect to flexibility at room temperature and strength at elevated temperatures.

Adhesion test

Adhesion is tested by the use of lap-shear strengths. The higher the lap-shear strength, the better is the adhesion. Cohesive failures are preferred appearances of fracture because then the shear strength of the adhesive is the limiting factor of the joint. Adhesion failure is not easy to identify since it is more often a “near-to-surface” cohesive failure where the adhesive line is almost in-detectable. For all the tested systems a cohesive failure was observed, but for the adhesives from the third round the near-surface failure was a bit more evident than for the other systems. In Figure 19 and Figure 20 lap-shear specimens are depicted to give an overview of what is cohesive failure and what is near-to-surface cohesive failure. Cohesive failure means a rupture of the adhesive’s matrix, whereas adhesive failures are related to a too little adhesive strength of the adhesive on the substrate.

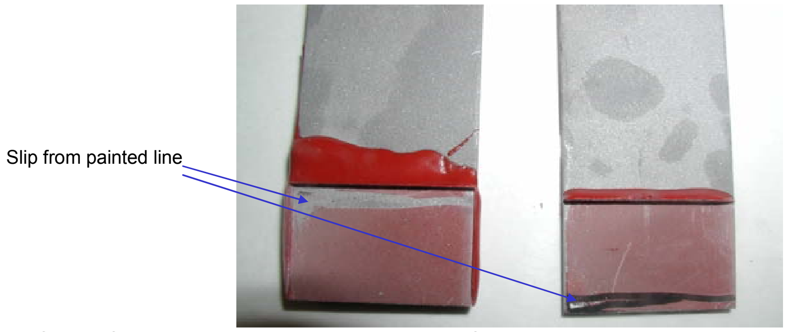


Figure 19: Full cohesive failure for PU-2.2 – the slip is due to slip of marker line

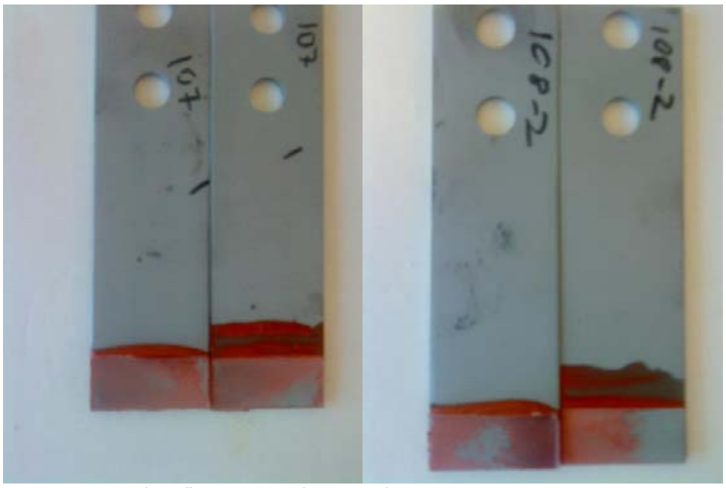


Figure 20: Cohesive and “near-to-surface” cohesive failure of the PU-3.107 and PU-3.108 systems

In Table 9 the results from the lap-shear tests are listed. The substrate, used as received, was sandblasted steel (SB steel).

Table 9: results from the lap-shear test at room temperature

Adhesive	Material	Tensile Shear Stress (TSS) [MPa]	Std. deviation
PU-2.2	SB steel	19.8	2
PU-3.107	SB steel	21.6	4.6
PU-3.108	SB steel	16.6	6.6

As it can be seen from the results, the lap-shear strengths are almost as high as the tensile strengths and there is a good adhesion to the sandblasted steel.
Torsional tests will be performed but no results were obtained when submitting this report.
Further adhesion analyses will be made on a primed surface.

Conclusion
All the analysed adhesives show good adhesion to the sandblasted steel and only small modifications might be needed when applying the adhesives on a primed surface which improves adhesion even more.

Characterisation of proposed adhesives
With the adhesives proposed by SIKADK, fundamental tests were performed at UPB including Differential Scanning Calorimetry, Dynamic Mechanical Analysis, tests to determine the shear stress and shear strain behaviour and tests using tensile specimens. As PU156 was pointed

out as the most promising adhesive, results of the tests made with this adhesive will be shown below.

Differential Scanning Calorimetry

The reaction kinetics of the curing reaction and the specific reaction enthalpy of the proposed adhesive were determined using a Differential Scanning Calorimetry (DSC). The used temperature profile had a range from -90°C up to 270°C with a heating rate of 8 K/min. Figure 21 shows the result of the DSC analysis for the polyurethane adhesive PU156. At temperatures above 0°C, at approximately 10°C, the curing reactions of the adhesive starts. This can be noticed by an increasing graph showing a positive heat flux as a sign for an exothermal curing reaction of the adhesive. The reaction reaches its maximum speed at a temperature of 110°C. The reaction enthalpy of the adhesive PU156 is 114.72 J/g.

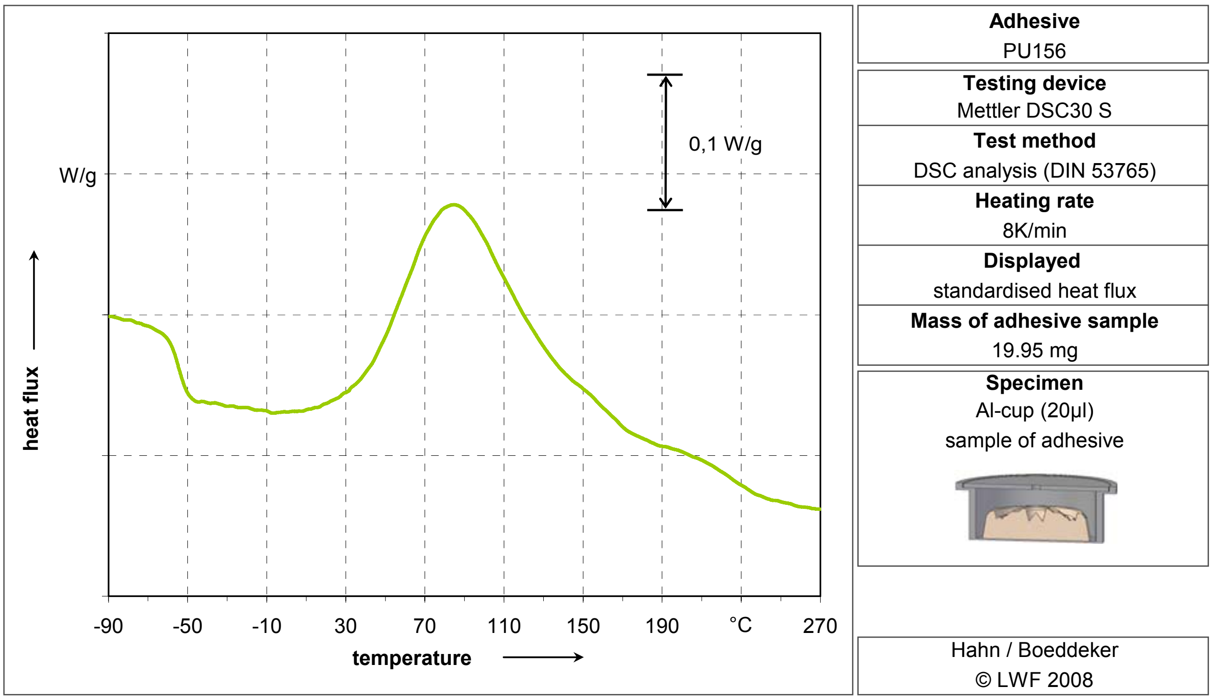


Figure 21: DSC Analyses of uncured PU156

Dynamical Mechanical Analyses

Mechanical properties of cured adhesives are depending on temperature and load conditions. To determine the visco-elastic behaviour of the adhesive the Dynamic Mechanical Analyses (DMA) was used. For this purpose cured adhesive samples were made and examined like it is displayed in Figure 22.

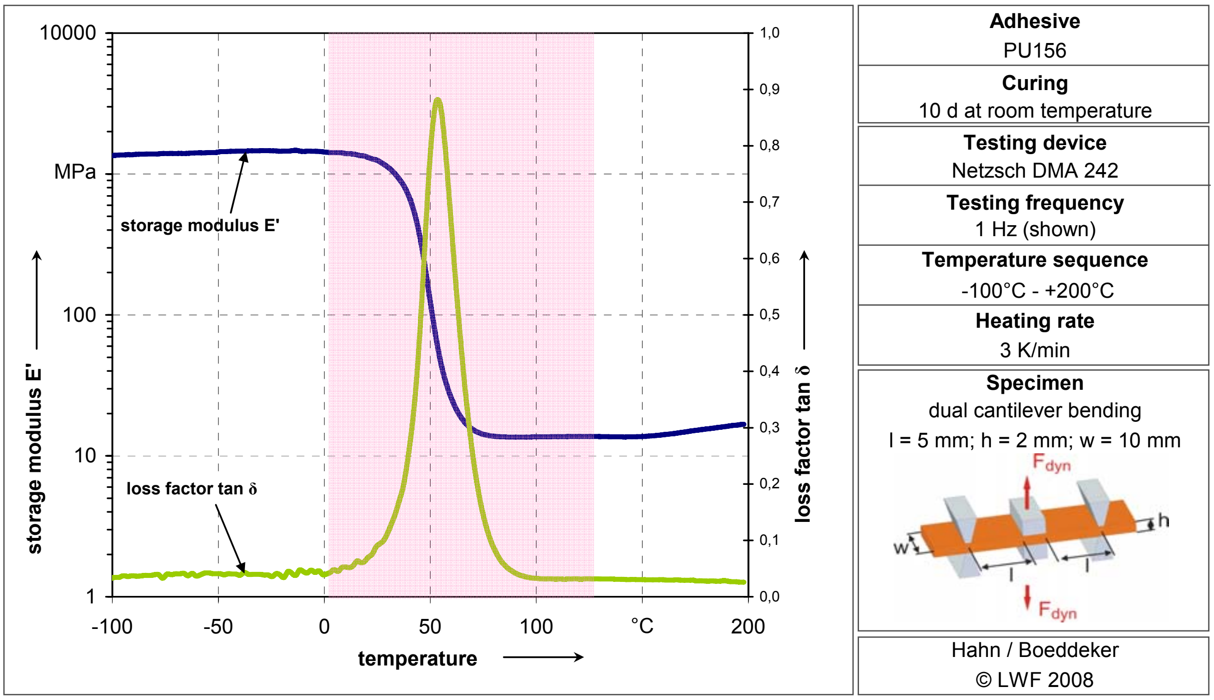


Figure 22: storage modulus E' and loss factor tan δ of PU154

The storage modulus of PU156 increases slightly in a temperature range from -100°C up to 20°C. Then a decreasing of the stiffness of the adhesive from a maximum of 1472.92 MPa to a minimum of 13.59 MPa can be noticed. The loss factor rises to his global maximum in this temperature range. The coloured area in the chart of the DMA analyses of PU156 marks a temperature range of possible applications of adhesively bonded pipes. The loss of stiffness in this area has to be taken into account by designing the pipe joint. PU156 shows an increasing stiffness at temperatures above 100°C. This effect can be explained by an additional curing of the adhesives at higher temperatures. Due to curing at room temperature, not all reactive components of the adhesive cured. Reactive components, still existing in the cured adhesive, are able to move through the adhesives' matrix due to the high temperatures to find other reaction partners. The loss of stiffness can be explained by a softening of amorphous urethane structures in the adhesives.

Shear Stress and Shear Strain Behaviour

To quantify the mechanical properties of the adhesive the thick-tensile-specimen in dependence on DIN ISO 11003-2 was used. The geometry of the thick tensile specimen with all relevant dimensions can be found in Figure 23.

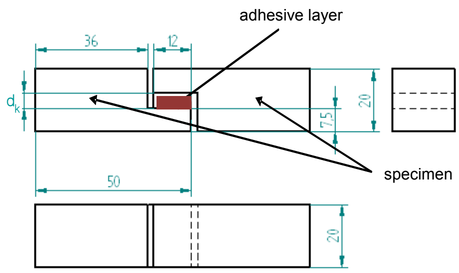


Figure 23: thick tensile specimen

The tests using the thick tensile specimen were performed with a shear strain rate depending on the thickness of the adhesive layer. Due to the expected tolerances of the adhesive joint of the bonded pipes, specimens with adhesive layer thicknesses of 0.5 mm, 3.0 mm and 5.0 mm were prepared to measure the influences of changing adhesive layer thicknesses on the strength of the adhesive joint. The shear stress-shear strain chart in Figure 24 shows the results for PU156 on representative shear stress-shear strain curves.

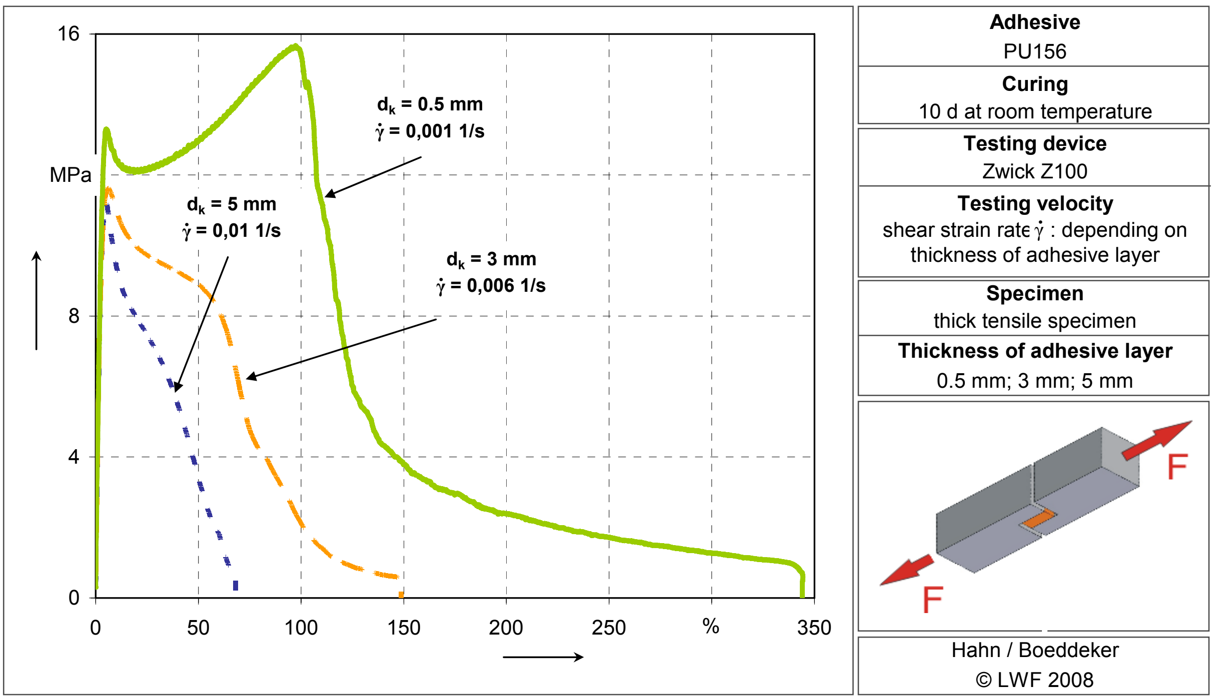
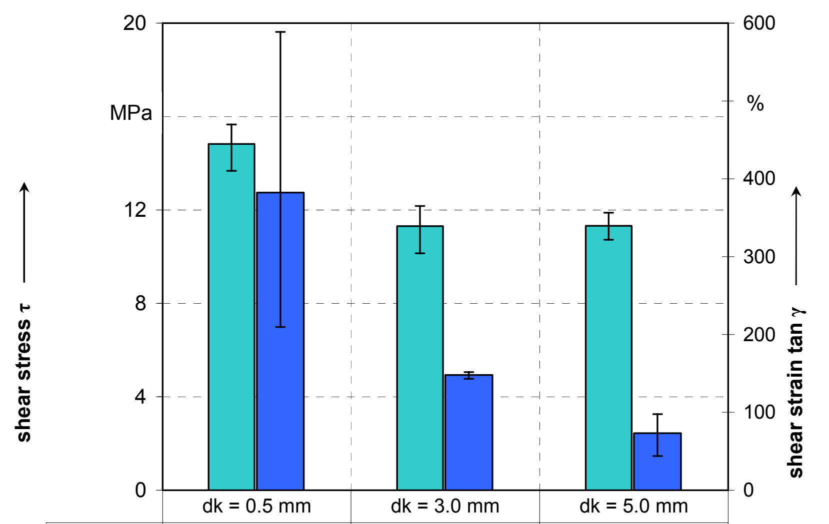


Figure 24: shear stress-shear strain chart for PU156 using adhesive layer thicknesses of 0.5 mm, 3.0 mm and 5.0 mm

One can see that the shear stress-shear strain behaviour is strongly depending on the thickness of the adhesive layer. The shear strain decreases from 15.66 MPa using an adhesive layer thickness of 0.5 mm to 10.73 MPa using specimens with a joint thickness of 5.0 mm (Figure 25).



	dk = 0.5 mm	dk = 3.0 mm	dk = 5.0 mm
τ-max	14,825	11,312	11,323
+	0,835	0,858	0,558
-	1,145	1,167	0,592
tan γ-max	382,401	147,873	73,153

Adhesive
PU156
Curing
10 d at room temperature
Testing device
Zwick Z100
Testing velocity
depending on thickness of adhesive layer
Specimen
thick tensile specimen
Thickness of adhesive layer
d_k = see diagramm

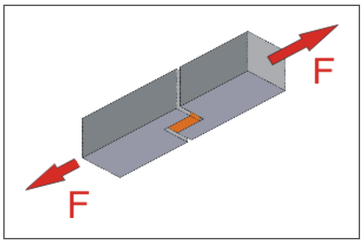


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Figure 25: comparison of shear stresses and shear strains of PU156 using different adhesive layer thicknesses d_k

Analysing Figure 25, one can notice that increasing the adhesive layer thickness from 3.0 mm to 5.0 mm does not lead to further sinking shear stresses. But it can be seen that the shear strain tanγ decreases from 382.4 % to 147.9 % using an adhesive layer thickness of 3.0 mm and going down to 73,15 % using the biggest adhesive layer thickness.
Summarising the results of the shear stress-shear strain analyses, it can be declared that big adhesive layer thicknesses, using this adhesive, have a major negative effect on the mechanical strength of an adhesive joint. The bigger the adhesive layer, the lesser is the strength of the joints. In addition, the shear strain decreases with an increasing adhesive layer thickness. By designing the pipe joint, the calculations have to be based on the mechanical properties measured with the biggest adhesive layer thickness.

Tensile tests
Tests with tensile specimens according to DIN ISO 527 were performed with PU156 (Figure 26). Stresses of 15.09 MPa could be reached as an average value. The specimen with the worst performance had a bubble on its cross-section which leads to higher stresses and to an earlier failure of the specimens.

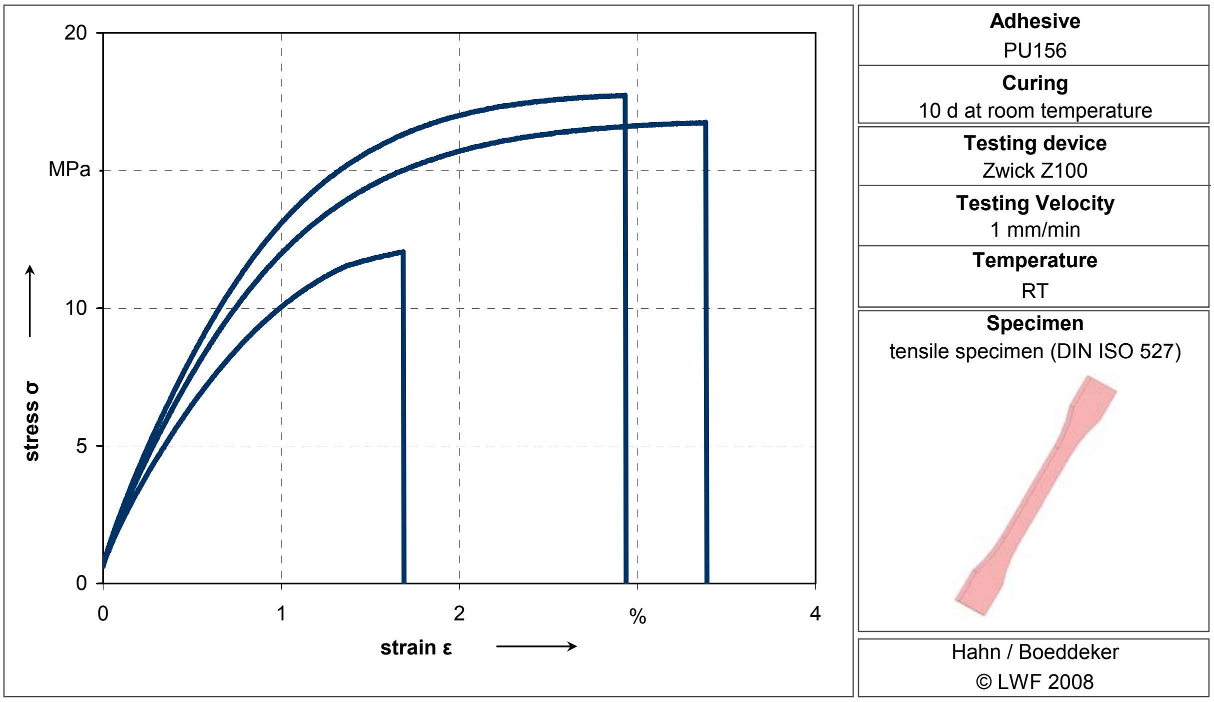


Figure 26: Tensile test of PU156 according to DIN ISO 527

Conclusion

PU156 as the most promising adhesive was characterised with standard tests like Dynamic Difference Calorimetry, Dynamic Mechanical Analysis, shear stress-shear strain tests and tensile tests. The determined properties can be used for dimensioning the pipe joints.

Next steps

As PU156 will be used until SIKADK has finished the formulation of an adhesive for pipe bonding, this adhesive will be characterised in further tests. These tests will include impact tests, dynamic strength tests, and tests on simplified joints under climate influence.

IV.2.1.4. Task 1.4: Selection of Economical and Technological Beneficial Surface Treatment

Surface pre-treatment has a significant influence on the expected strength of an adhesive bond. In case of pipe bonding, environment can affect treated surfaces on construction sites even before the pipe bond is prepared for adhesive application. As a result, surface treatments have to be as easy as possible and, if possible, should be done during pipe production process. For choosing an appropriate surface treatment, preliminary peel-tests were performed. These tests indicated that simple treatments like cleaning in an ultrasound bath with acetone as a cleaning medium does not lead to satisfying results. The appearance of fracture can be characterized as an adhesive failure (Figure 27). Sandblasting and silica based coating leads to cohesive failures. A fundamental disadvantage is that these treatments do not include any surface protection against humidity as it might appear while transporting or storing the pipes on construction sites.

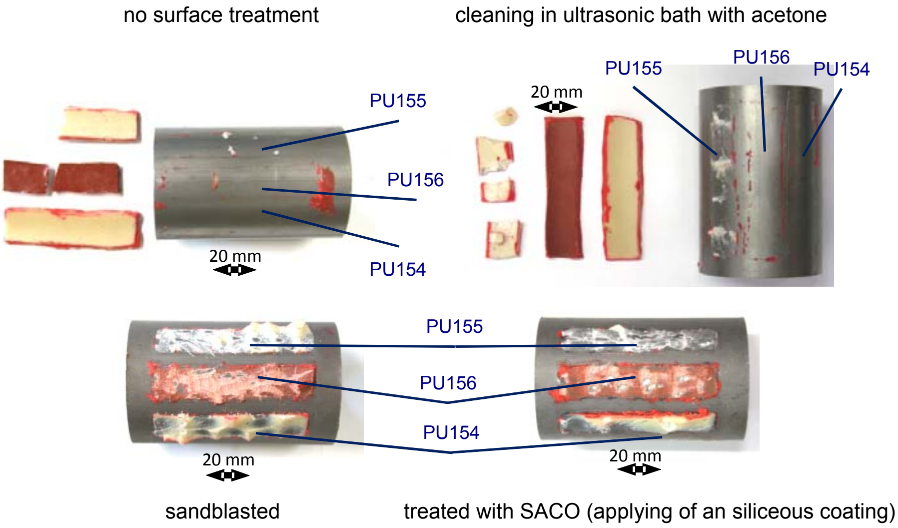
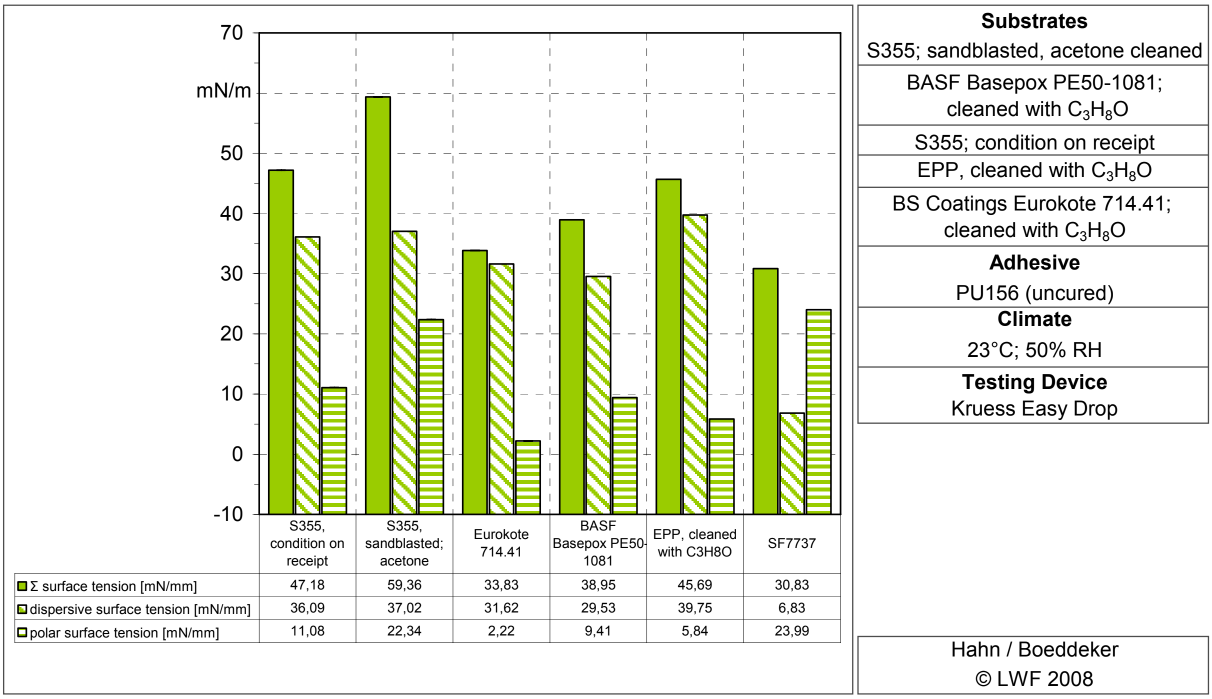


Figure 27: adhesion behaviour of the adhesives PU154, PU155 and PU156 using different surface treatments

This disadvantage can be avoided using coatings. Laboratory scale tests were carried out with epoxy coatings BS Coatings Eurokote 714.41, BASF Basepox PE50-1081 and an electrophoretic painting provided by SZMF. First, surface energies after use of the relevant surface pre-treatments were measured as shown in Figure 28. Surface energies of cleaned steel surfaces are higher then surface energies of plastics in general. This is related to the non-polar characteristics of plastics. Therefore, the polar surface energies of the epoxy coatings are low in comparison to the energies related to the steel surfaces. Depending on this, adhesive bonding of steel is often easier due to the, in general, comparably high surface energies. Adhesive bonding of plastics is possible as well, of course, but often special surface pre-treatments like corona and low pressure plasma can be necessary.



	S355, condition on receipt	S355, sandblasted; acetone	Eurokote 714.41	BASF Basepox PE50-1081	EPP, cleaned with C3H8O	SF7737
Σ surface tension [mN/mm]	47,18	59,36	33,83	38,95	45,69	30,83
dispersive surface tension [mN/mm]	36,09	37,02	31,62	29,53	39,75	6,83
polar surface tension [mN/mm]	11,08	22,34	2,22	9,41	5,84	23,99

Figure 28: surface energy calculation of tested surface treatments

To get an indication how the surfaces will be wetted by the adhesive, wetting envelopes were calculated, Figure 29.

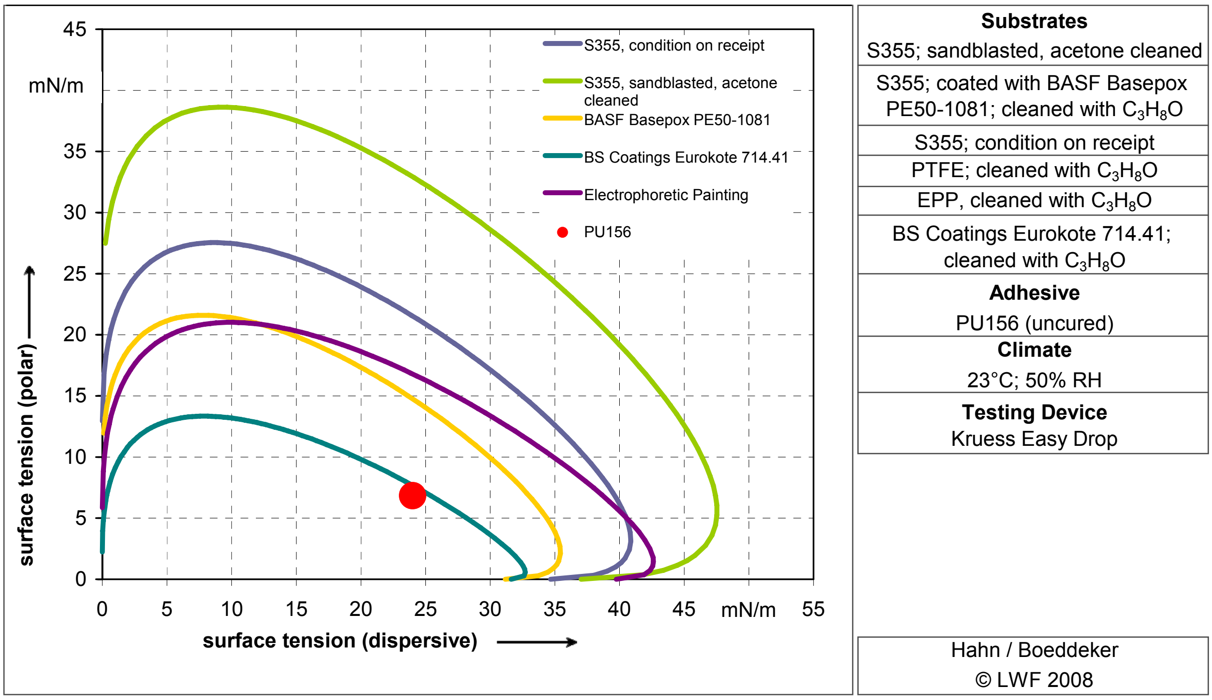
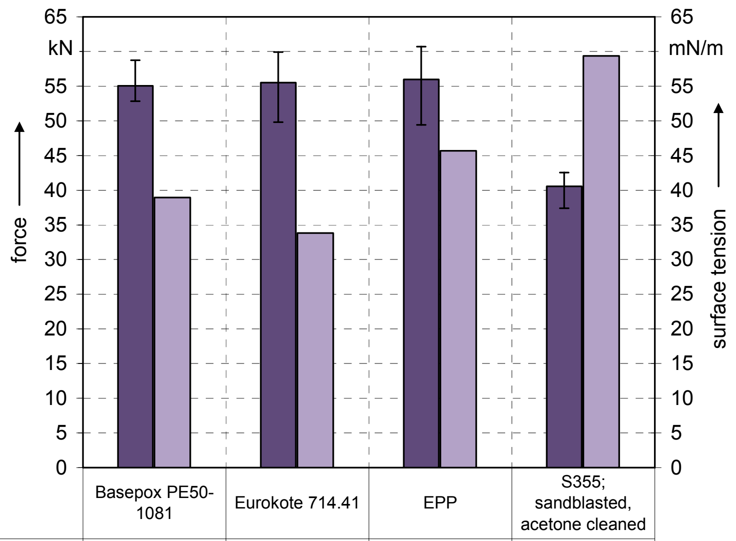


Figure 29: Wetting envelopes of tested surface treatments

Depending on Young's formula for describing the contact angle between a substrate and a liquid and the measured values of the surface energy of the substrates, the polar and dispersive surface energies of a liquid are calculated which allows a complete wetting of the substrate. After calculating the wetting envelopes, the surface energy of the liquid, intended to wet the substrate, has to be determined. The resulting polar and dispersive part of the surface energy will be charted in the same figure like the wetting envelopes. The liquid, respectively the adhesive, is able to wet the surface, if its measured surface energy value can be enveloped by the substrate's wetting envelopes. It can be seen that every tested surface is able for being wetted by the adhesive PU156. Strength tests on coated pipes show that wetting is only a necessary characteristic but not a sufficient one to predict the strength of the bonded pipes (Figure 30). It can be seen, too, in comparison with the only sandblasted and acetone cleaned pipe, that using epoxy coatings leads to significantly higher bond strength.



	Basepox PE50-1081	Eurokote 714.41	EPP	S355; sandblasted, acetone cleaned
Fmax [kN]	55,06	55,51	55,99	40,56
+	3,67	4,41	4,72	1,98
-	2,26	5,71	6,56	3,17
SFT [mN/m]	38,95	33,83	45,69	59,36

SFT: surface tension

Specimen small scale pipe specimen
Testing device Zwick Z100
Kruess Easy Drop
Testing velocity 10 mm/min
Adhesive PU156; cured at RT
Surfaces BASF Basepox PE50-1081; cleaned with C_3H_8O
BS Coatings Eurokote 714.41; cleaned with C_3H_8O
EPP; cleaned with C_3H_8O
S355; sandblasted,acetone cleaned

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Figure 30: comparison of strength of bonded pipes and surface energy

Therefore, it was decided to use coated pipes for further examinations as full-scale tests and pipe laying tests. For this purpose, a two component epoxy primer will be used, which can be applied under such rough conditions as they can be found on construction sites.

IV.2.1.5. Task 1.5: Development of Easy Application Method Including Curing Method

Application of adhesive

The manner of adhesive application depends directly on the geometry of the pipe joint. It is compulsory that the adhesive can not be applied until the pipes are in their final position. An adjustment and positioning of the pipes, with adhesive already applied, is, due to the bulky geometry of the pipes, not possible without wiping off the adhesive from the pipes. That leads to the fact that the adhesive has to be applied after the pipes are aligned and positioned correctly. Therefore, a system, based on the injection of the adhesive into the joint, seems suitable. The adhesive is injected into the gap using boreholes in the sleeve. The joint is completely filled, if the adhesive leaks out an upper borehole. Tests were performed to show the reliability of these methods. The parameters changed were the filling pressure, the viscosity of the adhesive and the position of the injection holes. For adhesive PU156 it was possible to identify parameters allowing a very good gap filling (Figure 31).

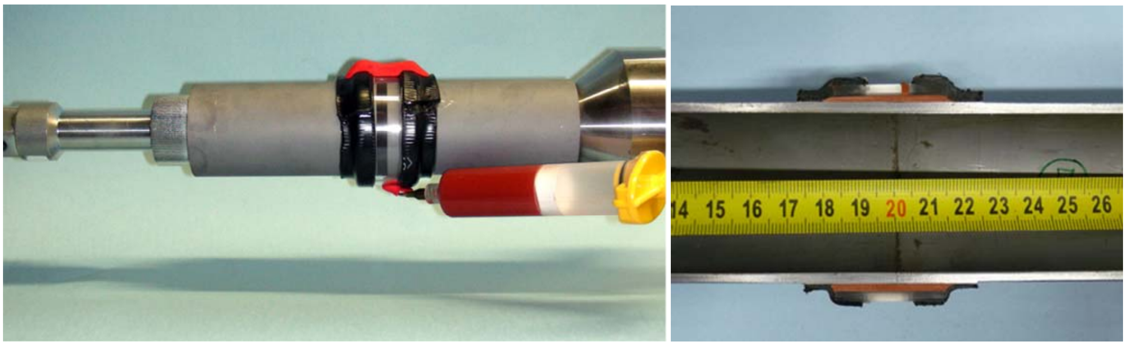

Figure 31: Adhesive application using disposable cartridges (left). Using PU156, good gap filling could be achieved

Devices for adhesive application commercially available are very cost expensive in purchasing and service. Due to this fact, a method was chosen to guarantee an efficient performance of the planned tests. It was decided to weigh and to mix the adhesive components by hand. After mixing, the adhesive was filled into disposable cartridges. Using these cartridges, the adhesive can be processed using pressurised air (Figure 31).

For full-scale testing and pipe laying tests, two different possibilities of application are considered. The first one is application by machine (Figure 32). It is easy to use and the mixing ratio can be adjusted more precisely. The main disadvantage is the need of power supply and pressurised air.

Figure 32: application machine for adhesive injection

The other opportunity is applying it by using a dual-cartridge system. One big advantage of this method is the low weight of the cartridge systems what allows an uncomplicated handling at the construction site. A main disadvantage is the price and pressurised air might be needed for the application gun. The methods are still discussed internally at SIKADK regarding advantages and disadvantages.

The adhesives to be used are cold curing. Therefore, slight increases of the temperature cause appreciable reduction of the curing time. Following an Arrhenius equation, the time for curing reduces to the half if the curing temperature rises about 10 K. Preliminary tests were performed to get an indication of an accelerated curing process by using a SIKADK internal curing procedure to simulate long term curing processes of adhesives. Tests on the adhesive bulk made with a DMA analysis show that a higher stiffness of the adhesive can be reached. In addition the thermal affected decreasing of mechanical properties shifts to higher temperatures (Figure 33).

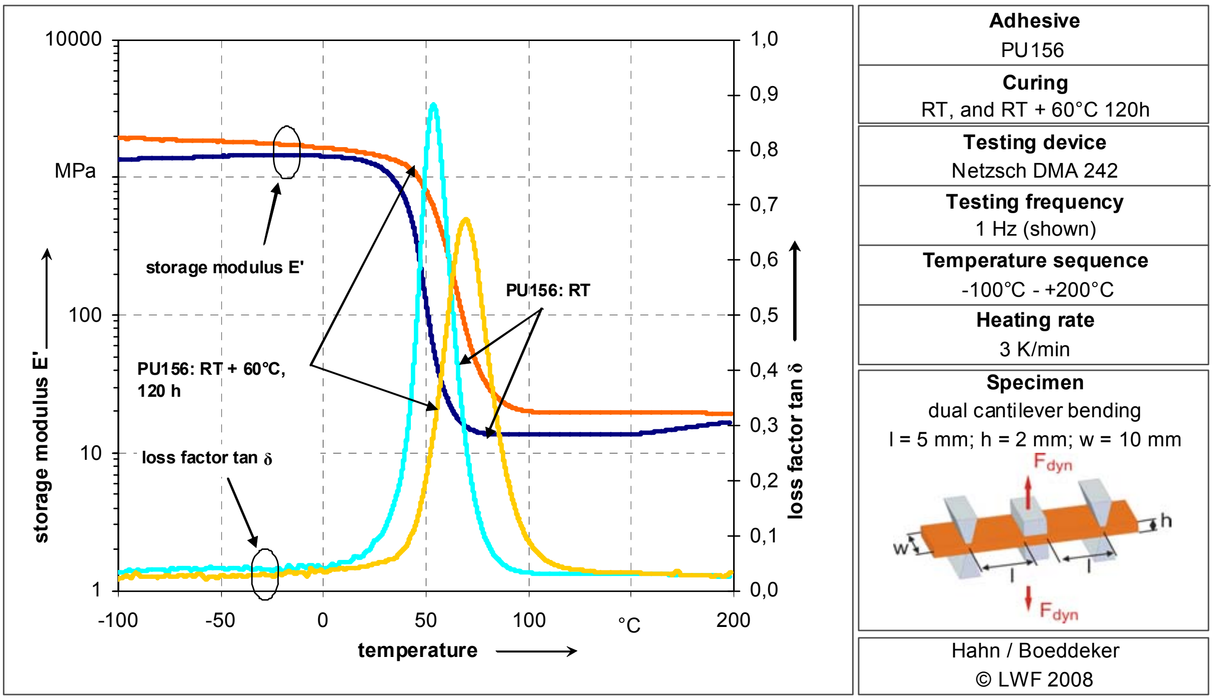

Figure 33: DMA-Analyses of RT-cured and accelerated cured PU 156

Small scale pipe specimens were used to determine, if these advanced mechanical properties could increase the mechanical properties of the pipe joints, too (Figure 34).

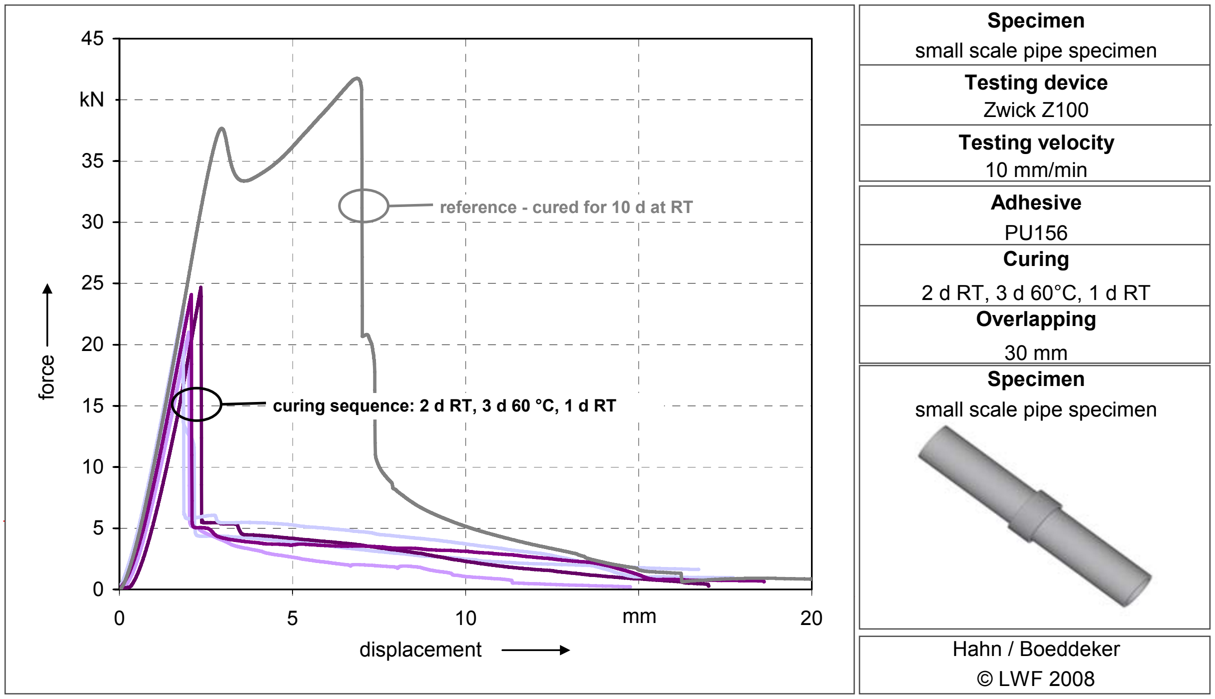

Figure 34: Comparison of strength of small scale pipe specimens cured using RT and SIKA curing condition

As Figure 34 shows, only 60 % of the strength can be reached using the described curing procedure. In addition, the displacements declined rapidly. Therefore, it is necessary to define the optimal parameters for a heat supported curing process.

Curing shall be done using a heated sleeve, so preliminary tests were performed using a heating sleeve as it is shown in Figure 35.

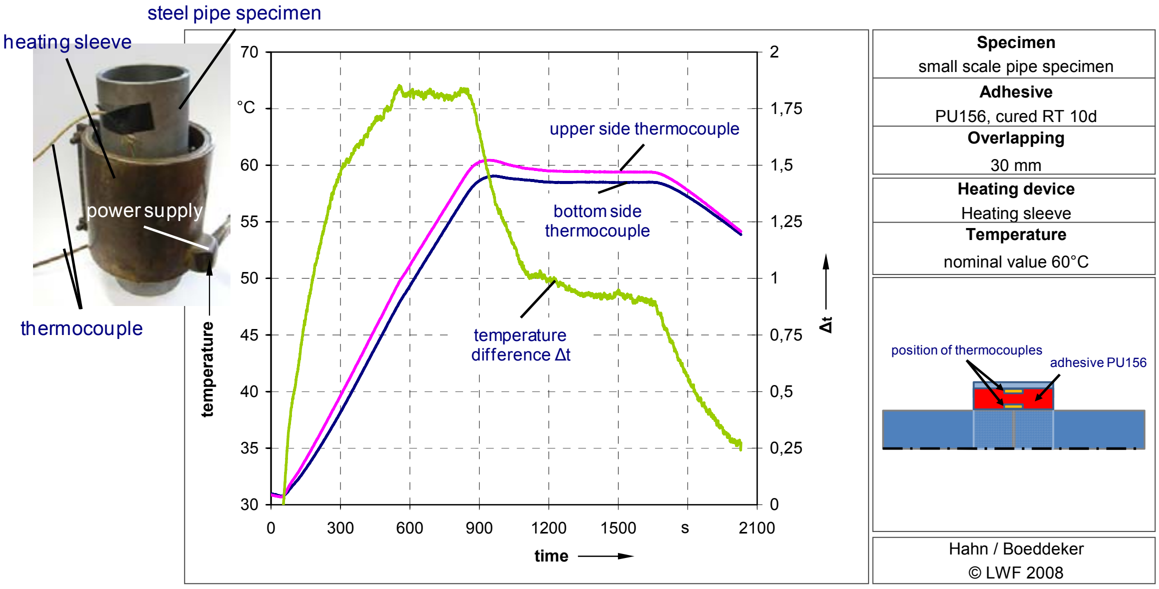

Figure 35: temperature profile of small scale pipe specimens heated using heating sleeve

For these first tests a cured pipe specimen was used. Thermocouples were positioned at the top and on the bottom side of the bondline. The nominal temperature value of 60 °C can not be reached in the bondline. Therefore, heating has to be done with a slightly higher nominal curing temperature. The temperature deviation between the upper side and the bottom side of the bondline is maximum 1,85 K. A constant heating of the bondline can be guaranteed. In the next steps, optimised heating parameters will be identified.

IV.2.2. Work Package 2: Qualification of Process for Field Conditions and Required Process Quality Control

IV.2.2.1. Task 2.1: Development of a Quality Control System

From the destructive testing experiments done it became obvious that the most critical defects are air filled voids with a diameter of at least 30 mm with a width of the complete gap between both steel parts. Thus the development of a non-destructive inspection technique was focused on this type of defect.

The same sort of samples from steel plates that were used for the destructive test was also used for the non-destructive investigations. Rings with different sizes were placed in the gap and then filled with the adhesive to produce a void between the plates (Figure 36). Additionally samples with Teflon pieces mounted on one steel plate were made to simulate kissing bonds.

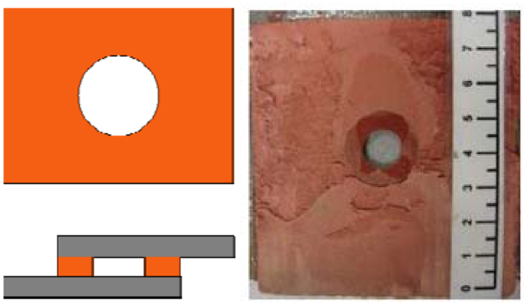

Figure 36: Artificial reference defect with a diameter of 20 mm as a model for an air filled void. Schematic drawing and real sample after destructive testing.

Inspection Techniques

During the inspection a steel plate of several millimeters has to be penetrated from outside. Thus from all possible inspection techniques ultrasound is most suitable as it is transmitted through steel easily offering good detection capabilities. Among the ultrasound techniques tested (reflection from the adhesive backwall with longitudinal and transversal waves, back-scattering, analysis of the frequency content of one echo and nonlinear techniques as the generation of second and third harmonic) only two allowed the detection of the reference defects.

1) The generation of second harmonics is strong at the steel – adhesive interface while, as expected, there is almost no generation at the steel air interface (Figure 37).

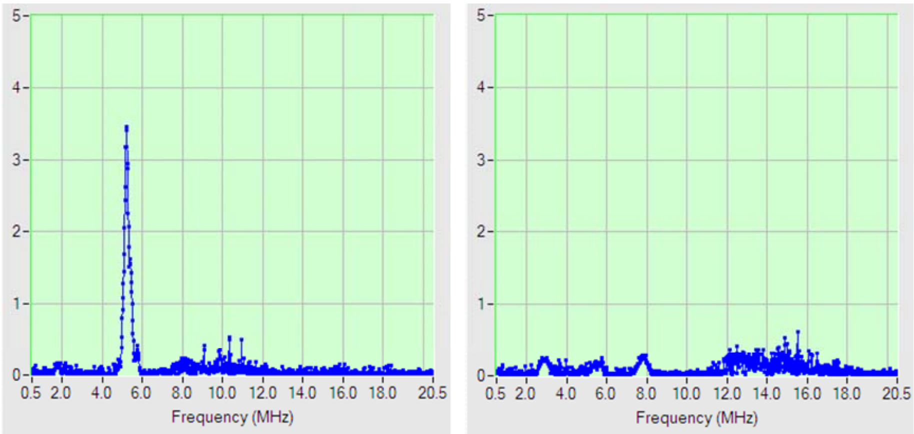

Figure 37: Generation of the second harmonic at the steel – adhesive interface (left) and at the steel – air interface (right) due to nonlinear effects.

The large signals thus can be used to detect a good bonding and a void when the signals miss. To realise this method a large instrumental effort is necessary and particularly the coupling of the transducers to the sample is a further task.

2) An inspection method that is based on conventional UT principles, but will not be reported here in detail as a patent application is intended and in preparation. This technique is less sensitive to voids compared to the nonlinear technique, but offers sufficient detection capabilities in combination with less complex handling in a water bath. The technique was optimised and used to detect both types of reference defects as voids (Figure 38) as well as Teflon strips.

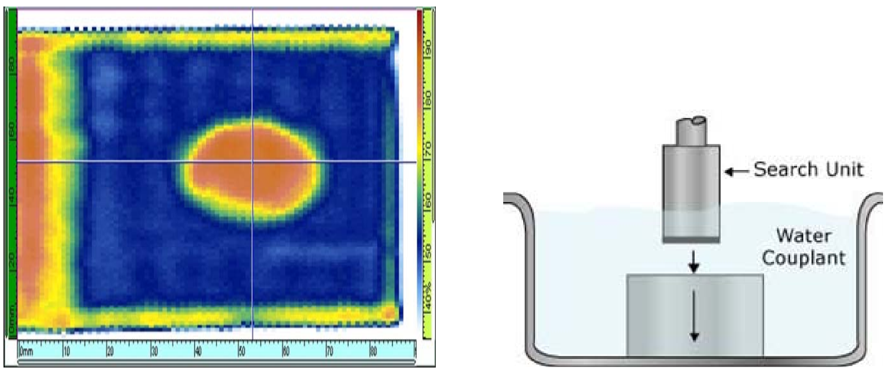

Figure 38: Detection of an air filled void of 30 mm diameter by the developed technique (left). The experiment was done in a water bath (right).

In both proposed techniques information typically from a region around the steel - adhesive interface are evaluated. Thus defects that do not penetrate the whole thickness of the adhesive or are not located on the surface under investigation, but on the opposite surface cannot be detected. As shown by the destructive tests this type of defect is not typical and, if the voids are small, not critical.

Results

Taking into account the detection capabilities and operating conditions, the technique analysing the ultrasound echo train is a little more favourable. It could be demonstrated that this technique can also be applied using EMAT transducer heads generating transversal waves by electromagnetic effects. Thus a water coupling is not necessary allowing dry inspection in the field. A slight drawback is a reduced lateral resolution of several millimeters and strong magnetic forces that have to be dealt with.
From the results it is concluded that a method can be developed that is able to detect the relevant defects that might occur during the adhesive bonding of pipes.

Next steps

- From natural defects in adhesive bondings it became obvious that the surface of the steel at a void is not necessarily clean, but may have, different from the investigated situation, a thin adhesive layer of about 100µm (Fig. 4 a). As the condition of the first interface is critical for the inspection suitable samples are in preparation. The same situation occurs when a primer is used.
  First experiments showed that the detectability of voids is still given. This topic will be investigated in more detail.

- The results of the inspection are of course influenced by the thickness of the steel plate. The dependencies will be investigated by step wedge samples varying the steel thickness. In a similar way the thickness of the adhesive is changed with in the typical range of several millimeters (Figure 39, right).

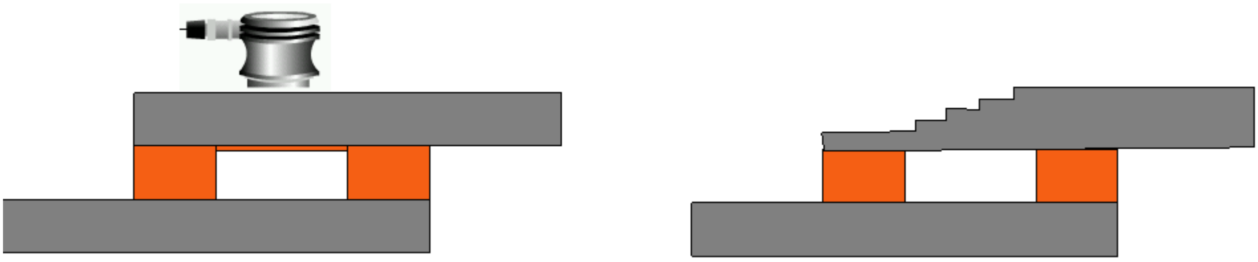

Figure 39: Side view of the next samples to be investigated: a thin adhesive layer may be present around the air void (left). The influence of variations of the steel layer will be investigated by a step wedge sample.

- The techniques developed were applied to plate material. The next step is to adapt it to the inspection of pipes in the lab.

- As for the inspection in the field ‘dry ultrasound’ without the need of a coupling medium as water, has big advantages concerning the handling, the EMAT - technique will be further developed.

IV.2.2.2. TASK 2.2: REPAIR PROCEDURE

SZMF performed first test using simple overlapped shear specimens. Defined failures were incorporated into these specimens like oil, carbon black and adhesive failures with defined dimensions. With these specimens strength tests were performed to determine the influences of the incorporated failures. A first concept for repairing bonded pipes was discussed and tested on simple overlapped shear specimens as well.

In order to test the influence of defects on the joint stability, it makes sense to use simple specimens. So the joining situation of the pipes was transferred into a lab shear specimen as shown in Figure 40.

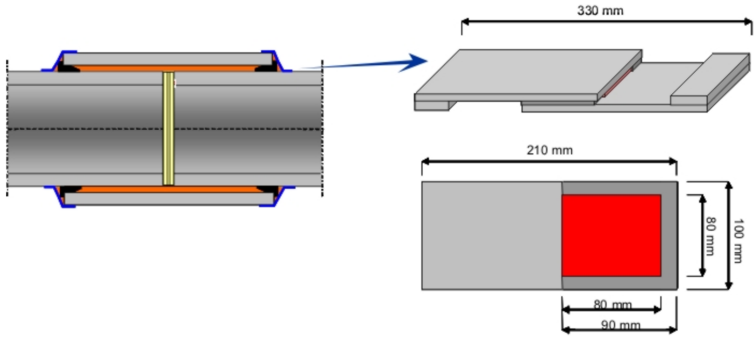

Figure 40: Geometry of used specimens

The simple specimen has big advantages for the application of the adhesive, because it was not necessary to inject it through a little hole like in the real joining situation. The specimens were built up like shown in Figure 41. So it was possible to fill the gap between the sheet materials with adhesive without causing failures in the adhesive joint while adhesive application.

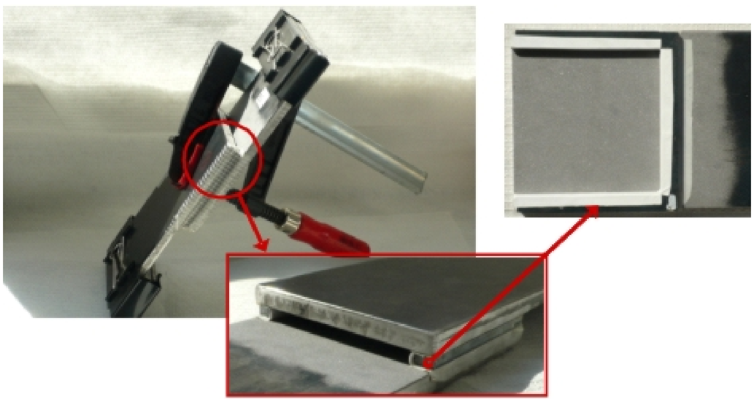

Figure 41: Application of the adhesive at the lap shear specimen

The gap between the two sheet materials was the same as used in the pipe application. To get a well defined gap, a u-shaped sheet is placed between the two parts of the specimen. The edge of the u-shaped sheet is prepared with PTFE-adhesive-tape in order to get no adhesion with the distance holder.
After this, the gap was filled with adhesive PU156. All the specimens were built up in the same way. The surface was sandblasted and cleaned by using a paper towel. Then the adhesive was put in the gap and cured in an oven at 60°C. Only when the influences of these parameters were investigated, they were changed. For each series, specimens were prepared to act as a reference.

The influences of changing the parameters of adhesive application and surface pre-treatment were determined using single overlapped shear specimens.
Figure 42 shows the influence of surface pre-treatments. Specimens which were cleaned with an ultrasonic n-heptane bath acted as a reference.

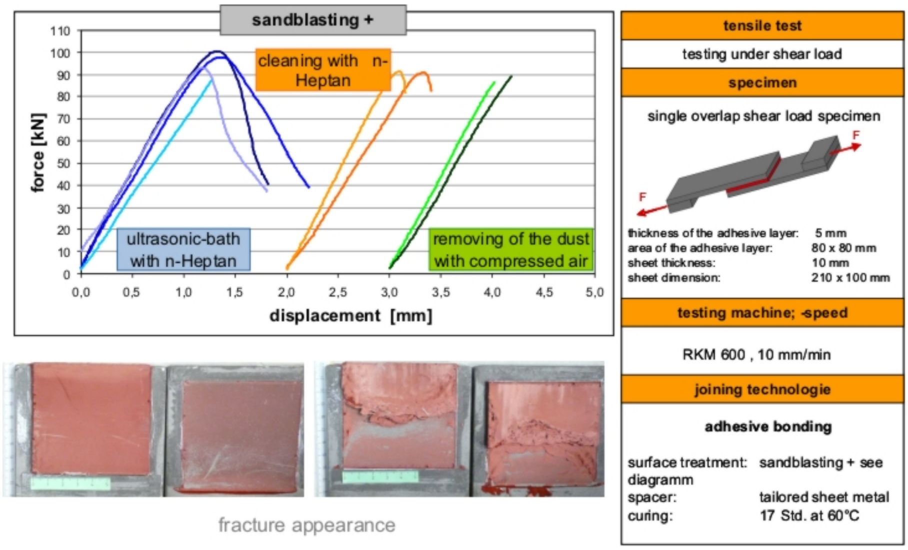

Figure 42: Influence of the surface pre-treatment

Results show that cleaning the specimens only with n-heptane or just removing the grit from sandblasting with pressurised air has only slight influences on the maximum bond strength. Reducing the bond area to simulate adhesion problems caused be contaminations of the substrate are displayed in the following figures (Figure 43 to Figure 45).

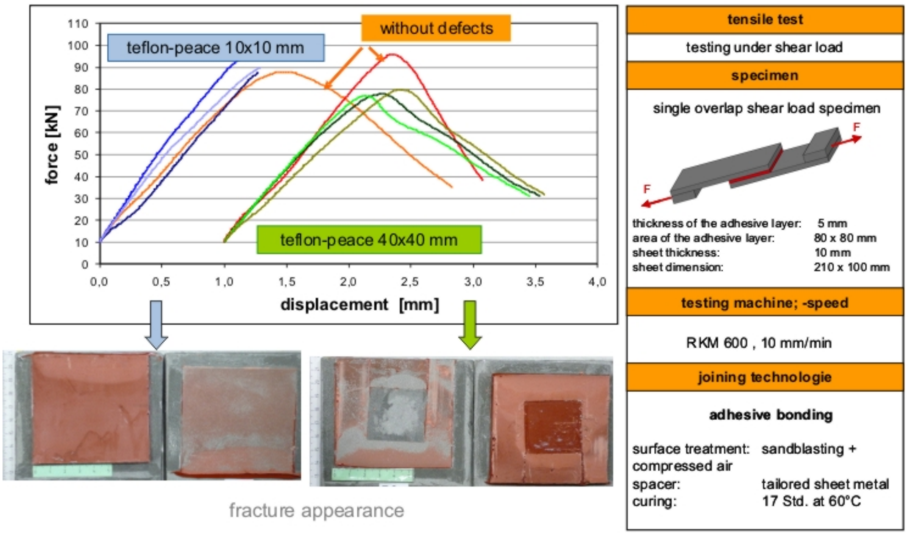

Figure 43: Influence of adhesion problems caused by special contaminations like silicone

Using different seized Teflon-pieces to simulate contaminations shows that maximum bond strength is only little affected, whereas the displacements decrease significantly using a 10 x 10 mm Teflon-piece. Using an area of 40 x 40 mm leads to lower maximum bond strength but to higher displacements. Downsizing the bond area to seven eighth to the initial situation reduces the maximum bond strength only at about 5 % (Figure 44).

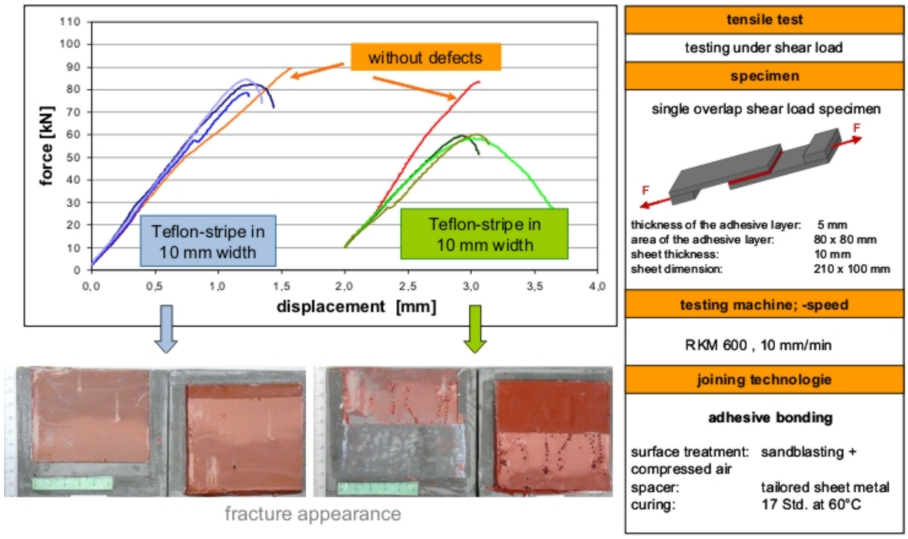

Figure 44: Influence of adhesion problems caused by special contaminations like silicone

Reducing the bond area to one half, leads to reduced bond strength of about two thirds of the strength the reference specimen could reach.
The contamination of the adhesive with scale has no influence of the mechanical properties of the joint as Figure 45 shows.

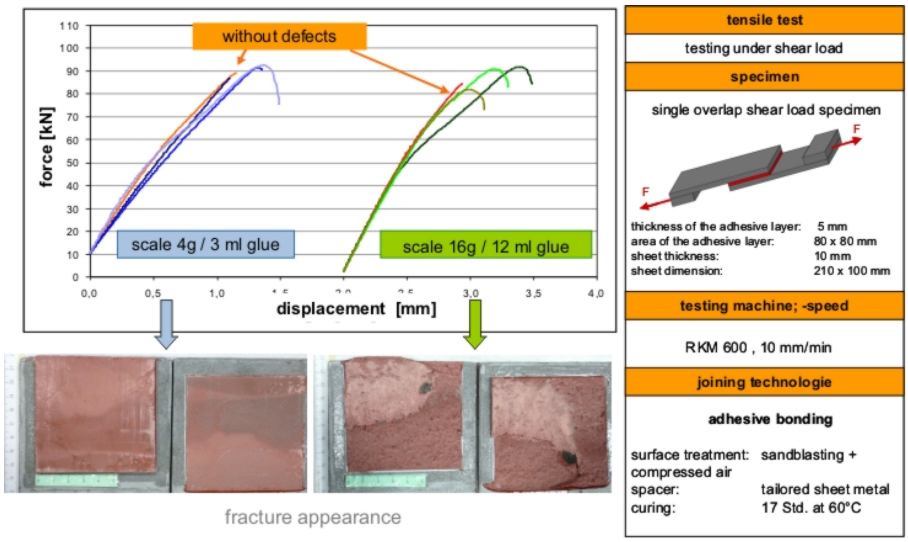

Figure 45: Influence of contamination of the adhesive with dust or scale

If oil is mixed into the adhesive in small doses, the mechanical properties of the adhesive joint will not be affected negatively, as it can be seen in Figure 46. Contrariwise, the maximum bond strength could be increased. If the amount of oil mixed into the adhesive's matrix is increased to 4 ml, the maximum bond strength reaches still the value of the reference specimens. The appearance of fracture shows a 50 % adhesive failure on both tested versions.

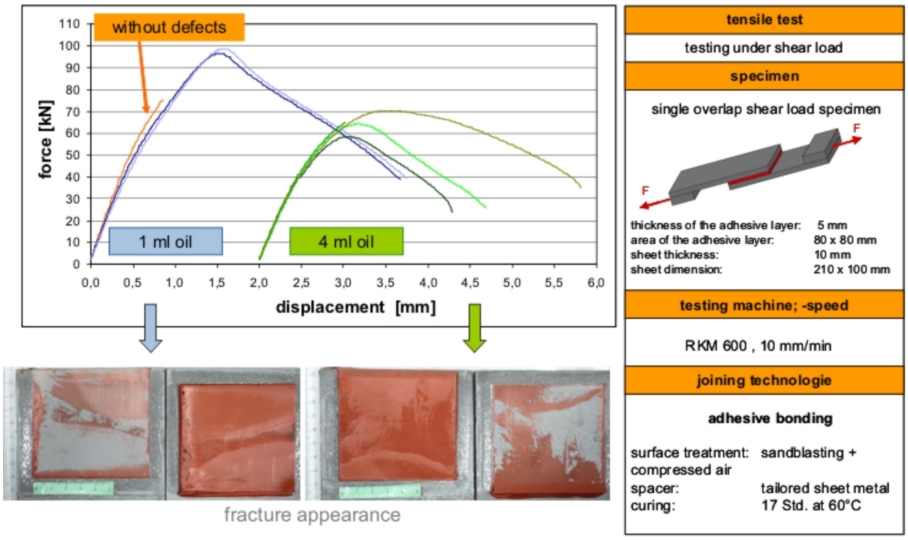

Figure 46: Influence of contamination of the adhesive with oil

Aging of adhesively bonded pipes shear specimens at 100°C for three hours causes a loss of maximum bond strength (Figure 47). Curing the adhesive for ten days at RT achieves comparable results as curing the adhesive for 17 h at 60°C.

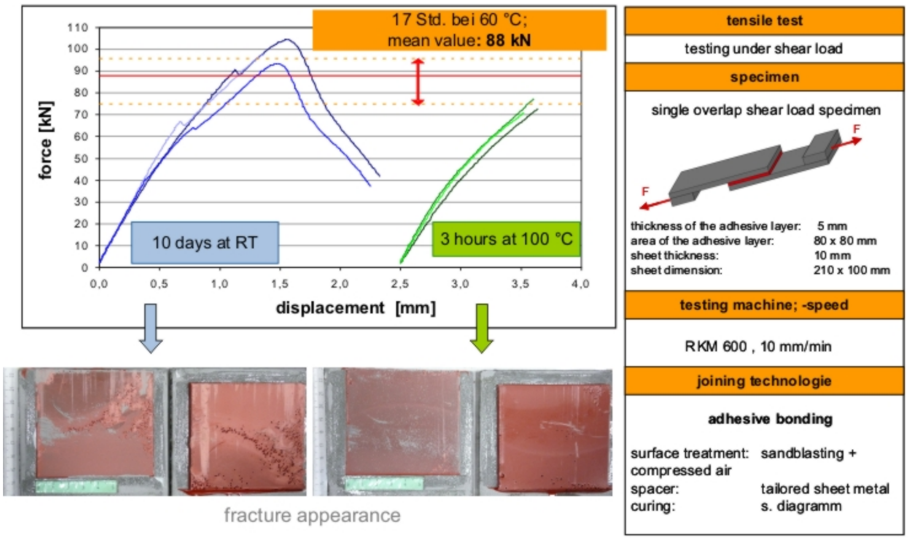

Figure 47: Influence of the curing conditions

The size of voids like air bubbles only effects the displacements reached. The maximum shear forces remain on the same level (Figure 48). This is related to the fact, that stress concentrations have a maximum at the endings of the overlapping and a minimum in the middle of the adhesive joint.

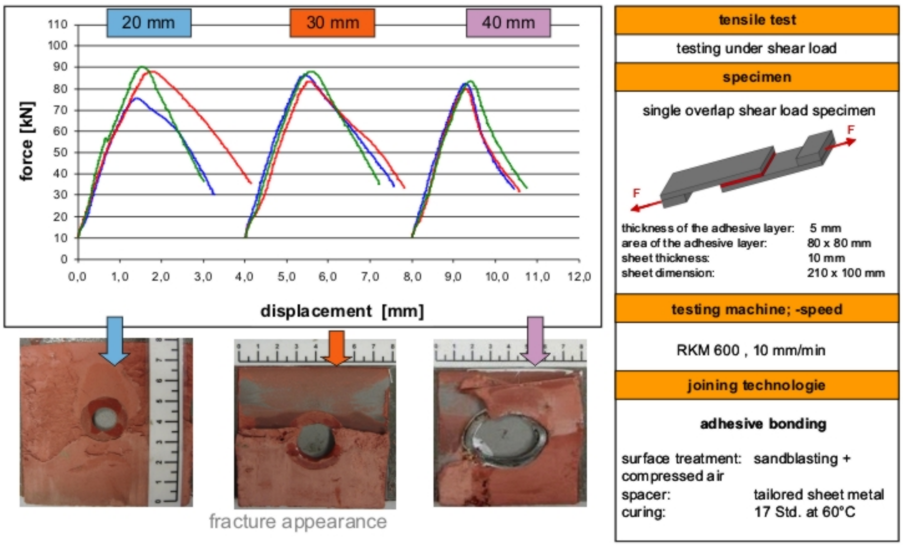

Figure 48: Influence of air bubbles occurring in the application process

The influence of the position of air bubbles was investigated in using different positions for them (Figure 49).

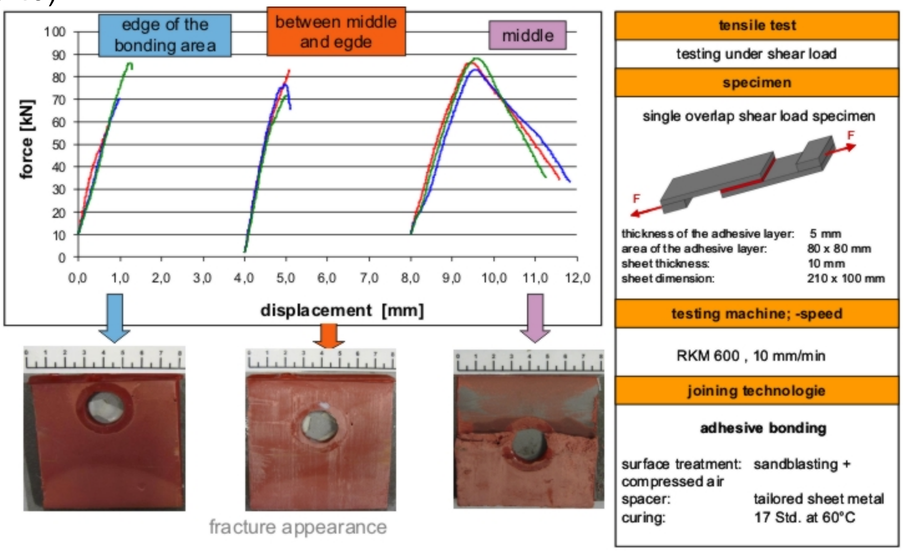

Figure 49: Influence of the position of air bubbles occurring in the application process

Tests on single overlapped shear specimens with adhesive layer thicknesses from 2 mm to 10 mm show decreased maximum shear loads but increased displacements (Figure 50).

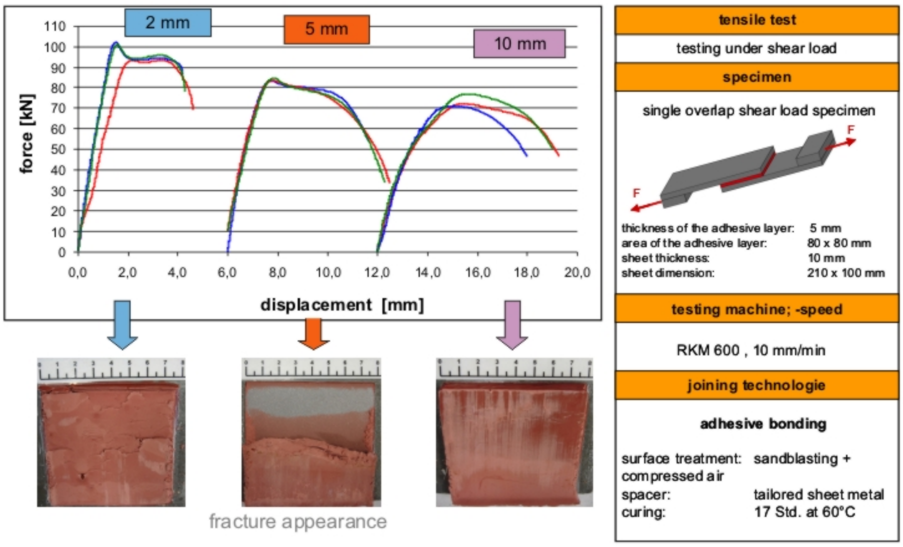

Figure 50: Influence of the adhesive layer thickness

A main result of the investigation concerning the different application mistakes is that the adhesive used for this application is very tolerant against nearly every influence. The only critical factor is the sensitiveness of the adhesive against precipitation of water as displayed in the following figure (Figure 51). Here, the substrate was exposed to dew, or respectively frost before bonding. Here it is necessary to prevent every possibility which causes occurring of water.

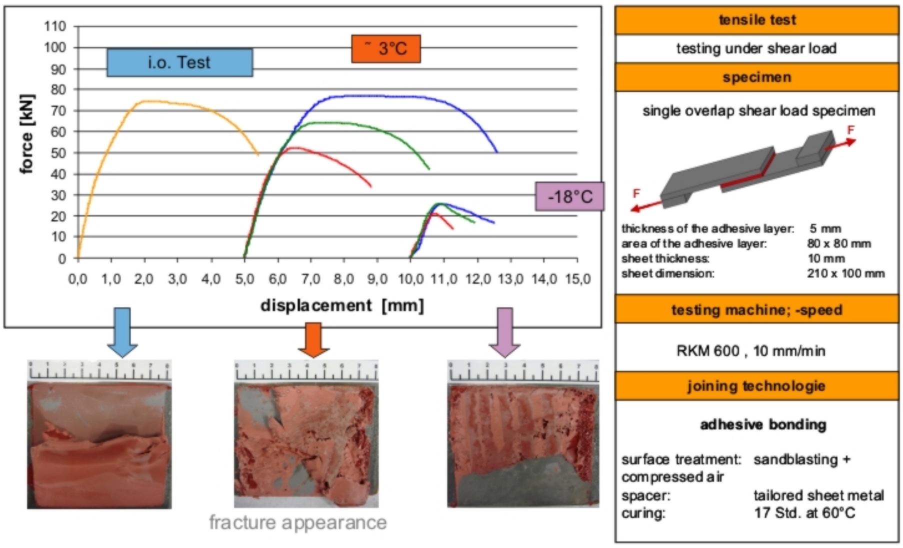

Figure 51: Influence sheet material temperature in the focus of precipitation of water

When air bubbles crop up in the adhesive layer, it is possible to detect them by using NDT. So it was necessary to investigate repairing procedures for this kind of mistake.

At first it was tested, if a second application of the adhesive has influences on the load bearing conditions. As it is shown in Figure 52 there were none.

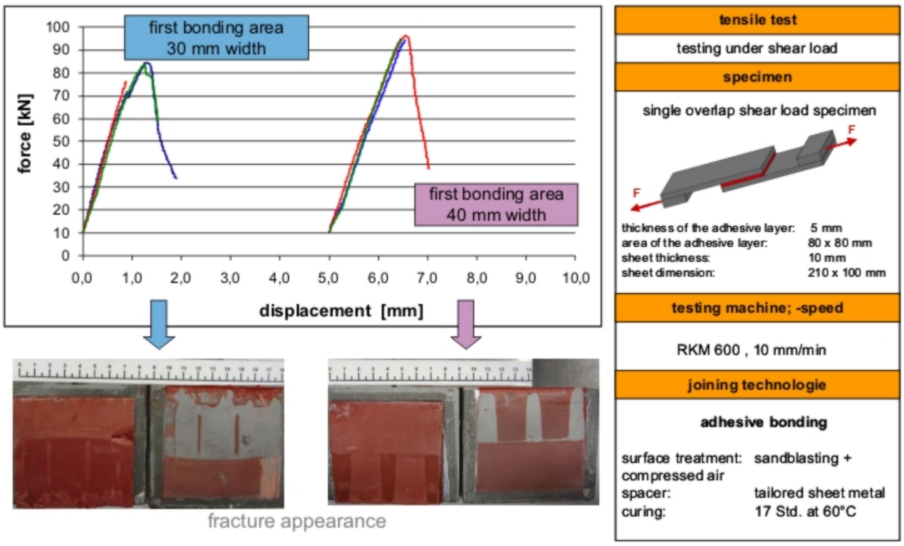

Figure 52: Influence of two sequenced applications of adhesive for one specimen in the focus of repairing procedures

The problem by focusing on the field condition is the fixed pipe. It will not be possible to turn the pipe in an optimal position for carrying out the repair procedure. Therefore, three different repairing positions were tested as they might appear on the construction site, as shown in Figure 53.

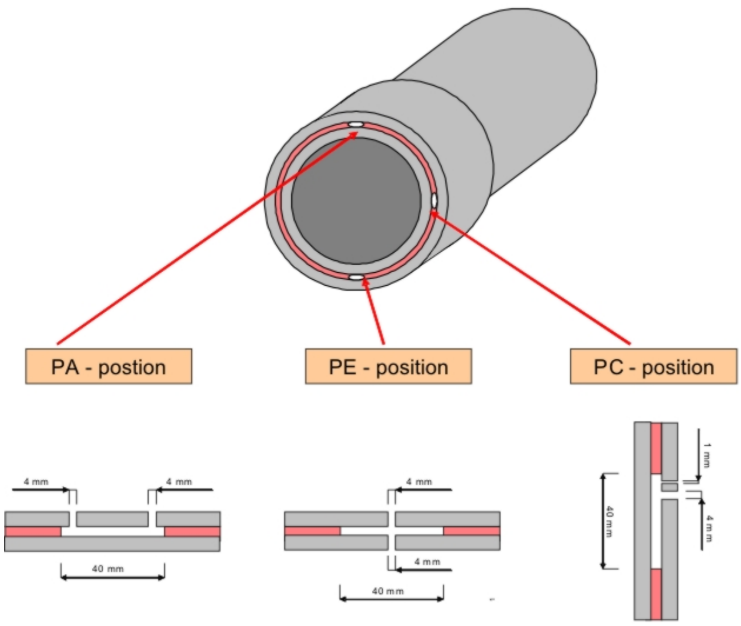

Figure 53: Repairing positions at the pipe

The results in Figure 54 show good conditions for application of the adhesive in position PA and PE. The solving of the problems in position PC is one of the next steps in this project.

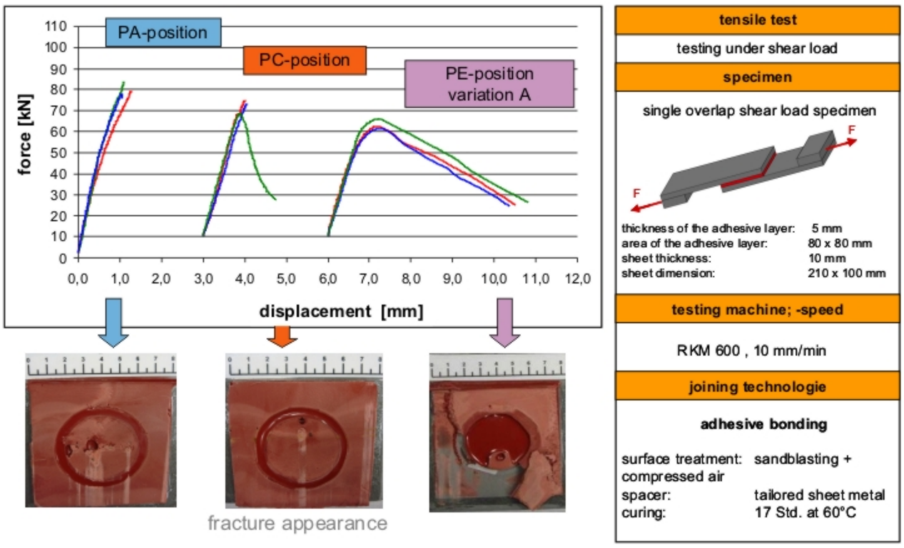

Figure 54: Results of different repair positions at the specimens

IV.2.2.3. TASK 2.3: TRANSFER TO FIELD CONDITIONS

From the beginning the field conditions were taken into account while developing a pipe joining concept. Therefore, even in laboratory scale, only methods, tools and materials are used which are available today and in use on construction sites. As an example, the pipe centring devices and the shrinking material are mentioned. Using disposable cartridges for application of adhesive in the field prevents the adhesive from contaminating with dirt as it might be possible by using barrels and pumps for emptying them. So it is guaranteed that adhesives can be processed under all conditions like humidity, heat or frost with having minimised influences on the adhesive's matrix.

Next steps

Tests will be performed at SZMF to adapt the developed NTD equipment to be used for the pipe geometry. Additionally, the developed joining technology will be adapted to be used on real scale pipes.

IV.2.3. WORK PACKAGE 3: FULL SCALE TESTING OF ADHESIVELY BONDED PIPE JOINTS

IV.2.3.1. TASK 3.1: DEFINITION OF MECHANICAL PROPERTIES

A testing procedure was agreed, whose summary is reported in Figure 55.

Dealing with the test assignment, it was agreed to perform initial tests at SZMF, in order to refine the joint manufacturing procedure, if necessary. The specimens will then be subjects of failure tests in different failure modes, in order to evaluate the mechanical strength of the joint.

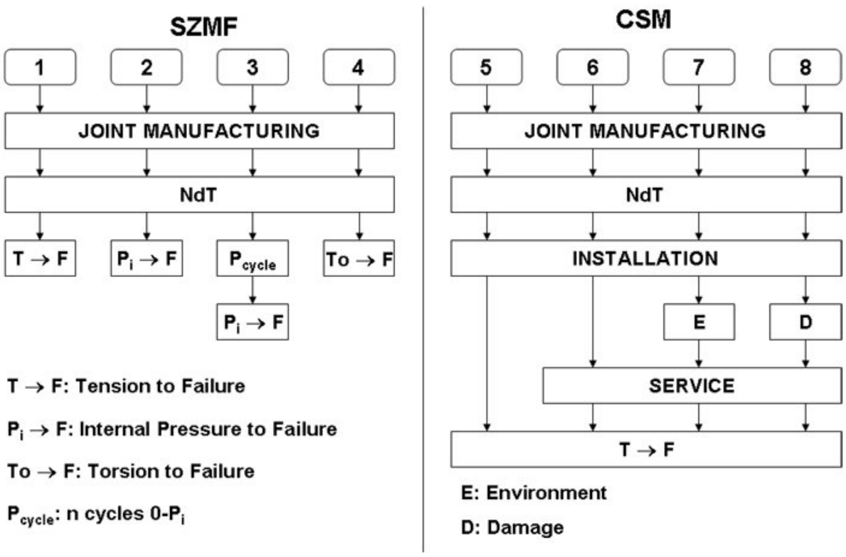

Figure 55: Summarised test procedure for full scale testing

The application of the loads, representing service life in combined load conditions, will be performed at CSM. It was agreed to separate the different loads to be applied to the specimens, in order to discriminate single parameters to be considered as the factor affecting the joint performance for that test. It was also agreed to consider it necessary to apply the installation load to all test specimens, as in any case this would be the first loading mode under real conditions. Environmental influences will be evaluated exposing the specimen to a heating cycle of 24 h at 80°C, simulating the effect of several annual heating cycles due to environmental conditions and/or service fluid temperatures in pipe application. After the combined load tests, all specimens will be tested to failure in the tensile mode, in order to verify possible effects of the application of installation/service loads to the joint strength.

It was finally agreed to apply a damage-like load to one of the test samples, with suitable equipment available at CSM. The intent of such tests is to reproduce a typical impact from a real excavator, in order to assess any influence of possible external damages on the joint performance during its service life.

The tests on the largest pipe size, 508 mm x 8.8 mm, will be carried out with water, while the tests on the smaller size, 168.3mm x 7 mm, will be carried out with gas (nitrogen) as a filling medium.

Schematic drawings of the loading sequences for the installation load tests and the service load tests, as defined above, are reported in Figure 56 and in Figure 57.

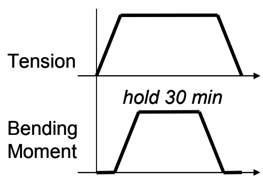

Figure 56: Loading sequence for installation load test

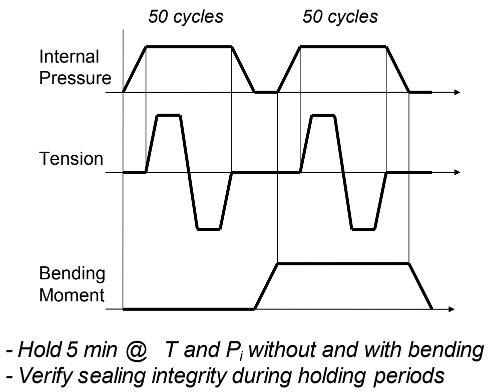

Figure 57: Loading sequence for service load test

In view of the complexity of the full scale tests, especially considering the size of the specimens and the time needed to perform one test, a trial test has been performed on a tubular sample cut from the largest of the pipe size to be tested. This sample was used to perform a trial loading test, in order to verify the set up of the full scale testing frame and to define the control parameters of the frame for this type of test. A picture of the trial specimen during the assembling phase into the load frame is reported in Figure 58.

Figure 58: Trial specimen loaded into the full scale test frame

Conclusion:
A full scale test procedure was defined and agreed. The specimen configuration was clarified.
A preliminary test on a real tubular specimen cut from the pipes to be tested was performed in order to set up the details of the experimental configuration. This included a welding trial of the end caps to the pipe specimens, in order to verify the end cap welding process.
The test frame is therefore ready to carry out the agreed test program, depending on specimen availability.

IV.2.3.2. TASK 3.2: SAVE DEFECT TOLERANCE CRITERIA

As part of the full scale test procedure, it was agreed to introduce in one of the test samples a damage load, to reproduce a typical impact from a real excavator, in order to assess any influence of possible external damage on the joint performance.

IV.2.3.3. Task 3.3: FEM Simulation Concept For Adhesive Pipe Joints

The choice of an applicable joint geometry was described in chapter IV.2.1.2. The first indications concerning the strength of the adhesive bonded pipes were obtained using the finite element method (FEM). Herefore, the software ABAQUS is used for qualitative calculations.
The possible joint-geometries, mentioned in chapter IV.2.1.2 were implemented in a FE-model. Modelling of the pipe-geometry and the material of the proposed pipes was done taking the characteristic properties determined in experimental analyses. The material models, both for pipes and for adhesives, have linear-elastic behaviour. One end of the pipes was mounted using rigid constraints. The loads were applied on the open end of the pipes using multiple point constraints.
Basing on the first adhesive tests it was stated out that the maximum allowable stress in the adhesive joint should not exceed 10 MPa. In addition, these stresses have to be in the elastic region of both pipes and adhesives. First simulations using the set up FE-model were performed. In these simulations, the qualitative stress progresses using different joint geometries were calculated. As an example the following figures show the stress progress under tension loads (Figure 59 & Figure 60).

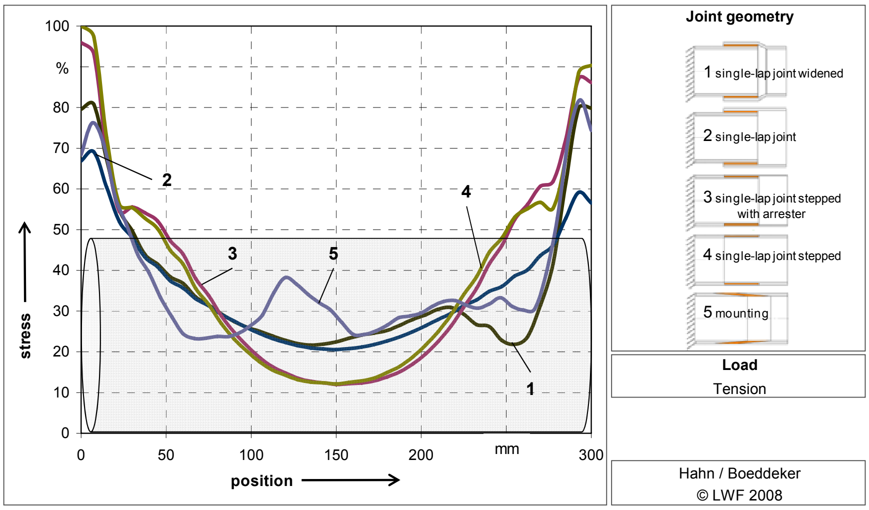

Figure 59: qualitative stress progress in adhesively bonded pipes using geometrically modified pipes

Highest stresses are expected using geometry 4. The lowest stresses are expected using joint geometry 6. Instead to the fact that geometry 8 has, under tension loads, a comparatively high stress level, this geometry is most suitable for pipe joining. This can be explained by the needs of the pipe industry and the requirements during pipe service. Mechanical modification of pipes is expensive and, therefore undesirable. Cranks, caused by using inner sleeves, are undesirable as well because of flow obstructions of conducted medium and, in addition, the use of pigs for pipe inspections is inhibited. Further simulations will be performed to optimise the stresses in the adhesive layer.

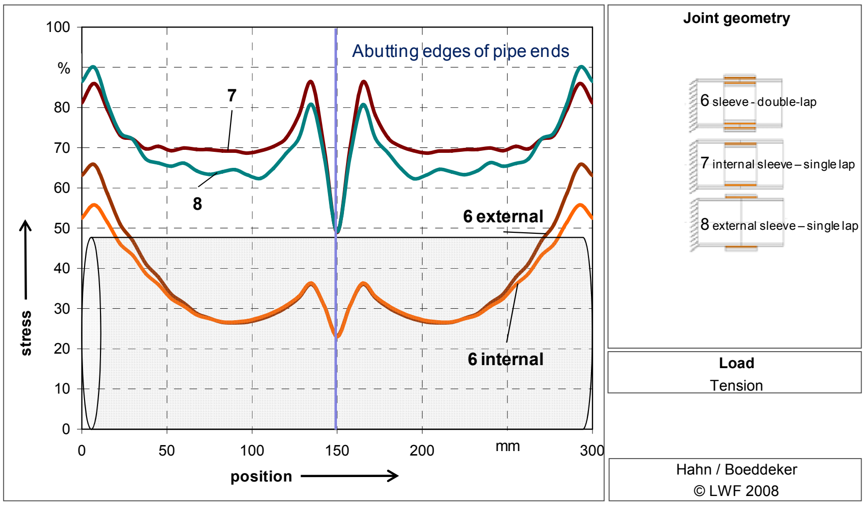

Figure 60: qualitative stress progress in adhesively bonded pipes using sleeves

IV.2.4. Work Package 5: Co-ordination

Due to the insolvency of project partner BOHLENDP, a replacement of this project partner became necessary. As the german company Bohlen & Doyen Bauunternehmung is not intended to be a substitute, the project team decided to subcontract the pipe laying tests. For this purpose, pilot-plants and qualified companies have to be identified. This plan could not be finalised during the reporting period.

For preparing reports, reporting modules were prepared by the project partners and compiled by the co-ordinator. Co-ordination meetings were held every six month to discuss results achieved and to decide the next steps in the project.

IV.3. Next Steps

The next steps in the JoinTec project are as follows:

The adhesive for pipe bonding will be enhanced and modified to fit on the needs of adhesively bonded pipes. Adhesive PU156, which will be used for pipe bonding until the adhesive to be developed will be available, will be characterised using climate and corrosion tests and tests under dynamic and crash loadings using simplified joints. To speed up the bonding process on construction sites, an accelerated curing procedure will be developed and the effects from heat introduction of the mechanical properties of the adhesive bulk and bonded pipes will be determined. For getting information about the lifetime of the pipes, they will be tested using corrosive and climate tests. These tests will be made with the adhesive bulk as well. The test programme set up for full-scale testing will be started.

The repair procedure will be further evaluated. The work on the non-destructive testing procedure will be continued.

For testing the pipes under field conditions, the proposed joining technology will be scaled to be used at real scale pipes. For this issue, an application method using an application machine or a gun dispenser will be chosen.

EUROPEAN COMMISSION
RESEARCH DIRECTORATE-GENERAL

Directorate G – Industrial Technologies
Research Fund for Coal and Steel

ANNEX I

Form 1-1
<u>OBLIGATORY AT THE SUBMISSION STAGE</u>

TECHNICAL ANNEX

Project acronym: JoinTec
Proposal No[2]: RFS-PR-06010
Contract No: RFSR-CT-2007-00035

TITLE:

Innovative and competitive new joining technology for steel pipes using adhesive bonding

---

OBJECTIVES

WORK PROGRAMME AND DISTRIBUTION OF TASKS

PROGRAMME BAR CHART

OBJECTIVES:

The general aim of the Research Fund for Coal and Steel (RFCS) is to increase competitiveness of the European steel industry. As pointed out in the "European Steel Technology Platform – Vision 2030" (March 2004) an increase in steel market share can be achieved by the use of new bonding technologies.

Joining techniques such as welding, brazing, riveting and screwing are used by industry all over the world on a daily basis. As a result of the very successful developments in recent years a further method of joining is becoming more and more important and is already a key technology in many areas: adhesive bonding.
The main innovative value of this research work is the introduction of the pace developments in adhesive bonding technology of recent years into the steel pipe industry by means of an interdisciplinary European team work between leading companies and research facilities from the steel and adhesive industry area. The focus of this proposal is on joining steel pipes with a diameter *d* up to 200 mm (main focus *d* = 168,3 mm) for water distribution as well as on joining steel pipes with a diameter up to 600 mm (main focus *d* = 508 mm) for the gas, water and heat transportation. The joining concept will be based on the present pipeline requirements including operation and maintenance processes.

Main objectives:

- Elaborating an efficient, integrated and easy-to-use joining technique for adhesive bonding of steel pipes.
- Development of guidelines, design calculation methods (both analytical and numerical with the Finite Element Method) and non-destructive testing methods including a repair concept for adhesively bonded steel pipes.

Transferability of the elaborated innovative bonding concept including an adequate in-process non-destructive technique for quality control and a repair concept will be verified by pipe laying field tests at the construction site. Additionally, simulation tools for the prediction of the joint's long-term stability will be developed. Furthermore, a detailed cost calculation which will be done at the end of the project to compare this new concept for pipe joints with conventional joining techniques will reveal the economic benefits of this innovative joining concept.
The project team comprises the entire product chain by connecting leading suppliers of both pipes and adhesives with the pipe laying industry and the end users including testing leading institutes for non-destructive and destructive pipe testing and universities as well as umbrella organisations. This ensures an optimal implementation of the developed technology and dissemination of the results. The strong participation of industrial partners reveals the clear industrial interest to carry out the proposed work on European level. The project connects five European countries and eight project partners with complementary profiles. All project partners are leading representatives in their fields of work.
All activities of this project are concentrated on the aim to strengthen the competitiveness of the European steel sector as a whole; at a time where there is an increasing demand on new pipelines for the gas, water and heat distribution. For instance: it is predicted that natural gas consumption will double over the next 20 years. The improvements of living conditions, the global population growth, and last but not least the increasing environmental consciousness is increasing the need for new and safe pipeline constructions.

ANNEX I
Form 1-2
OBLIGATORY AT THE SUBMISSION STAGE

WORK PACKAGE DESCRIPTION	**WP No**	**1**

Work package Title	Joining Fundamentals verified on small scale tests	**Number of man hours**[29]
WP Leader	University of Paderborn (UPB)	5200
Contractor	Salzgitter Mannesmann Forschung GmbH (SZMF)	370
Contractor	Gaz de France (GdF)	10
Contractor	Sika Danmark A/S (SIKA)	750
Contractor	Bohlen & Doyen Polska Sp. Z o.o. (B&D)	100
Contractor	Centro Sviluppo Materiali S.p.A. (CSM)	10
Contractor	Mannesmann Fuchs Rohr GmbH (MFR)	10
Contractor	Arbeitsgemeinschaft für Wärme und Heizkraftwirtschaft e.V. (AGFW)	30
Total		**6480**

1 – Objectives

The main objectives of this work package are the following:

- Survey of main requirements, design standards and of main in-service loading conditions in pipe joints in the gas, water and heat distribution net with regard to adhesive bonding.
- Choice of joint design.
- Development of adequate adhesive.
- Selection of economical and technological beneficial surface treatment.
- Development of easy application method including curing method.

2 - Work programme and distribution of tasks with indication of participating contractors

Task 1.1: Survey of main requirements, design standards and of main in-service loading conditions in pipe joints in the gas and water distribution net with regard to adhesive bonding.

At the beginning of the research project the technical specifications and requirements for adhesively bonded joints in the gas, water and heat distribution net have to be defined in close collaboration with all project partners. The pipe laying company B&D (Bohlen & Doyen Polska Sp. Z o.o.) as well as Gaz de France (end user) and the umbrella organisation AGFW (Arbeitsgemeinschaft für Wärme und Heizkraftwirtschaft) will act as consultants in order to provide the other project partners about technical requirements, design standards and their practical experiences and problems in the field of gas, water and heat piping systems made of steel.
This survey including a literature research of the main standard criteria for steel pipe joints forms the foundation for the following tasks. It is also important in order to discuss the geometry of small scale specimens. Simple standard specimens and small scale pipe specimens will be used in this WP. All partners of the WP1 will bring in their individual expertise in Task 1.1.

Task 1.2: Choice of joint design

As the result of adhesive bonding strongly dependents on joint design, choice of adhesive, surface preparation, application method and curing concept it is necessary to research all these areas in order to develop a consistent joining concept. This will be done in close collaboration with the adhesive industry (SIKA).
When switching from welding to adhesive bonding, designs must be reviewed and altered. In principle, adhesive bonded joints could be loaded by three main types of stresses: shear, tension, and peel stresses. The goal is to achieve as uniform stress distributions as possible. Adhesive joints should be designed in such a way that the joint is stressed in shear. Peel stresses should be avoided [26]. Therefore, lap joints are the most commonly used adhesive joints and work best with metal applications because the rigid nature of metal substrates helps to achieve a more uniform stress distribution under shear loading.
Fig. 3 on the following page shows a systematisation of possible joint designs for pipes. Beneficial in terms of adhesively bonded pipes are overlapped and tapered joints as well as joints with a coupler [13] because in these cases the adhesive layer is stressed by shear forces (and torsion). The adhesive butt joint is most probably not the appropriate joint design for pipe applications covered by this project because of the small surface area and the normal stresses in the adhesive layer. The different joint designs with lashings (bushings) always need additional joint devices but offer – similar to overlapping joints - a big surface area for the adhesives. The taper/taper joints have the great advantage in comparison to the other joint designs that the stress peaks in the adhesive layer are avoided [13]. Therefore, in principle these joint designs can transfer higher loads. Disadvantageous is the effort to produce the pipes´ tapered ends. The widened single lap joints are preferred for pipes with small wall thickness due to industrial/economic interests. Generally, the stress peaks in the adhesive layer in overlapping joints can be reduced by chamfers in order to optimise the stress distribution.
In terms of glass-fibre reinforced polymer (GRRP) pipes where adhesive bonding is already used the joint is typically formed using either a bell system (overlapping joint) or a coupler (single lap – outer) [19].

Task 1.2: Choice of joint design (cont´d)

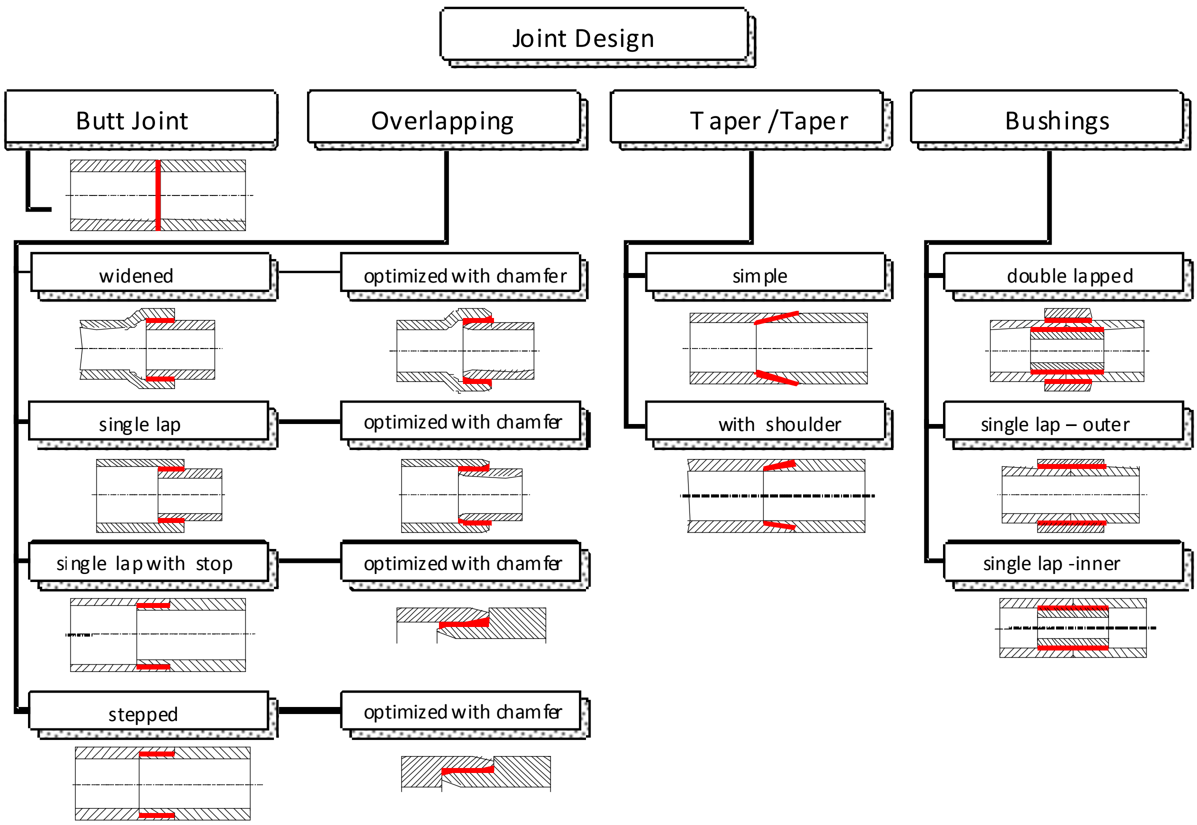

Fig. 3: Systematisation of pipe joint designs [13].

The focus of this new proposal is on joining steel pipes with a diameter *d* up to 200 mm (main focus: *d* = 168,3 mm) for water transportation as well as on joining steel pipes with a diameter up to 600 mm (main focus *d* = 508 mm) for the gas, water and heat transportation. During the last couple of months the project team developed for both the small and large diameter pipes a new, innovative adhesive joint geometry which takes the requirements for a long term use of the pipe (material aging, creep, corrosion) into account. Fig. 4 shows the developed joint design for the large pipes.

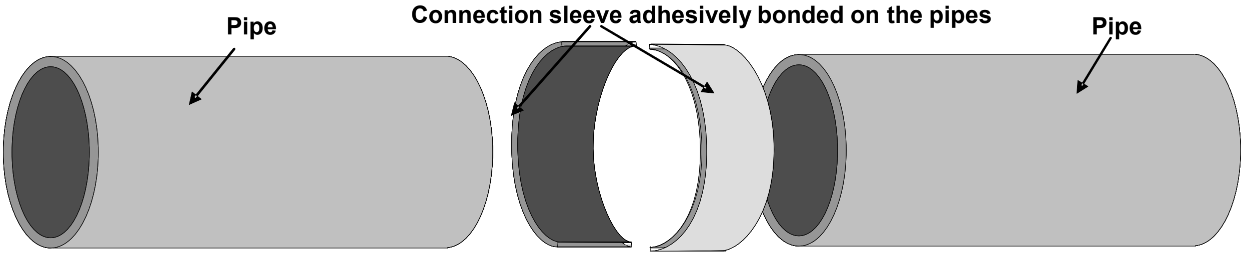

Fig. 4: Developed joint design geometry for steel pipes up to 600 mm in diameter.

The pipes are laid down in a way that they rest against each other. The connection sleeve is divided into two parts in order to ease the joining process. Preliminary stress calculations revealed that the connection sleeve needs a maximum length of 400 mm so that it is overlapping each pipe by 200 mm.

Task 1.2: Choice of joint design (cont´d)

The joint design which will be further evaluated in the research project has to take the present pipeline requirements for operation and maintenance processes (such as piggability and CP for underground lines) into account in order to fulfil the requirements from the end users.

Fig. 5 shows the joint design geometry for the smaller pipes with up to 200 mm in diameter.

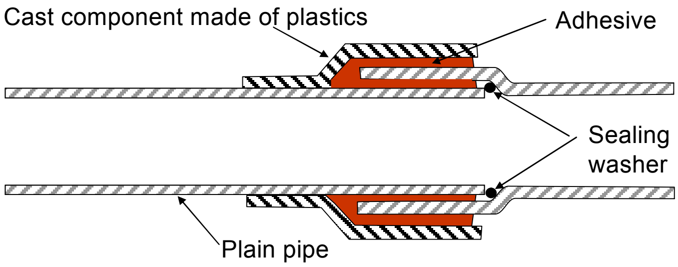

Fig. 5: Developed joint design geometry for steel pipes up to 600 mm in diameter.

The pipe socket which is a cast component made of plastics ensures that the adhesive can be applied easily at the pipe joint. Furthermore, this pipe socket defines the thickness of the adhesive layer. The sealing washers prevent the adhesive from penetrating inside the pipes. Preexaminations done by the project team for the preparation of this proposal pointed out that only an overlapping length of 30 mm is required.

The exact dimensions of these joint geometries will be specified according to the industrial needs by Finite Element simulations (UPB) and by tests on small scale pipes (axial loads, torsion, and pressure) done by SZMF, except dynamic tests which will be done by (UPB). The definition of the exact geometry will be supported by the adhesive industry (SIKA). SIKA will bring in a lot of practical experience since this company supplies already structural adhesives for blade bonding for wind turbines and sandwich panel bonding.
Task 1.2 interrelates with the development of an adequate adhesive. Therefore, on these tasks will be worked simultaneously.

Task 1.3 Development of an adequate adhesive

According to DIN 16920, an adhesive is a non-metal material being able to join adherents by surface adhesion and inner strength. The junction is a result of cohesion and adhesion forces [9]. Engineers can choose the correct product from a great variety of adhesives since 250,000 different adhesives are produced worldwide and about 25000 different adhesive products are available for trade, only in Germany.

Adhesives can be classified in chemically reacting systems and physically reacting adhesives. Chemically reacting adhesives are used for high load assemblies and severe service conditions such as heat, cold or the influence of different mediums. Thus, only chemically reacting adhesives should be considered in this project. In chemically reacting adhesives, there are monomer and pre-polymer molecules ready for reaction in the adhesive layer. They react in the adhesion process with each other under certain conditions, e.g. pressure or temperature, forming polymers in the adhesive splice.

Task 1.3 Development of adequate adhesive (cont´d)

Depending on whether or not the addition of heat is necessary for the curing, chemically reacting adhesives can be divided in cold-setting and hot-setting adhesives. The chemical reactions leading to curing are polymerisation, polyaddition and polycondensation reactions [12, 22], (Fig. 6).

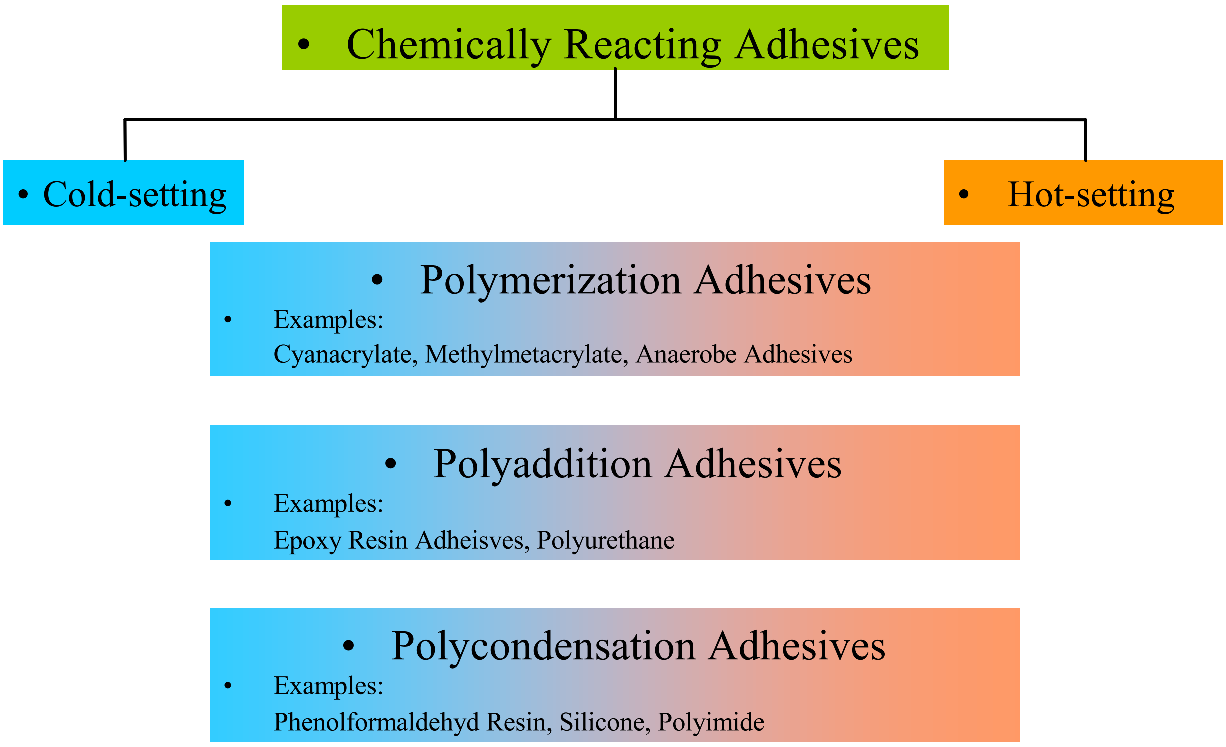

Fig. 6: Chemically reacting adhesives.

For example: polyaddition adhesives based on epoxy resins used in automotive shell construction are hot-setting materials that require temperature above 100°C (212°F) to set. Chemically reactive adhesives can be further subdivided into two groups: one-component systems and two-component systems (mix and no-mix).
One component systems that cure by heat include epoxies, polyurethanes, polyimides and usually consists of two pre-mixed components, which eliminates the need for metering and mixing.
Two component systems come in several forms but usually consist of one part called the adhesive or resin, and a second part called the hardener, catalyst or accelerator. The two components are brought together, i.e. mixed, in a variety of ways, with the mixing starting a chemical reaction, which leads to hardening of the adhesive. Some two component systems do not require careful mixing, such as modified acrylics, in which the accelerator is applied to one surface, adhesive to a second, and the surfaces are joined. Other two-part adhesives, for e.g. some epoxies, often need more accurate mix ratios. Different methods have been developed to help with this mixing, such as pre-measured packs, or cartridges and mixer nozzles. Two component adhesives can cure at room temperature, although some need an elevated temperature to achieve full cure.

Task 1.3 Development of adequate adhesive (cont´d)

Certain technological properties can be achieved by adding different additives and filling materials to the chemically reacting adhesives. New so-called adducts or prepolymers especially suitable for metal bonding have been developed in recent years to further optimise epoxy adhesives [31, 32, 33]. The adhesive formulator can use these components as powerful building blocks in a modular system [2].
Nanotechnology which has become an area of intensive adhesive research in recent years developed methods to synthesise nanosized filler particles which are advantageous in comparison to conventional fillers since much better physical properties of the cured adhesive can be achieved [31]. Recent research even showed that the performance of both one and two component epoxy adhesives can be further improved by combining adducts with these new nanoparticles [31].
For adhesively bonded joints in glass fibre reinforced epoxy (GRE) piping systems used in the oil industry two component epoxy resin adhesives are being used [25]. These GRE-pipes have to resist internal pressures of 100 bar while exposed to water. The most commonly used adhesives for steel joints are epoxy adhesives, modified epoxy adhesives and polyurethane adhesives.

The best adhesive for a given application is generally a function of part design, processing needs and performance requirements. Main performance requirements for this project are durability (material aging, creep, and corrosion), stability against water and gases and an easy handling at the construction site under field conditions. In terms of adhesive bonding of steel pipes which is the scope of this research proposal two component Polyurethanes are the adhesives to be considered. Based on an interdisciplinary research done by the project team as part of the preparation for this proposal the two component adhesive should have an E-Modulus of about 100 MPa, a minimum elongation at fracture of 20 % with a lap shear strength of 10 MPa.

The development and selection of the adhesives will be done by SIKA. This project partner can look back over a long and successful history of structural adhesive bonding and has a great variety of appropriate research capacities. SIKA will approach the project objectives from the chemical point of view.
The selected adhesives will be evaluated by fundamental tests such as adhesion tests, Differential Scanning Calorimetry (DSC) and Dynamic Mechanical Analysis (DMA). This work will be done by UPB. All small specimens tests including shear tests (aged, not-aged), τ-γ tests (aged, not-aged), σ-ε tests (aged, not-aged), dynamic strength tests (Woehler) and impact tests on simple overlapping joints (aged, not-aged) will also be done by UPB. All tests on small pipe specimens – also including tests to optimise the processibility - will be done by SZMF expect the corrosion test (VDA 621-415), the climate tests (P-VW 1200) and tests on small pipe specimens under impact forces. These three tests will be done by UPB. The tests are essential in order to satisfy the industrial requirements for a long term use of the pipeline.
Based on the analysed test results the adhesives will be further evaluated in the WP2, WP3 and WP4. SIKA will supply all project partners with adhesives they need in order to do their work on this project.

Task 1.4 Selection of economical and technological beneficial surface treatment

Surface preparation is very important because the adhesive "only sees the surface". Therefore, the strength of a joint strongly depends on the condition of the surfaces. Surface preparation can range from simple cleaning to extensive anodising and priming. The degree of surface preparation depends on the adhesive used, needed performance and service lifetime. Some adhesives are more tolerant of surface oils and require a minimal amount of surface preparation. In general, a clean dry surface is important for achieving maximum bond strength and repeatable environmental durability.

Main applied preparation methods are:

- Degreasing with steam, organic solvents or alkaline cleaners.
- Mechanical methods such as blasting, brushing or grinding with emery-paper.
- Applying a primer.

It has to be taken into account that the adhesive bonding process has to be done at the construction site under field conditions. This requires a tolerant adhesive bonding process, including surface preparation. Adhesively bonded steel bridges constructed already in the fifties and sixties of the 20^{th} century and still in use have proven that adhesive bonding can successfully be done at the construction site under field conditions [21, 36]. However, in terms of adhesive bonding of glass reinforced epoxy (GRE) piping systems it is reported that the surface treatment done outside at the construction site is sometimes problematic due to the weather conditions. Furthermore, it would be time-consuming.
Therefore, the work should be transferred from outside to inside by doing the surface preparation already in the factory and protecting the prepared joints. This method was already successfully applied in 1963 for another adhesively bonded steel bridge: The steel joints were prepared in the factory by sand blasting, before the surfaces were covered by a corrosion protective coating which had not been removed at the construction site [36].
The objective of this part of the project is to develop and verify an effective, easy-to-use, inexpensive and fast surface treatment for the pipe joints. Such an adequate and efficient surface treatment for adhesive bonding of pipes should be transferred from outside to inside the pipe factories. This has also social benefits as the transfer of surface treatment from outside to inside the pipe factory enables improved working conditions due to controlled temperature, humidity and light conditions together with improved ergonometry by allowing easier access to the pipes.

The selection of the surface treatment, e.g. supply of adhesive tapes will be performed by SIKA. UPB will be in charge of simple adhesion tests and tests to determine the contact angle in order to verify the results which will be discussed by all partners in this WP in order to ensure that the developed surface treatment is also beneficial with regard to the requirements at the construction site.
It is worth noting that all tasks of WP1 interrelate with each other.

Task 1.5 Development of easy application method including curing method

After the surface treatment, the adhesive has to be applied to the joints. There are different adhesive application methods, such as brushing, spraying, dipping, roll coating, knife coating and melting. The adhesive has to be distributed as a uniform film with the correct thickness over the entire circumference. Additionally, it is necessary that the adhesive system accommodate variations in gap at the joint arising from normal production tolerances in order to enable a fast installation process.

A simple idea for the application process is to apply the adhesive with a ring shape at the end of one pipe and before the pipe is inserted into a fitting of the other pipe end. This method is already successfully practiced for adhesive bonding of stainless water tubing [15]. Washers can be helpful for the assembly process. They ensure a defined thickness of the adhesive film over the entire radius. Furthermore, washers can help to easily centre the pipes in the correct position and to prevent that the adhesive leaks from the joint. This method using washers is used for both indoor and outdoor adhesively bonded balustrades in architecture [28].

The focus of this project is to develop a competitive joining technique. For this to be achieved, consideration must be given not only to the base cost of the adhesive (which are very low) but also to the simplicity and cost of application process. In order to reduce the costs in comparison to conventional joining techniques, it is important for the adhesive system to allow installation at a comparable or faster rate. The other boundary condition is that reasonable adhesive cost and ease of installation must be accompanied by satisfying service performance. The joint should function as an integrated part of the pipe.

In order to achieve these objectives different adhesive application concepts have to be evaluated. A most probably very good application method in terms of both from a commercial and technological point of view is to inject the adhesive in the joint area by pressure. The use of washers can keep the adhesive in a defined joint area. It is planned that SIKA will be in charge of the application concept supported by UPB. In order to take the situation at the construction site into account the pipe laying industry Bohlen & Doyen Polska Sp. Z o.o. (B&D) and the end users (Gaz de France) together with umbrella organisations (AGFW) will support the work with their experience and requirements.

3 - Interrelation with other work packages

In work package WP1 a consistent preliminary adhesive bonding concept is elaborated on simplified small scale specimens. The results will be evaluated in detail in the following two packages (WP2, WP3) in terms of full scale tests. Additionally, both a repair and an in-process quality control concept will be developed (WP3). Transferability to field conditions of the results will be verified in WP4 by field tests at the construction site. Furthermore, the evaluated experimental test data obtained in WP1 will be used in terms of the FEM calculation concept of adhesively bonded steel pipe joints under real loading conditions, see WP3, Task 3.2.

4 - Deliverables and milestones

The first deliverable is a compilation of main requirements for adhesively bonded steel pipe joints in terms of economic, loading and environmental requirements. The main deliverable is a preliminary adhesive bonding concept. Information will be available about a fundamental qualification of different adhesives, joint designs, surface treatment concepts and adhesive application methods for steel pipe bonding.

ANNEX I
Form 1-2
OBLIGATORY AT THE SUBMISSION STAGE

WORK PACKAGE DESCRIPTION	WP No	2

Work package Title	Qualification of processes for field conditions and required process quality control	**Number of man hours**[29]
WP Leader	Salzgitter Mannesmann Forschung GmbH (SZMF)	2300
Contractor	Gaz de France (GdF)	20
Contractor	Sika Danmark A/S (SIKA)	30
Contractor	Bohlen & Doyen Polska Sp. Z o.o. (B&D)	80
Contractor	Mannesmann Fuchs Rohr GmbH (MFR)	200
Contractor	Arbeitsgemeinschaft für Wärme und Heizkraftwirtschaft e.V. (AGFW)	10
Contractor	University of Paderborn (UPB)	200
Total		**2840**

1 – Objectives

The main objectives of this work package are the following:

- Selection of an adequate NDT method to develop an in-progress quality control concept capable for the application in the field.
- Repair procedure.
- Transfer of the technologies to field conditions.

2 - Work programme and distribution of tasks with indication of participating contractors

Task 2.1 Development of a quality control system (Non-Destructive-Testing, NTD)

The use of adhesive bonding for the joining of pipes in the field will involve a new demand of in-process quality control. Up to now, adhesively bonded joints for non-critical applications are inspected mainly by random samples. In the scope of the requirements with regard to testing time and the environmental conditions in the field, there is evidence of need for an adequate non-destructive technique.

In general, two types of defects may arise in adhesively bonded joints: Those within the adhesive layer itself, like cracks, porosities, poor curing and precuring defects and spurious materials and those within the proximity of the adherent-adhesive interface like uncomplete filling of the bondline, kissing bonds and delaminations. Depending on the size of the defects, a considerable decrease of the bond strength as well as leaking may result.

Many different non-destructive evaluation techniques have been used to detect cracks and other adhesive defects. Those comprises:

- Ultrasonic techniques.
- Vibration techniques.
- Holographic inspection.
- Radiographic inspection.
- Thermographic inspection.
- And more specialised techniques used in the laboratory scale.

The aim of the this part of the project is to select an adequate NDT method, to develop a detailed inspection procedure and to design a concept for a real application in the field, taking into account all necessary boundary conditions. This leads to limitations in the applicability of some techniques that give suitable results only under laboratory conditions (holographic, radiographic techniques). The transfer of the developed techniques to field conditions has to be insured. The procedure will be as described in the following, concentrating on a one side accessibility:

Laboratory: Use of linear ultrasonic inspection (normal incidence)

This method uses the ultrasonic reflectivity at the interfaces as the observable. The main focus lies on the detection of delaminations at the interfaces adherent/adhesive and imperfections in the adhesive layer (porosity cracks etc.):

Instrumental:

- Choice of suitable transducers on piezo basis (normal incidence) for pulse-echo-mode (wave mode, frequency, geometry).
- Choice of suitable transducers on EMAT basis (normal incidence, no coupling medium) for pulse-echo-mode (wave mode, frequency, geometry).
- Development of suitable laboratory inspection mechanics (probe holder, mounting on the pipe) prepared to allow reliable reproducible and complete testing of the bond in the field.

Task 2.1 Development of a quality control system (Non-Destructive-Testing, NTD), (cont´d)

Ultrasonic inspection of bonded plates and pipes in dependence on:

- Wall thickness of the adherends.
- Adhesive.
- Adhesive layer thickness.
- Surface state and surface preparation.
- Artificial defects in/at the adhesive layer.
- The curing state (during and after curing).

Laboratory: Use of nonlinear ultrasonic inspection (normal incidence)

This technique will use shear waves at high inspection frequencies. It uses the transfer from a base frequency to the higher harmonics in the bond as the observable. The main focus lies on the detection of disbonds, voids and cracking.

Instrumental:

- Careful choice of suitable transducers on piezo basis (high power, very linear behaviour, normal incidence)
- Necessary modification of testing mechanics (expected to be minor).

Ultrasonic inspection of bonded plates and pipes in dependence on:

- Steel grade.
- Wall thickness of the adherents.
- Adhesive.
- Adhesive layer thickness.
- Surface state and surface preparation.
- Artificial defects in the adhesive layer interfaces (especially kissing bonds).

Laboratory: Use of linear ultrasonic inspection (oblique incidence)

This method uses the ultrasonic reflectivity at the interfaces as the observable. The main focus lies on the detection of kissing bonds at the interfaces adherend/adhesive.

Instrumental:

- The choice of suitable transducers on piezo basis (frequency, sound field, geometry, oblique incidence).
- Development of suitable laboratory inspection mechanics (probe holder, adjustment of angle of incidence, mounting on the pipe) adapted to the requirements of oblique angle incidence testing.

Task 2.1 Development of a quality control system (Non-Destructive-Testing, NTD), (cont´d)

Ultrasonic inspection of bonded plates and pipes in dependence on:

- Steel grade.
- Wall thickness of the adherents.
- Adhesive.
- Adhesive layer thickness.
- Surface state and surface preparation.
- Artificial defects in the adhesive layer interfaces (especially kissing bonds).
- Transducer characteristics (angle of incidence, frequency, etc.)

Laboratory: Use of ultrasonic surface waves

This method uses the ultrasonic waves with different polarisation directions, travelling along the axial direction. It uses the reflectivity at the interfaces as the observable and offers the possibility to inspect large areas. The main focus lies on the detection of imperfections in the adhesive layer and of delaminations.

Instrumental:

- The choice/development of suitable transducers on EMAT basis (wave mode, polarisation direction).
- Adaptation of the inspection mechanics to the requirements of ultrasonic surface testing.

Ultrasonic inspection of bonded plates and pipes in dependence on:

- Wall thickness of the adherents.
- Adhesive.
- Adhesive layer thickness.
- Surface state and surface preparation.
- Artificial defects in the adhesive layer interfaces.
- Wavelength (frequency) of generated ultrasound.

Laboratory: Thermography and vibration techniques

Thermography is used to inspect the curing procedure of large area bonds. Here the temperature development during the process as well as external excitation (electrical, microwave, light, vibration) can be used. Low frequency vibration methods have a certain potential to detect disbonds in adhesively bonded joints. Those techniques in principal detect local variations in stiffness of a bonded structure (mechanical impedance method) as a consequence of a good and defective area.

All the described techniques will be evaluated. Comparing the results of the different studies and techniques, a decision has to be made which method or combination of methods will be suitable for the application in the field. SZMF will be in charge of this part of the project (Task 2.1).

Task 2.2 Development of a repair procedure

In case a defect has been detected, it has to be decided whether it is tolerable or has to be repaired. In this case a procedure has to be worked out, how a fast and reliable repair can be performed and how eventually the adhesive pipe joint can be separated again. As a basis for the decision, the NDT-methods have to exhibit quantities (i.e. amplitudes, thresholds) determined by the studies on artificial and natural defects, which give a clear and reliable indication of where and how a repair has to be performed.

SZMF will do the work on the development of a repair procedure in the laboratory. The repair procedure will be evaluated mechanically in the next work package (WP3) with destructive tests and from a logistical point of view in WP4 where a practical pipe laying test will be performed. The work on this task will be done by SZMF with main consultancy of SIKA. The necessary full scale pipes will be supplied by MFR.

Task 2.3 Transfer of the technologies to field conditions

All the above mentioned procedures have to consider the situation in the field, which gives limitations to:

- Handling of the pipes.
- Handling of the NDT equipment.
- Education of the inspection people.
- Environmental influences (dirt, water, humidity etc.).
- Spare time for the inspection.

A concept has to be developed, how the methods can be applied to full sized pipes, taking into account:

- The inspection of the whole bonded area without any gaps. This comprises a concept for a robust and field suitable mechanical set-up.
- The application of sensors and transducers: In case of piezo transducers, the question has to be answered how the coupling medium can be applied to the specimen.
- How the results are presented to the inspection engineer (user interface).

The work on this task will be done by SZMF with support of UPB and under consultancy of the pipe laying industry (B&D) and the end users (Gaz de France). All full scale pipes which are necessary for the examinations will be supplied by MFR, (only short parts of pipes are necessary in this work package.)

3 - Interrelation with other work packages

This work package needs the results coming from WP1. WP2 will not only use the preliminary concept worked out in WP1 on small specimens tests, furthermore it is worth noting that the survey of main requirements for pipe joints in the field and in-service loading conditions (Task 1.1) is essential in order to preselect adequate non-destructive-testing methods and repair methods that are capable to meet the requirements on the construction site. Although, the development of the in-process quality control concept (Task 2.1) can already start right after the survey of the requirements (Task 1.1) as the project team already developed joint geometries for both small and large steel pipes as part of the preparation stage for this proposal. This guarantees a smooth work progress of this project also in case of delay of WP1.

Both the repair method and the non-destructive-testing technique will be verified on a practical pipe laying test in the field which will be performed in WP4. Furthermore, joints with defect for full scale testing in WP3 will be selected and prepared. The results of these tests will have influence on the valuation of the inspection results.

4 - Deliverables and milestones

The aim of work package WP2 is the development of a detailed inspection procedure and the concept for a time and cost saving application method in the field. Therefore, the deliverables will be an evaluation of different inspection procedures in terms of its use for adhesively bonded steel pipe joints. At the end of this work package a suitable non-destructive-testing procedure for adhesive steel pipe joints will be available as well as a reliable repair method for the application in the field.

ANNEX I
Form 1-2
OBLIGATORY AT THE SUBMISSION STAGE

WORK PACKAGE DESCRIPTION	WP No	3

Work package Title	Full scale testing of adhesively bonded pipe joints	**Number of man hours**[29]
WP Leader	Centro Sviluppo Materiali S.p.A. (CSM)	4380
Contractor	Mannesmann Fuchs Rohr GmbH (MFR)	300
Contractor	Arbeitsgemeinschaft für Wärme und Heizkraftwirtschaft e.V. (AGFW)	10
Contractor	University of Paderborn (UPB)	1500
Contractor	Salzgitter Mannesmann Forschung GmbH (SZMF)	1850
Contractor	Gaz de France (GdF)	10
Contractor	Sika Danmark (SIKA)	20
Total		**8070**

1 – Objectives

The main objectives of this work package are the following:

- Definition mechanical properties (stress strain design curves) based on a dedicated test program on full scale pipes.
- Save defect tolerance criteria based on a dedicated test program on full scale pipes.
- FEM simulation concept for adhesive pipe joints.

2 - Work programme and distribution of tasks with indication of participating contractors

Task 3.1: Definition mechanical properties (stress strain design curves)

In industrial environment, only limited time is available for the design phase of pipe lines or other constructions. The most efficient material laws from a user point of view are undoubtedly based on tabulated stress-strain curves obtained directly from physical testing. Useful data is necessarily based on experimental material testing.

The general aim of this work package is the definition of mechanical properties and the evaluation of in-service performance of adhesively bonded steel joints in order to derive a criterion for stress/strain design of pipeline made using adhesively bonded joints. To achieve this goal a dedicated test program will be set up and performed in collaboration with both the adhesive industry and the pipeline industry.

The test program will be subdivided in two phases: laboratory tests on small parts of pipe joints and full-scale tests performed on a limited numbers of selected joints. The tests performed on small-scale pipe joints will be executed by SZMF. In parallel, a dedicated full-scale test program will be performed, first, in order to verify the findings made on small-scale specimens and, second, to finally validate the new joint design concept under realistic service conditions. In detail, the full-scale test program will comprise the items listed below:

- Static tensile tests (positive axial force) …(SZMF)
- Static bending tests …(CSM)
- Static torsion tests …(SZMF)
- Static pressure containment tests …(SZMF)
- Alternating tensile/compression tests (positive/negative axial force) …(SZMF)
- Cyclic pressure containment tests …(SZMF)
- Multi-axial testing 1: pressure containment + positive/negative axial force (static and cyclic) …(SZMF)
- Multi-axial testing 2: pressure containment + bending moment …(CSM)
- Multi-axial testing 3: pressure containment + torsion …(SZMF)
- Evaluation of resistance against denting and puncture simulating dynamic external threats such as impact due to mechanical equipment like excavators …(CSM)

In the above tests, loads and displacements shall be recorded continuously during testing, notably in axial direction directly at the interface between joint and out-bounding pipe. Prototype testing shall neither lead to any form of burst failure nor de-bonding nor leakage.

The full scale test program will be done in joint co-operation of CSM and SZMF, both parties having extensive expertise in this field. CSM can perform its part of the test program making use of existing dedicated facilities like an excavator simulator (suitable for any type of diameter and a maximum length of about 5 m) and readily available equipment for simulating interaction of internal/external pressure and bending loads. Likewise, SZMF is capable of performing its part of the test program independently utilizing approved testing facilities.

The full scale test program in Task 3.1 will be done on selected types of joints (maximum 3 geometries). MFR (Mannesmann Fuchs Rohr) is in charge for the supply of these pipes.

Task 3.2: Save defect tolerance criteria

The above indicated full scale test program will not only be performed on selected kinds of received joints, moreover it is planned to also perform these tests on joints with "defect" and joints damaged by environment and cyclic loads. About this last, a realistic load/environments laboratory cyclic to reproduce the potential in service damage will be fixed under consultancy of pipe laying industry (B&D) and end users (Gaz de France). The experimental tests will be done by CSM. UPB will work out the defect tolerance criteria based on the experimental test data (CSM).
MFR (Mannesmann Fuchs Rohr) is in charge for the supply of the pipes. All joints will be made and inspected by SZMF using the methods developed already in the previous work package WP2.

Task 3.3: FEM simulation concept for adhesive pipe joints

Simulation with the Finite Element Method is state-of-the-art today. Simulation is important to verify construction concepts and to shorten the time used for the design phase.
The aim of this task is to develop a suitable Finite Element calculation concept to simulate adhesive pipe joints. Furthermore, these simulation tools should have the capability to predict the long-term stability of the joint. The result will help design engineers to optimise new pipe joint geometries. The FE-concept has to take into account not only the mechanical forces, such as axial loads. Moreover, the properties of the used adhesives under different mediums and temperature have to be modelled. The FE-concept will be worked out by UPB and will be verified by the full scale tests done in this WP. It has to be mentioned that UPB has a great expertise and long-term experience in modelling adhesively bonded joints since UPB is working on the development of FE-calculation concepts together with adhesive industries and end users since many years. It is worth saying that the FE-calculation concept for adhesive bonded pipe joints can be based on the experience and knowledge gained in terms of modelling of adhesive joints in the automotive industry where adhesive bonding is already a key technology. The UPB is working on this research field with the automotive industry since many years.

3 - Interrelation with other work packages (please give WP No)

For the successful competition of this work package the WP1 and WP2 are important and their conclusions are needed. For instance: the joints with "defect" that are tested in Task 3.2 of this WP will be inspected by the non-destructive-testing methods developed in Task 3.1 of the previous WP. The knowledge gained in this WP will be used in WP4 in order to derivate guidelines and a easy-to-use design method for adhesively bonded pipe joints in the gas, water or heat distributing net.

4 - Deliverables and milestones

At the end of this work package a dedicated know-how about the design and inspection of adhesive pipe joints will be available. The stress strain design curves together with a save tolerance criteria as well as a Finite Element calculation concept are main deliverables. This experimental data is obtained under a variety of different loads, typical for the wide range of different load conditions in the gas, water and heat supply industry. A realistic FE-model for adhesively bonded pipes is another important step in order to introduce the developments of adhesive bonding technology of recent years into pipe laying industry.

ANNEX I
Form 1-2
OBLIGATORY AT THE SUBMISSION STAGE

WORK PACKAGE DESCRIPTION	WP No	4

Work package Title	Verification of consistent adhesive bonding concept under field conditions	**Number of man hours**[29]
WP Leader	Bohlen & Doyen Polska Sp. Z o.o. (B&D)	1870
Contractor	Centro Sviluppo Materiali S.p.A. (CSM)	10
Contractor	Mannesmann Fuchs Rohr GmbH (MFR)	400
Contractor	Arbeitsgemeinschaft für Wärme und Heizkraftwirtschaft e.V. (AGFW)	30
Contractor	University of Paderborn (UPB)	2460
Contractor	Salzgitter Mannesmann Forschung GmbH (SZMF)	40
Contractor	Gaz de France (GdF)	40
Contractor	Sika Danmark A/S (SIKA)	50
Total		**4900**

1 – Objectives

- Practical pipe laying test at construction site in order to verify the developed adhesive bonding concept under field condition and in order to assess developed adhesive bonding concept against conventional joining techniques
- Detailed cost calculation to compare this new bonding technology for steel pipes with conventional joining techniques.
- Fixing practical guidelines/recommendations and design calculation methods for adhesive bonding of pipes in the gas, water and heat distribution net.

2 - Work programme and distribution of tasks with indication of participating contractors

Task 4.1: Practical pipe laying test at construction site in order to verify the developed adhesive bonding concept under field condition and in order to assess developed adhesive bonding concept against conventional joining techniques

WP4 is scheduled after the first three work packages where a consistent adhesive bonding concept for steel pipes has been elaborated and evaluated with small scale specimens (WP1) over full scale non-destructive-tests (WP2) up to full scale destructive tests and FE-calculations (WP3). Finally, the developed bonding concept will be verified on a practical field lay test at the construction site under field conditions (WP4). The practical pipe laying tests is important because it reveals logistical and technical advantages and disadvantages of the new bonding concept.

The lay test will be done by the pipe-lying company Bohlen & Doyen Polska Sp. Z o.o. (B&D) which have more than 50 years experience in pipe constructions. Mannesmann Fuchs Rohr GmbH (MFR) will supply B&D with the pipes for the pipe laying test at the construction site. The field tests will be done under consultancy of Gaz de France.

Task 4.2: Detailed cost calculation to compare this new bonding technology for steel pipes with conventional joining techniques.

In order show the progressiveness of the developed adhesive bonding concept an assessment of this concept against conventional joining techniques (welding, mechanical fastening) will be performed by UPB based on an analyse of the field tests. This includes a detailed cost calculation done by UPB under consultancy of both B&D and Gaz de France in order to compare the developed new concept with conventional joining techniques. This comparison has to cover not only the costs for the bonding process itself but also for all parts and technical devices necessary for a long term use of the pipeline. Therefore, also present pipeline requirements for operation and maintenance processes such as piggability and CP for underground lines have to be taken into account.

Task 4.3: Defining practical guidelines/recommendations and design calculation methods for adhesive bonding of pipes in the gas, water and heat distribution net

Together with the background of knowledge gained in the first three work packages the evaluation of the practical pipe lying test will be the foundation to derivate practical guidelines for an easy-to-use bonding concept at the construction site. This work will be done by UPB under participation of B&D and Gaz de France. The work in this task will be supported by AGFW. AGFW which is an umbrella organisation ensures an optimal exchange of experience prepares technical standards ("AGFW work sheets") with requirements and test procedures also as instructions for the use of the technical solutions. New standards will be worked out with all groups concerned (manufacturer, suppliers, test laboratories and others). Before a new standard coming into force the whole branch of industry has the possibility to give their statements to the published working documents.

3 - Interrelation with other work packages (please give WP No)

This WP will take into account all previous work packages with their analysed results.

4 - Deliverables and milestones

The deliverable of this work package is the presentation of an innovative bonding concept using the pace developments of adhesive bonding in recent years. Furthermore, practical guidelines for adhesive bonding of pipelines will be supplied. Furthermore, a detailed cost calculation will be worked out under consultancy of Gaz de France. This evaluation covers not only costs for the bonding process itself but also for all devices and technical requirements necessary for a long term use of the pipeline. The costs will be compared with the costs for conventional pipe joints.

ANNEX I
Form 1-2
OBLIGATORY AT THE SUBMISSION STAGE

WORK PACKAGE DESCRIPTION	**WP No**	**5**

Work package Title	Management and co-ordination of the project	**Number of man hours**[29]
WP Leader	University of Paderborn (UPB)	950
Total		**950**

1 – Objectives

- Management and co-ordinations of the project and maintaining adequate lines of communication between all partners in order to achieve the project objectives within the time and budget allocated.
- Preparation of the output of the project including the final report.

2 - Work programme and distribution of tasks with indication of participating contractors

5.1 Management and co-ordinations of the project

Fig. 7 shows the management structure of the project.

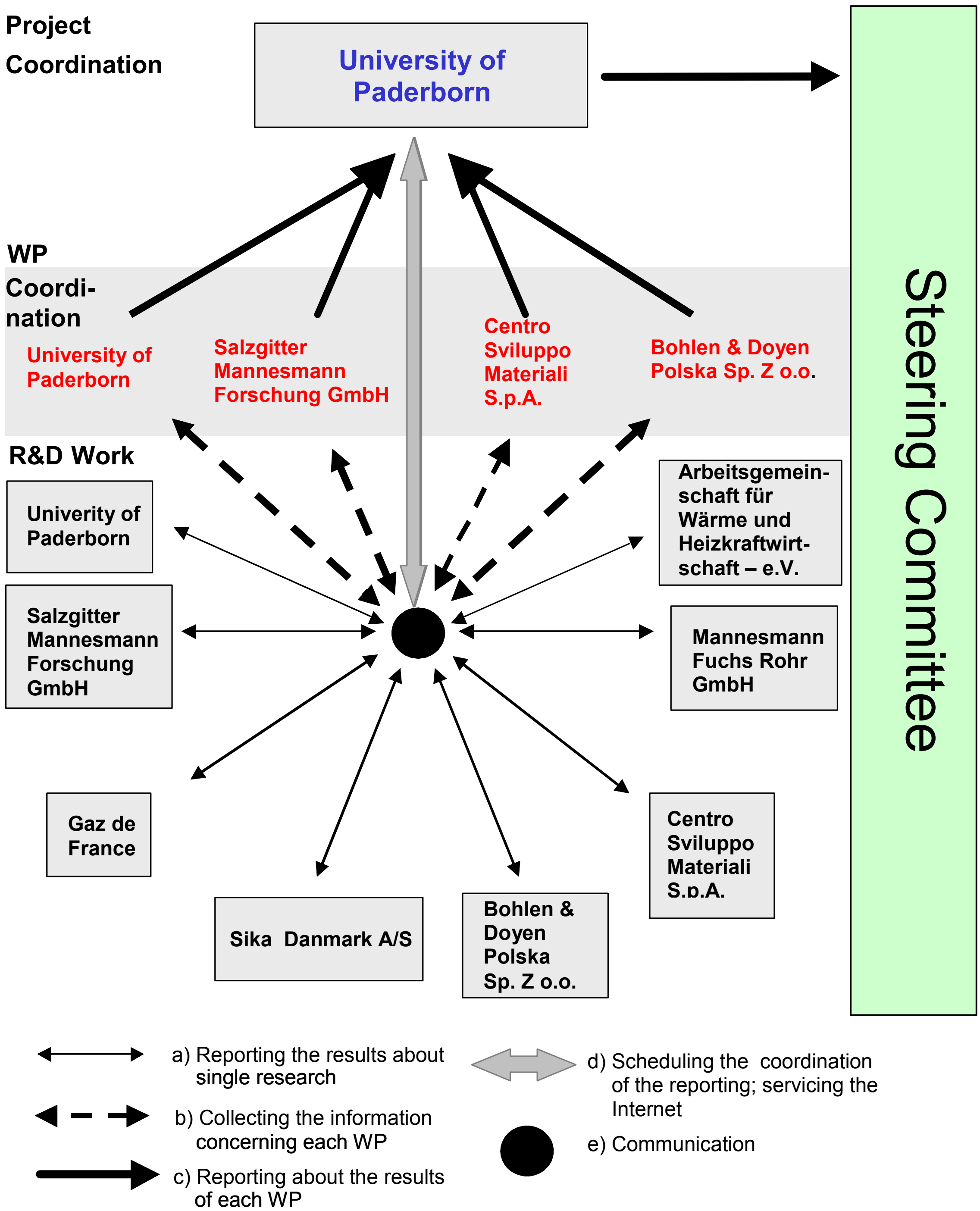

Fig. 7: Management Structure.

5.1 Management and co-ordinations of the project (cont´d)

The project coordinator (UPB) manages the research programme including the financial coordination. Progress will be monitored against the project plans by comparing resources consumed and the technical progress made with the costs and objectives planned in each sub-work package. This will be done twice a year on the occasion of the project meetings to be held in which each coordinator of a sub-work package presents a progress report. Progress reports will summarise technical progress and project expenditure every three months, identify to what extent progress and expenditures are in line, identify any technical difficulties or circumstances likely to affect progress and outline planned activities for next reporting period. The work of each work package will be accompanied and monitored by the Coordinator (UPB). In this way any difficulties can be identified and dealt with when they arise. These reports will be assimilated by the project coordinator and used to compare with the scheduled programme and resource allocation.
Decisions will be made concerning future direction of each partner and action will be taken to rectify any activities where progress is not in line with the programme. The work of each work package will be accompanied and monitored by the Coordinator (UPB).
A steering committee which will by formed by Prof. Dr. Hahn (UPB), Prof. Dr. Niemeyer (SZMF) and Dr. Demofonti (CSM) will meet in the case of major problems during the research work.

The Laboratory of Materials and Joining Technologies (LWF) which is a department of the University of Paderborn (UPB) will actually execute the work on this research project. LWF has a long experience in coordination and development of research projects in the field of joining techniques The LWF allocates resources and qualified staff for management of the project. Furthermore, the co-ordinator Dipl.-Ing. Wissling (LWF), in particular, brings in also practical experiences from the pipe laying industry since he worked as an engineer on several international pipe laying projects. Before he started his research career at the LWF, Mr. Wissling worked in the Netherlands and the USA for Heerema Marine Contractors (HMC) which is a Dutch company that provides design, transportation and installation services to the international oil and gas industry.

The Europe Liaison Office at the University of Paderborn consults the UPB as the project coordinator in special questions of administrative affairs in order to guarantee an optimal financial coordination and optimal project process. As the Europe Liaison Office is part of the University of Paderborn collaboration is easily possible.

As coordinator his responsibilities for the Consortium and towards the Commission are:

- Collect all reports and documents submitted to the Commission or other participants.
- Collect progress reports.
- Send all cost statements and consortium agreements.
- Ensure prompt payment of financial contributions.
- Verify timetable in the way that milestones are met.
- Review project progress in the way that economic and technical objectives and targets are met.
- Solve possible problems arising from administrative, contractual or partnership issues
- Organisation of meetings.
- Provision of meeting minutes and follows up of agreed actions.

The progress monitoring may require coordinator visits to different partners when major task is executed (large scale testing on pipes) or prior to milestones of key deliverables.

5.1 Management and co-ordinations of the project (cont´d)

Communication structure:
Internet based project centre will be launched for collecting reports and related information. This centre will be linked to e-mail which notifies added documents and reports. Proactive frequent informal communication between participants is encouraged vial e-mail.
Next to the normal meetings additional conferences may be called when urgent problems arise and solving of them is needed. In order to save time and travelling resources, some of those meetings will be held via e-mail ballot and confirming conference call or internet-assisted meeting when all partners may discuss and select one of their screens to watch (e-meeting). In addition to official meetings, the facilities can be used within technical discussions with smaller number of participants.

5.2 Preparation of the output of the project

Every month the WP leader will assess and report on the progress of task in his WP. Possible deviations from the detailed project plan will be reported. Proposals for corrective action to ensure that key deliverables and milestones are met. Every six months progress report will be circulated that contains summary of all work carried out in the previous six-month period.

After 18 months, a report which covers the whole first period of the project will be prepared. The expenditure of funding is included and comparison to allocation in the budget is done by each participant. This report is also mid term review of the project, where critical examination of results available is done reflecting the resources and allocated costs.

3 – Interrelation with other work packages

WP1-WP4: management and co-ordination of the project

4 - Deliverables and milestones

Progress reports, progress meetings, final report, etc.

EUROPEAN COMMISSION
RESEARCH DIRECTORATE-GENERAL

Directorate G – Industrial Technologies
Research Fund for Coal and Steel

ANNEX I
Form 1-3
OBLIGATORY AT THE SUBMISSION STAGE

PROGRAMME BAR CHART (TASK, PARTNER, DELIVERABLES, MILESTONES)

or pac ages	*or pac ages title*	*eliverables*	**Hours on project/ Contractor(s)**								**1st year**				**2nd year**				**3rd year**			
			1	2	3	4	5	6	7	8	I	II	III	IV	I	II	III	IV	I	II	III	IV
WP 1	**Joining Fundamentals**		**3460**	**205**	**10**	**750**	**100**	**10**	**10**	**30**												
Task 1.1	Survey of requirements	Working points	100	50	10	20	50	10	10	10	■	■										
Task 1.2	Optimisation joint design	Joint geometry	200	50		50					■											
Task 1.3	Development adhesive	Adeq. adhesive	1100			450					■	■										
Task 1.4	Selectio. surface treatment	Surfa. treatment	900			100	25			10	■	■	■	■								
Task 1.5	Devel. application method	Opt. applic. met	1160	105		130	25			10		■	■	■	■							
WP 2	**Process uality Control**		**200**	**1900**	**20**	**30**	**80**		**200**	**10**												
Task 2.1	Quality control system	Control system		900			10		100			■	■	■								
Task 2.2	Repair procedure	Repair proced.		800		30	10		50				■	■	■	■						
Task 2.3	Transfer t. field conditions	Suitability	200	200	20		60		50	10			■	■	■	■						
WP 3	**Full scale testing**		**1500**	**1850**	**10**	**20**		**4380**	**300**	**10**												
Task 3.1	Full scale tests	Stress strain cur	350	1700				2080	250						■	■	■	■				
Task 3.2	Defect tolerance criteria	Tolerance crit.	350	150	10			2000	50	10							■	■	■			
Task 3.2	FEM-model	Calc. model	800			20		300			■	■								■		
WP 4	**Adhesive bonding concept**		**2460**	**40**	**40**	**50**	**1870**	**10**	**390**	**30**												
Task 4.1	Pipe laying test at site	verification	300	20	30		1200		300	10							■	■	■	■		
Task 4.2	Comparison with welding	Cost calculation	1500	20	10	40	500		50								■	■	■	■		
Task 4.3	Guidelines, design criteria	Design criteria	660			10	170	10	40	20									■	■	■	■
WP 5	**Co-ordination**		**950**																			
Task 5.1	Co-ordination	Teamwork	500								■	■	■	■	■	■	■	■	■	■	■	■
Task 5.2	Reports	Reports	450									■		■		■		■		■		■
Total Hours on project			**8570**	**3995**	**80**	**850**	**2050**	**4400**	**900**	**80**												