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EXAMINATION OF CORROSION CAUSE OF WELDED PIPES

Abstract

In the production of welded pipes the fluid for cooling, lubricating and rinsing is applied, which acts as an anticorrosion agent as well. As the production process is finished, pipes are transported to a warehouse. After being stored for a certain period of time, on some pipe areas a corrosion process was observed. The aim of this work was to examine the causes of welded pipes corrosion. Therefore, the chemical composition of the pipe steel, technological parameters of the pipe manufacturing process and the possible pipes contamination during the manufacturing process and storage were examined in detail as possible corrosion causes. As in the pipe production process the metalworking emulsion was used, it was assumed that one of the possible causes of the corrosion could be the emulsion. The results of the examination show that the emulsion did not cause corrosion of welded pipes.

Key words: steel, welded pipes, corrosion, emulsion

Introduction

The welded pipes manufacturing process begins with cutting the sheet in lamellas of which width equals to pipe circumference [1,2]. Lamellas are cross welded in “endless” band, from which first cylinder is shaped by several rolls and then welded in a pipe, mostly by high frequency welding [1-3]. In a precise welded pipe manufacturing process, the welding of the pipes is followed by examination of their quality, according to requirements of the pipe production standards, and then by the pipe edges processing. Finally, the pipes are stored as bundles. The pipe diameter is defined by the width of the lamella, while the pipe wall thickness is defined by the thickness of the sheet from which the pipe is manufactured [4]. In hot-rolled welded pipes manufacturing process, the lamellas are always of the same width and consequently the welded pipes are of the same dimensions [5]. After welding, the pipes are first heated to the normalizing temperature to remove internal stress, and then to the hot plastic deformation temperature (over 950 ^{o}C). Because of this process, the pipe diameters and the wall thickness will differ from their initial size.

After the heat processing, the pipes are cut to the proper length, cooled and examined in accordance with current standards, packed and stored [5-7]. During the manufacturing process of both precise and hot-rolled pipes, in several process phases the pipes come in the contact with the emulsion Fig. 1.

In the Mechel ironworks in Sisak, in a rolling mill of hot-rolled and precise welded pipes, the emulsion with antirust properties, produced by the same manufacturer, was used. As a cartridge for pipe production, hot-rolling bands of different size and quality are used. Sheets are purchased from different suppliers. The quality of each sheet was checked in regulatory periods of time (sheet supplied by a new supplier was checked at the beginning of its use and periodically through a longer period of rolling), according to current standards [8,9]. The pipe quality is checked by providing mechanical, technological and structural examinations, according to the type and requested quality of the pipe. Rolled hot-rolled and precise welded pipes of required quality are stored in various storages which are physically separated one from another.

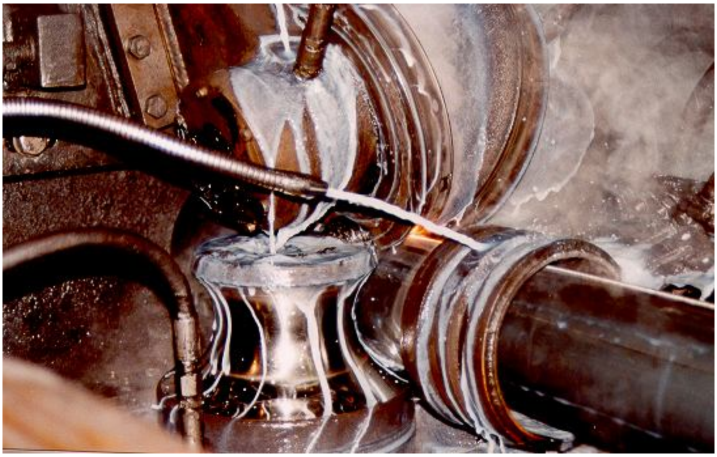


Figure 1: Cooling of an impeder with a cooling emulsion during pipe welding

Special attention is paid to pipes with unsatisfactory properties. They are excluded from the process and their delivery to the customer is not allowed. Special attention is paid to any customer's complaint as well. This work presents the results of examinations of the pipes which aroused customer's complaint concerning their corrosion. By detailed inspection the corrosion was observed on still stored and undelivered pipes, which were rolled in the same batch as the pipes customers had complaints about. All corroded pipes were rolled from six melts of sheets the same quality but of different dimensions, purchased from the same manufacturer. The corrosion was found on 80 % of the pipes, rolled from the same sheet delivery in the same period of time.

The corrosion was observed thirty days after the pipes were rolled [10]. It definitely required exceptional attention and requested immediate answers to the question of why the corrosion occurred, with the aim to eliminate its causes.

This work presents examination results concerning possible connection between pipes properties and corrosion causes on welded hot-rolled and precise pipes. Standard methods of pipe examination were applied. Special attention was paid to examination of pipe corrosion resistance and corrosion causes.

2. Experimental part

The examinations were performed on hot-rolled welded pipes of size 12.7 mm x 2.65 mm and 38.1 mm x 3.25 mm, as well as on precision welded pipes of size 25 mm x 25 mm x 2.00 mm. Methods for examining the chemical composition, mechanical properties, macro and micro structure of the weld and the basic material, as well as methods for examining the metal working fluids and their anticorrosive properties, according to international ISO, DIN and ASTM standards and internal methods of lubricant producer were applied [11-13].

The chemical composition was determined by the optical emission quantometer MA-ARL 8660. Mechanical properties of the pipe were examined on Instron tensile testing device. The samples for macro and micro examination were prepared by standard metallographic procedures: grinding with emery paper of different grain size, polishing and etching by nital. Examinations were carried out with an optical microscope at different magnifications.

Anticorrosive activity of the emulsion was examined by three methods. One of them is a well known method for anticorrosive properties testing by Herbert: DIN 51360/1, based on a determination of corrosion effects on cast iron plate covered with steel millings. On cast iron plate, size 100 mm x 100 mm, two grams of steel millings are placed, then wetted with one milliliter of emulsion and left in test chamber at a normal temperature and defined air humidity for 24 hours. Then metal millings are removed and changes on the plate areas where steel millings were placed are assessed. According to the method, the results are expressed as SXRY, where S is colour intensity (X = 0 - 6) and R is size of the corroded plate area (Y = 0 - 6).

Filter paper test DIN 51360/2 is based on the inspection of the stains that corroded cast iron millings leave on the filter paper. For that purpose, two grams of cast iron millings are placed on the filter paper of a defined size, then wetted with two milliliters of the test emulsion and left in the test chamber for two hours at a room temperature. The intensity of the millings corrosion is assessed on the scale from 1 to 6, according to the corrosion stains that millings leave on the filter paper.

The corrosion test, internal test 11 [12], simulates the conditions in use, in a way that the concerned material is exposed to corrosion in the presence of the metalworking emulsion, either by immersing the material in the emulsion, or by coating the material with the emulsion. In both cases, the material is exposed to corrosion atmosphere in a wet chamber without drying.

3. Results and discussion

Precise welded pipes, size 25 mm x 25 mm x 2 mm were rolled from hot-rolled steel band of S240 quality, thickness 2 mm. Hot-rolled welded pipes, size 12.7 mm x 2.65 mm and 38.1 mm x 3.25 mm were rolled from hot-rolled band of S240 quality, thickness 3.8 mm. The corroded precise welded pipes in the rolling mill storage are shown on Figure 2.

Figure 2: Corroded precise welded pipes 25 mm x 25 mm x 2 mm

Table 1: Chemical composition of the pipes

Melt	Pipe size/mm	Mass portion of components in steel, *w* / %								
		C	Mn	P	S	Si	Cu	Al	Cr	Ni
1	25x25x2	0.15	0.50	0.012	0.012	0.13	0.08	0.040	0.040	0.040
2	25x25x2	0.18	0.49	0.014	0.012	0.10	0.06	0.030	0.040	0.040
3	12.7x2.65	0.18	0.50	0.016	0.013	0.12	0.06	0.020	0.020	0.020
4	12.7x2.65	0.18	0.50	0.012	0.009	0.12	0.06	0.020	0.020	0.020
5	38.1x3.25	0.15	0.49	0.011	0.012	0.11	0.08	0.020	0.040	0.030
6	38.1x3.25	0.18	0.50	0.012	0.010	0.13	0.08	0.040	0.040	0.040
Contracted composition		Max 0.19	-	Max 0.060	Max 0.060	-	-	-	-	-

Table 2: Mechanical properties of the pipes

Melt	Pipe size / mm	R_e / MPa	R_m / MPa	A_5 / %
1	25x25x2	336 to 360	390 to 415	26.3 to 30.5
2	25x25x2	342 to 360	370 to 410	30.0 to 30.5
3	12.7x2.65	430 to 440	430 to 450	26.9 to 30.0
4	12.7x2.65	440 to 430	440 to 450	30.3 to 32.0
5	38.1x3.25	395 to 405	450 to 470	29.3 to 30.0
6	38.1x3.25	435 to 440	460 to 475	28.3 to 30.5
Contracted pipe properties		Min 235	360 to 480	Min 26.00

R_e = yield point, R_m = tensile strength, A_5 = elongation

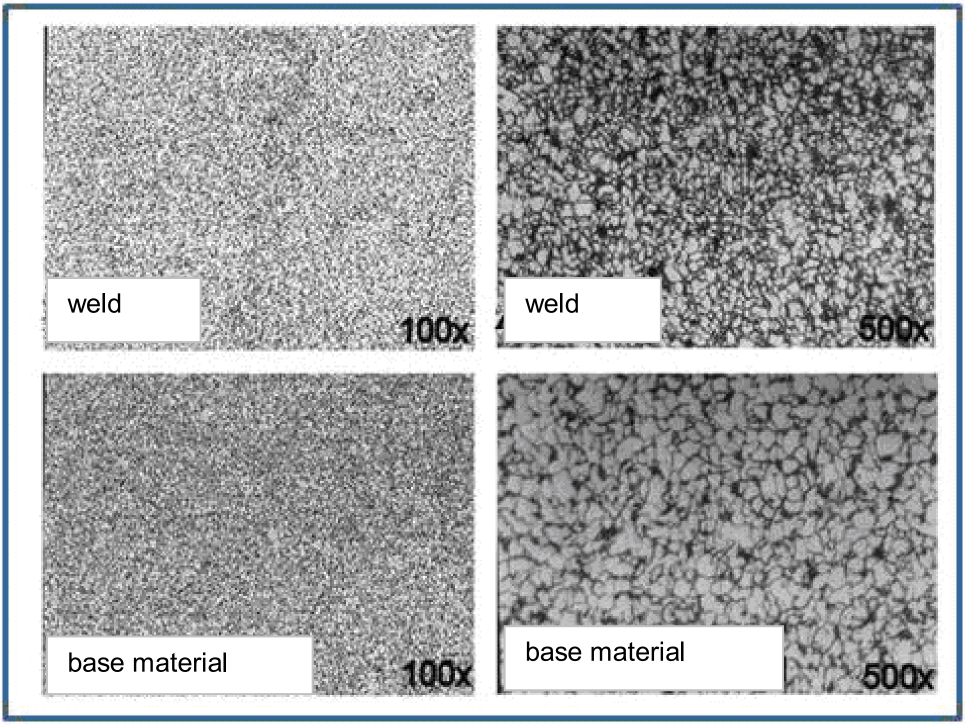


Figure 3a) The structure of welded pipes - hot-rolled welded pipe

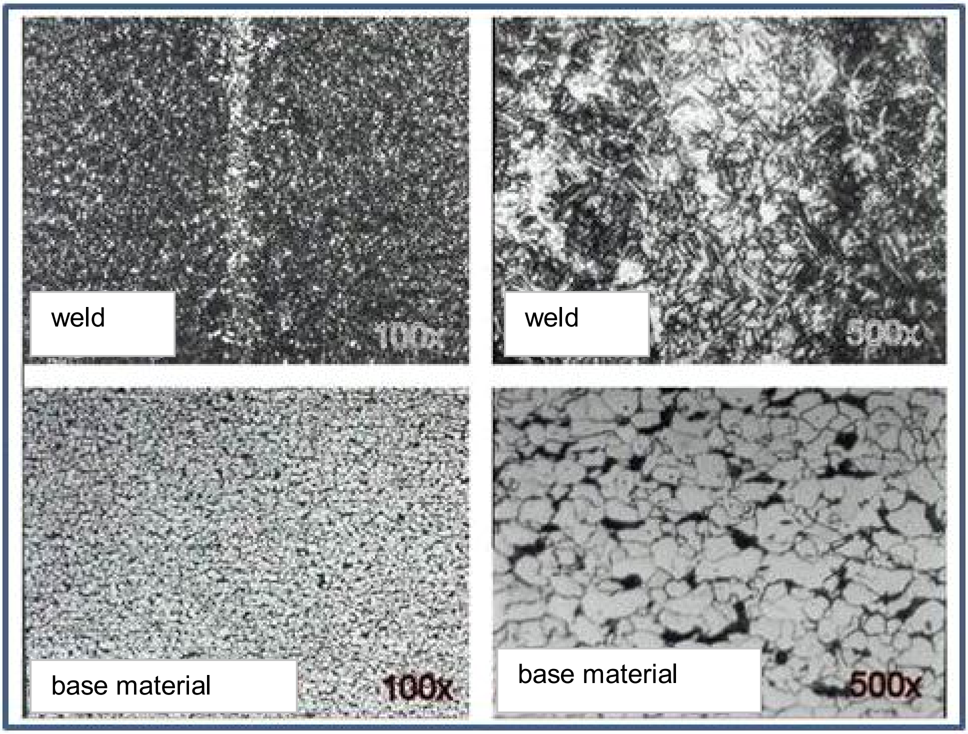
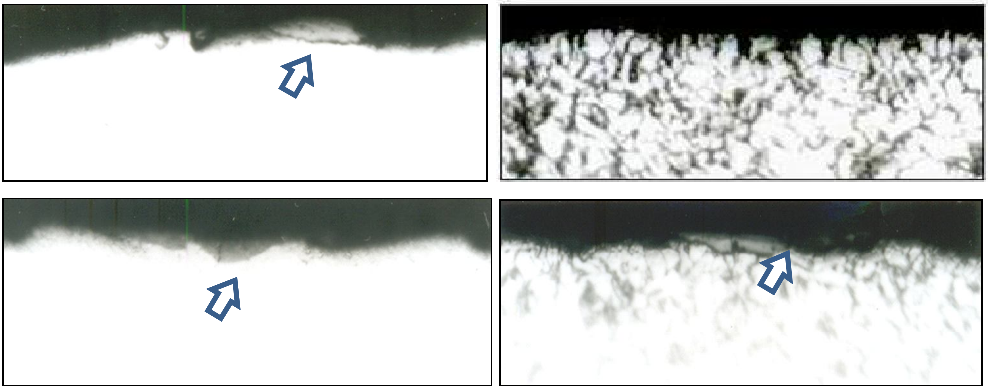


Figure 3b) The structure of welded pipes - precise welded pipe

Control analysis of the chemical composition was performed on all six samples of melts from which corroded pipes were manufactured. The results obtained are given in Table 1. From Table 1, we see that the content of all controlled elements in steel, except copper, is within the prescribed limits. Copper content in this quality steel range is from 0.15 % to 0.20 %. According to the literature it is known that steel with a very low content of copper has low resistance to atmospheric corrosion. Corrosion influences the Cu content over 0.13 % [14]. Then, the mechanical properties of the pipes are examined. The results are shown in Table 2. Mechanical properties of all pipes correspond to properties regulated by the standard and demanded by the customer. Metallographic analysis was provided on grinded samples, cut out from the pipe cross-section. Structural analysis was provided on the basic material and on the weld area of hot-rolled and precise welded pipes, Fig. 3. The results of the structural analysis provided on a larger number of pipes do not show any structural variations which could have caused the pipe corrosion. The structure of both hot-rolled and precise welded pipes was homogenous, without any visible inclusions and damages on grain boundaries [1,2].

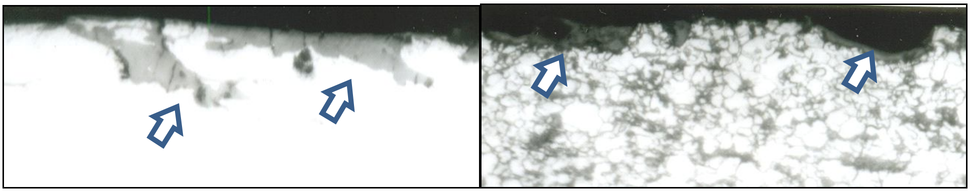
The structure of characteristically corroded pipe samples was analyzed in detail, Figures 4-6. On external surface of pipe size 25 mm x 25 mm x 2 mm hardly visible traces of corrosion were detected depth of 0.006 mm, while the corrosion was not detected on the internal pipe cross-section [10]. Characteristic photos of the external and internal pipe surface are shown on Figure 4.



a) polished b) etched by nital

Figure 4: Corrosion on the external pipe surface, pipe size 25 mm x 25 mm x 2 mm (marked by arrow)

The corrosion occurred on hot-rolled welded pipes, size 12.7 mm x 2.65 mm and 38.1 mm x 3.25 mm [10]. By detailed metallographic analysis of several samples with corroded external surface, the corrosion process was detected on the internal surface as well, Figures 5 and 6.



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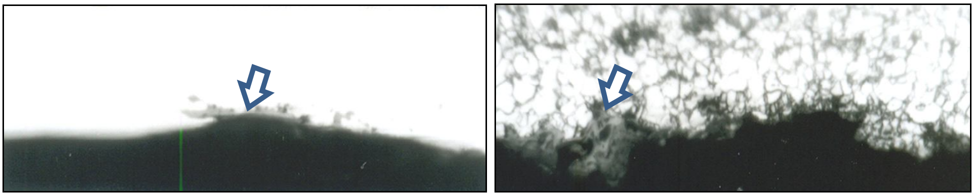

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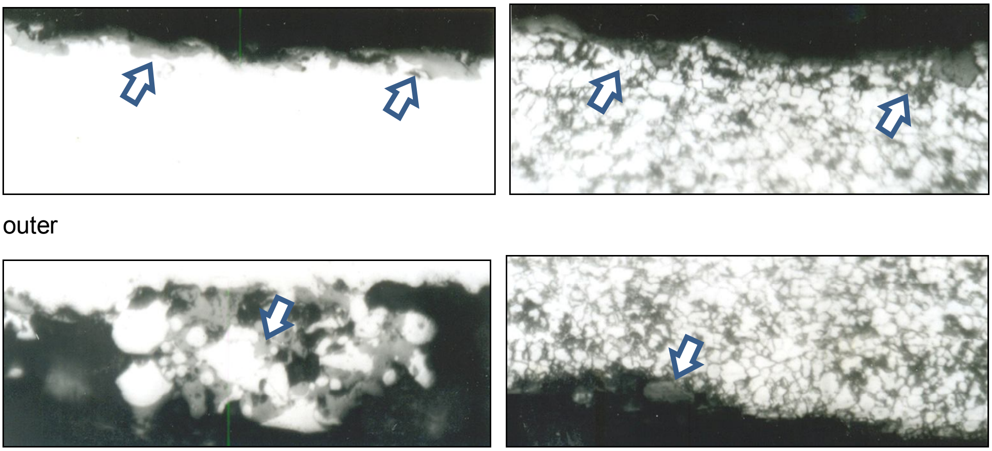
a) polished b) etched by nital

Figure 5: Corrosion on the external and internal pipe surface, pipe size 12.7 mm x 2.65 mm (marked by arrow)

On the pipes, size 12.7 mm x 2.65 mm, Fig. 5., the corrosion process was more pronounced on the external pipe surface, with the corrosion depth up to 0.028 mm, while on the internal pipe surface the corrosion was detected only on certain areas as a very thin layer, with maximum depth up to 0.001 mm.

On the pipes, size 38.1 mm x 3.25 mm, the corrosion process was detected only on the external pipe surface, with maximum depth up to 0.01 mm.



outer

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a) polished

b) etched by nital

Figure 6: Corrosion on the external and internal pipe surface, pipe size 38.1 mm x 3.25 mm (marked by arrow)

According to analysis, the pipes have proper chemical composition and satisfying mechanical properties. The copper content for this steel quality is not prescribed but limited, as for all steel types, and would not exceed 0.3 wt. %. Although lower copper content implies lower corrosion resistance of steel, without further appropriate examinations it can not be concluded that the corrosion of the pipes is caused by low copper content. It is possible that some other process parameters increase the potentially unfavourable influence of low copper content, causing the pipe corrosion. This is especially the case in the winter period when, due to increased air humidity and unfavourable temperatures, the atmospheric corrosion is more pronounced.

The metalworking coolants, used in pipe production process, were marked as the first possible cause of the pipe corrosion. The emulsions prepared directly in the factory by adding the emulsifiable metalworking fluid concentrate into the water were applied. In both rolling plants the same emulsifiable metalworking fluid concentrate was used. Therefore it was reasonable to assume that this concentrate solely, i.e. its emulsions were the cause of the pipe corrosion.

Detailed examinations of the industrial water, the composition of the emulsion which was not regularly exchanged due to a discontinuous rolling plant work and particularly the influence of the emulsion on the pipe corrosion were carried out.

The industrial water used in the pipe production process was examined first. The examination results are given in Table 3. The results obtained by examination of the emulsifiable metalworking fluid concentrate and emulsions, as well as examination methods common for this type of fluid [15] are given in Table 4. The emulsions were prepared using hard water T.V. from waterworks.

Table 3: Water examination results

Property	Measured value
Water hardness / °dH, ASTM D 1126	14.12
pH Value, ASTM D 1293	8.2

The emulsifiable metalworking fluid, EM-BU, consists of paraffinic mineral oil, approximately 70 %, natural oils, surfactants and corrosion inhibitors without aromatic ring [12]. It contains no harmful compounds, such as nitrites, nitrates or chlorine compounds [16]. It contains no boron compounds as well. When mixed with water, it forms stable white emulsions which have no undesirable effects on workers. Its protective properties against the corrosion of working materials are excellent, from iron to non-ferrous metals. It is an excellent lubricant as well.

Table 4: Results of concentrate and emulsions of the metalworking fluid analysis

PROPERTIES	EM-BU, fresh	EXAMINATION METHODS
Concentrate		
Appearance, colour	clear, brown oil	visual
Viscosity, 40 °C / mm^2s^{-1}	55	ISO 3104
Stability, 0, 20, 50, 70 °C / 24 h	stable	Internal test 1
Emulsion, 5 % in T.V.		
Appearance and colour	white	visual
Stability, 20 °C / 24 h	stable	Internal test 1
Reserve alkalinity, ml 0.1 M HCl	2.5	ASTM D 1121
pH Value	8.9	ASTM D 1287
Corrosion, Herbert test, 1.2 % em. T.V.	S0R0	DIN 51360/1
Corrosion, Filter test, 2 % em. T.V.	0	DIN 51360/2
Corrosion / Cu, Al, brass, SiAl, 3 & 5 % em.	none	Internal test 11
Foaming, volume / mL / after 5 min / mL	30 0	Internal test 2 (ASTM D 3601)
Lubrication properties		
Average wear diameter / mm	0.58	ASTM D 4172
Surface wear area / mm^2	30.4	Reichert balance
Welding point / N	1260	ASTM D 2783

When used, the emulsion is externally contaminated, e.g. by the protective agents from the basic material, by microorganisms, dust, etc. Contaminants reduce the functioning emulsion properties, i.e. its working lifetime and could cause some unwanted appearances concerning emulsion system as well as working materials [17]. Results obtained by examination of working emulsion from the working plant, taken from four different places in the pipe production process are given in Table 5.

Table 5: Results of working emulsion analysis

WORKING EMULSION SAMPLE	RE 16	RE 17	RE 18	RE 19	Limiting values
Emulsion appearance and colour, visual	milky, dirty emulsion	dirty emulsion, floating oil	milky emulsion with impurities in traces	milky emulsion with impurities in traces	change of colour, oil separation, precipitate
pH Value, ASTM D 1287	7.25	7.15	8.35	8.05	8 - 10
Reserve alkalinity / mL 0.1 M HCl, ASTM D 1121	0.31	0.13	1.51	0.80	± 25 % of initial
Concentration by refractometer, Internal test 9 / %	1	1	4.3	2.8	± 1 of initial
Corrosion -Herbert, DIN 51360/1 -Filter test, DIN 51360/2	Unsatisfy 4-strong	Unsatisfy 4-strong	Satisfy 0-none	Satisfy 0-none	Visible corrosion
Number of microorganisms, CFU / mL, Deep slide - Total number / 24 h - Fungi, moulds / 72 h	100 000 Moderate infection	10 000 000 Moderate infection	100 000 Moderate infection	100 000 Slight infection	Unpleasant odour, Max. 10^6
Fe content, X-ray / ppm	8	53	4	13	-
Sampling place / working plant	Hydrotest HRWP*, under oil	Hydrotest HRWP*, pump	PWP** line Voest	PWP** line Somenor	-

*HRWP = Hot-Rolled Welded Pipe, **PWP = Precize Welded Pipe

The working emulsions from the hydrotest process RE 16 and RE 17 were taken from two places in a container with cca. 60 tons of fluid, containing emulsion and floating oil. The surface of the emulsion which has not been exchanged for many years was completely covered by oil. The sample RE 16 was taken under the oil layer and RE 17 from the vicinity of the circulation pump. The working conditions for the emulsion are very unfavourable, without contact with air, creating favoruable conditions for microorganisms growth. The quality of samples RE 16 and 17 are not satisfactory, due to a too small portion of the concentrate in the water, which should be at least 2 % for the emulsion to be protective against the corrosion. That means that the emulsion must be refreshed by increasing concentrate portion. Nevertheless, due to a great amount of free oil and other impurities, it is advised to change the emulsion along with the necessary cleaning of the container and other elements of the emulsion circulation system. Samples RE 18 and 19 are of adequate quality, although there are impurities. These emulsions can continue to work by normal emulsion refill, emphasizing that in the emulsion RE 19 the mass portion of the concentrate should be nevertheless increased to 3 %, as this is the given value for the pipe production process.

The analysis of the samples taken from both rolling plants has shown that the concentration portion widely varies, from 1 to 4.3 %. The requested limiting values of the emulsions with higher concentrate content are satisfactory, while that of emulsions with 1 % of concentrate and in presence of extensive pollution are not. Further examinations were provided on pipe and emulsion samples. The pipe samples were cut and investigated in the emulsion which was taken from the rolling plant, as well as in clean, freshly prepared emulsion (1 and 3 %), in conditions of increased humidity, at various temperatures (-20, 4, 20 and 40 ^{o}C) and at different times (1, 3, 7, 30, 100 days), Figures 7 and 8.

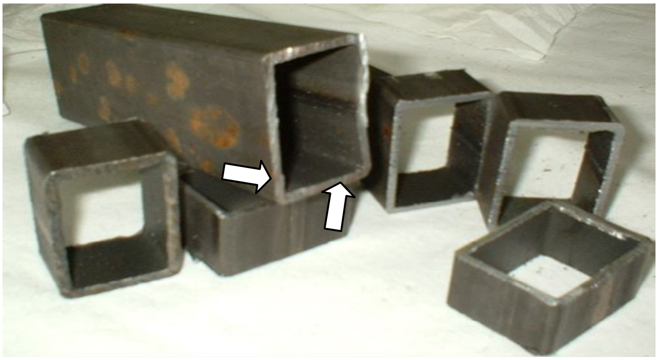

Figure 7: Freshly cut pipe samples for corrosion examinations (corrosion at the cut is marked by arrow)

The pipes which were immersed in the emulsion and exposed to different temperatures did not corrode, not even in traces. In the conditions of increased humidity there was no corrosion on the pipe surface. The results of all examinations have shown that there was no corrosion in any of the tested emulsions of different quality, even with the smallest portion of concentrate i.e. 1 %. Slight corrosion that appeared on a cut while cutting the pipe samples for dry testing did not spread while treated in the emulsion containing 1 % EM-BU. In the pipe production process the emulsion comes in contact with the pipe surfaces. The task of the working emulsions for metalworking is the protection during the process and in interphase times. To protect the materials against the corrosion, especially the sensitive ones, during their storage or transport the additional protective agents are required [18].

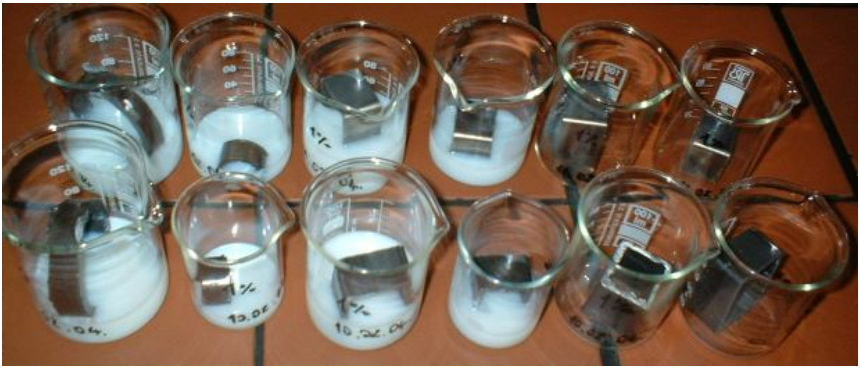

Figure 8: Corrosion examination on pipe samples in 1 % emulsion, immersed and coated only, without immersing

4. Conclusion

The results of the pipe chemical composition and mechanical properties have shown that the values of all parameters are within regulated limits. The copper content in the steel is not regulated by standard, but detailed examinations showed that its content is less than the usual, i.e. the one that contributes to the pipe stability against corrosion.

Based on a suspicion of insufficient working emulsions EM-BU anticorrosion properties, the detailed examinations of the emulsions in the absence and in the presence of the cut parts of the pipe were carried out. There was no evidence of any corrosion on the pipe surface. Therefore it can be concluded that the emulsion did not cause the pipe corrosion during storage.

One of the possibilities is that the corrosion occurred due to a lower copper content in the steel. This is confirmed by the corrosion that occurred on the fresh cut after a very short period of time, while on the same sample on the pipe surface the corrosion does not occur even after extended period of time.

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