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POSSIBILITIES OF INCREASING CONNECTIONS DURABILITY FOR LARGE DIAMETER PIPES, BY GLASS COATING INTERNAL SURFACE

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Abstract: *Time of operation, or durability, of a part represent the actual time of operation until reaching the limit condition of wear. Bends are the parts of the fluids transport installations subject to wear, erosion being the main cause of degradation. When flow direction is changed using bends, the particle would not follow the fluid, but would impact the bend wall. Interior coating of bends used enamelling technology by applying frit produced by Pemco BVBA company in Bruges. A mixture of three frits has been used, as follows: 5% (R5750); 25% (R10) and 70% (R25). Glass coating the interior surface of bends has the advantage of substantially reducing the friction between the fluid and the interior surface of the bends, increasing the operational durability of bends.*
Keywords: *connections, bends, durability, glass, frit, enamelling.*

1. INTRODUCTION

Implementing the principles of sustainable development in the machinery industry, at this moment when the national economy is looking for stimulating solutions is not only needed, but also at a good moment. Considering the importance and necessity of the three aspects of product functionality – technical, economical and ecological, the present paper identifies some directions to be followed when searching sustainable solutions for a product.

The technical-economic aspects should promote the pragmatic and immediately effective actions. The taxation and penalty system should ensure the deterrence of polluting industries and technologies and promote the so-called “clean” technologies.

“Cleaner technologies” is a concept covering multiple aspects of the economical operations as well as of the environment protection. The said concept is based on the premise that preventing is easier and cheaper than remedying after polluting the environment [2].

Cold plastic deformation is one of the most important processing operations on metallic tubes, and the resulting products have a wide range of uses in car industry, aeronautics, machinery, installations, chemical industry and medical applications. Hot deformation has the purpose of reducing the material’s deformation strength and increasing its deformation characteristics.

2. TECHNOLOGICAL ASPECTS REGARDING THE PRODUCTION OF LARGE DIAMETER PIPE BENDS

Bend manufacturing technology using mandrel curving and pulling with induction heating is the most efficient bend manufacturing method (fig.1). This is the most accurate technology producing bends at 45, 60, 90 and 180° with low energy consumption, the coil can be centered and adjusted horizontally and vertically, the final product has no ovalisation, bend wall thickness is uniform, without ED (extrados) thinning or ID (intrados) thickening [3], minimum radius is of 1.5D below 2D as provided by [11], [SR EN 10253-2:2008], using high advancing speed (for Dn 168.3 bends the advancing speed is of 300 mm/min), no decarburation occurs in the final product, and the oxidation is mitigated by sand blasting and protective painting.

Fig 1. Bend manufacturing by mandrel pulling and induction heating (Dn 168.3 x 4.5 mm).

The technology is extremely effective, generating high quality bends, with low arching, minimal ovalisation, no variation of pipe thickness in bent area and no creases. The downside of this technology is the quite high cost of equipment and the wear of supporting mandrels.

A basic analysis reveals that, without requiring high accuracy, the product very well fulfils its functional purpose, as compared to similar products manufactured with other methods or technologies, the interior ovalisation is 0.86% and the exterior ovalisation is 0.57%, variation of pipe wall thickness ranges between 12.65 and 15.00% below the 17% measured at similar products obtained with other technologies [9].

The use of electric energy in industrial heating processes has always been justified by economical reasons, however the modern technologies based on inductive heating have developed fast in recent period in the context of material and energy savings and automation of industrial processes [5], [6].

The most important objective in the plastic deformation of metals is the production of defect free parts, with the intended mechanical and micro-structural characteristics, which can be achieved with adequate designing and proper control over the process parameters, and by knowing the behaviour of materials in semi-solid state for the purpose of modelling.

Bends are most worn out parts of the piping systems where erosion is the main degradation cause. When flow direction is changed with bends, the particles would not follow the fluid but would impact the bend wall in a complex isometric diagram (see fig. 2). [1 p. 18].

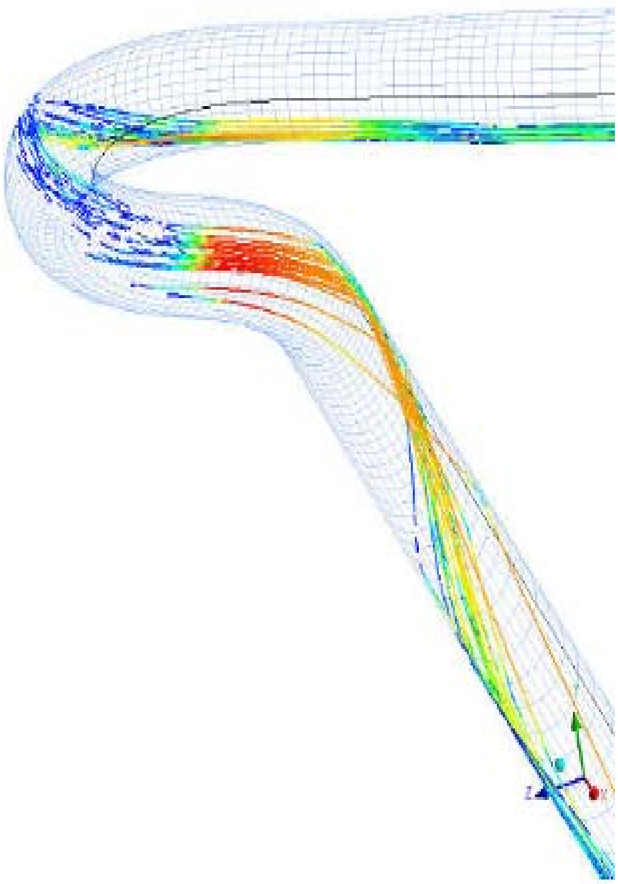

Fig 2. Fluid flow direction in a complex isometric diagram.

3. GLASS COATING THE INTERNAL SURFACE OF BENDS WITH ENAMELLING TECHNOLOGY

3.1 General

Several recipes of calco-sodium glass have been prepared for coating the internal surface of bent pipes, with the following characteristics:

a) high adherence to base layer;

b) dilation index the same as P 265GH steel [10], (SR EN 10028-2:2009), which is 1.3 x 10^{-5} [K^{-1}];

b) melting point 800-850 °C.

c) chemical compatibility with graphite.

Research has been oriented towards the following:

-Identify a glass recipe with a melting temperature close to 850°C and a dilation index of 1.3 x 10^{-5} [K^{-1}];

-Direct application of frit on the pipe's interior surface protected by graphite layer;

-Subsequent application of frit and burning it at approx. 850°C.

Enamelled steel combines the advantages of glass, namely: hardness, endurance to chemical aggression, lustre and pleasant look etc.

3.2 Raw materials for enamels

Raw materials for enamels may be grouped as follows:

-Refractory materials and fondants or the materials forming glass (halogens);

-Auxiliary materials or adhesion agents and oxidising agents;

-Mill additives (clay materials, density adjustment agents, water).

Three recipes of calco-sodium glass have been elaborated, with their oxidic composition presented in Table 1.

Oxidic compositions **Table 1**

No.	Raw materials	Unit	Frit 1	Frit 2	Frit 3	F1+F2+F3
1	Hudeşti sand **(SiO_2)**	%	64.697	62.008	64.183	63.630
2	Sodium oxide **(Na_2O)**	%	22.001	21.792	21.832	21.875
3	Potassium oxide **(K_2O)**	%	4.615	4.839	6.170	5.208
4	Calcium oxide **(CaO)**	%	8.497	3.416	3.176	5.030
5	Lead oxide **(PbO)**	%	-	7.816	-	2.605
6	Boron oxide **(B_2O_3)**	%	0.190	-	-	0.098
7	Zinc oxide **(ZnO)**	%	-	-	4.640	1.554
8	RO_2	%	64.697	62.008	64.183	63.630
9	R_2O	%	26.616	26.631	28.002	27.083
10	RO	%	8.497	11.232	7.815	9.287
	Dilation coefficient x10^{-7}	K^{-1}	**130.002**	**129.967**	**130.011**	**129.993**

As presented in Table 1, all three recipes prepared are adjusted to the P-265GH steel dilation coefficient (1.3 x 10^{-5} [K^{-1}]).

Recipes 1 and 3 have more chemical stability than recipe 2, which is more elastic and with the lowest softening point.

4. EXPERIMENTAL RESEARCH

Experimental research comprised two alternative recipes for calco-sodium frits, applied on both the internal and external surface of the bend.

4.1 Frit recipe I

Recipes were prepared (table 1) and melted, followed by cooling with water, and after fritting the mixture was grinded in a ball crusher.

After drying up, 9% clay (kaolin) 0.40 kg has been added in order to maintain the frit in suspension in the water based slurry; the slurry is fixed with fixation agents 0.003 kg B_2O_3 (boron oxide which fixes alkaline environment) and (nitrite) $NaNO_2$ 0.004 kg which fixes the slurry to the interior surface of the bend. Resulting dry mixture weighed 4.937 kg. A quantity of 2.47 kg of water was added for slurry.

With the resulting slurry two bends 90° 2D 168.3 x 4.5 mm were glazed, and after drying those were burnt for 31 minutes in the enamel oven.

4.2 Frit recipe II

Bend coating with glass using enamel technology was also studied using frit produced by *Pemco BVBA* company from Bruges. Three frit recipes were tested, two on R10 and R25 recipes for enamelled cast iron thick bowls, used as ground enamel, while R5750 is regular frit for enamelled steel sheet.

A mixture of the three frits was prepared: 5% (R5750); 25% (R10); 75% (R25); table 2 presents the composition of the three frits [7].

Table 2.

Pemco frit recipe (Solution II)

	Oxide	Unit	R5750	R10	R25	**R5750** 5%+**R10** 25%+**R25** 70%
1	**SiO_2**	%	30	33	50	44.75
2	**B_2O_3**	%	25	22	20	20.75
3	**Na_2O**	%	20	20	8	11.50
4	**CaO**	%	6	8	8	7.90
5	**Al_2O_3**	%	8	6	4	4.70
6	**Fe_2O_3**	%	-	-	0,3	0.10
7	**MgO**	%	2	2	-	0.60
8	**P_2O_5**	%	4	2	2	2.10
9	**MnO**	%	2	1	1	1.05
10	**NiO**	%	1	1	2	1.70
11	**CuO**	%	-	2	1	1.20
12	**CoO**	%	-	1	1	0.95
13	**K_2O**	%	-	-	3	2.10
14	**BaO**	%	2	2	-	0.60

To the resulting frit, solution II, 9% clay (kaolin) 1.80 kg has been added in order to maintain the frit in suspension in the water based slurry, as well as fixation agents 0.07% 0.014 kg B_2O_3 (boron oxide which fixes alkaline environment) and 0.09% (nitrite) $NaNO_2$ 0.018 kg which fixes the slurry to the interior surface of the bend, and a quantity of 10 litres of water was added.

The interior and exterior surface of bends were glazed by immersion in frit slurry, and after drying those were burnt in the enamel oven.

4.3 Analysis of experimental research results

Securing high quality of large diameter tubular bends depends on selecting the bending technology. For the purpose of selecting the bending method and equipment, the mechanical characteristics of pipe material have to be known. Main factors affecting the quality of bends are: pipe diameter, bending radius, wall thickness, pipe material, bending conditions etc.

Glass coating of the interior bend surface has the advantage of substantially reducing the friction between the fluid and the interior surface, which increases the durability of the bends.

Recipe I. As presented in Table 1, all three recipes are calco-sodium recipes and are adjusted to the P-265GH steel dilation coefficient.

Compared to the normal calco-sodium glass recipe, all these recipes have an increased amount of soda with the purpose of decreasing the frit's melting point (from 1600°C to 1200°C), as well as the softening point from 1000°C to 500°C.

Recipes 1 and 3 have more chemical stability than recipe 2, which is more elastic and with the lowest softening point. There are premises for an increased adhesion to the base material due to increased amount of PbO, of 7.816% (table 1).

Fig. 2. Bend enamelled inside and outside (Solution I)

Fig. 3. Bend enamelled inside (Solution I)

As presented in figure 2 and figure 3 the bends have ground enamel application defects, with uneven surface. Enamelled frit vitrified, however the adhesion to inside surface is improper, and in areas with thicker layering the vitrified surface became brittle.

Recipe II. Frit composition with combined Pemco recipe (5% - R5750; 25% - R10; 70% - R25) has been tested on large diameter bends. Two bends of 90° 2D 168.3 x 4.5 have been manufactured, then sand blasted and lacquer coated (after sand blasting the bend surface is active for oxidation within 4 hours if not protected with lacquer) (fig. 4a), glazed and dried (fig 4b), fixed by burning (fig 4c), in the enamel oven, resulting the final product (fig 5).

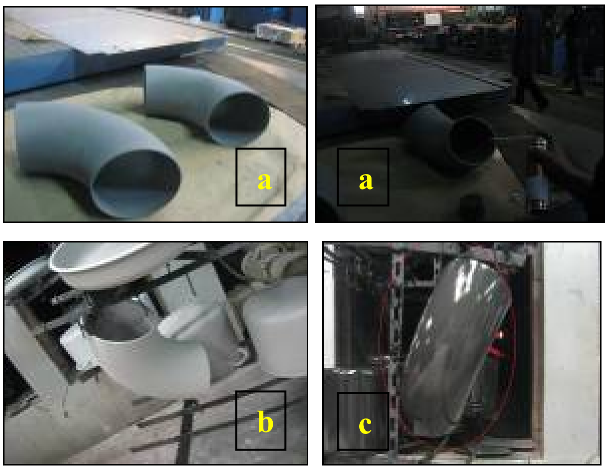

Fig. 4 Bends of 90° 2D 168,3 x 4,5 mm enamelled with frit prepared as per Pemco recipe

Fig. 5 Bend 90° 2D 168,3 x 4,5 mm with Pemco combined frit, interior detail

Tearing strength or stretching resistance, compression strength, plasticity, hardness or puncture strength can be approximated based on glass composition using Winkelman and Schot factors [8 p. 222 tab. 42, p. 223 tab. 43, p. 226 tab. 44, p.230 tab. 45, p.231 tab. 46] or Heimsoeth and Weining factors for hardness, with the following additive equation [8 p. 220]:

$$X = a_1 \cdot y_1 + a_2 \cdot y_2 + ... + a_n \cdot y_n , \quad (1)$$

where: a_n percentual contents of various oxides;

y_n are factors.

Table 3.

Mechanical properties of frit recipes deduced with additive relations

No.	Mechanical properties	Unit	Solution 1	Solution 2
1	Density	g/cm^3	2.6065	2.6434
2	Compression strength	daN/mm^2	80.4964	82.4872
3	Breaking strength	daN/mm^2	7.3814	7.7690
4	Plasticity	daN/mm^2	7201.92	8389.24
5	Adherence	-	insufficient	good

Applying the principle of additivity and factors to pre-calculate the properties from the oxidic composition is not, and cannot be, accurate in all instances, yet are useful for calculating the approximate values for mechanical properties [8 p. 219]. This is a non-destructive method to determine values, ideal to compare two enamels against average values of the enamels (tab 3).

Relative hardness of a body may be observed as the body subject to testing is, or is not scratched by another body. The Mohs scale was developed based on this principle, which uses minerals as reference substances.

Adherence is the force to be applied such as to overcome adhesion and take the enamel off the enamelled object, completely exposing the metal surface. There is no adhesive more resilient than enamel. All assessments regarding adherence are based either on qualitative assessments or on methods which are only in correlation conditioned by direct measuring of adherence. From [8 p. 230] the adherence is inversely proportional to boron content and directly proportional to nickel oxides content (between 1.0…1.5%) and cobalt oxides (between 0.2…0.5%), so the positive result of the second solution as regards the adherence and hardness is caused by the presence of the two oxides (fig. 6).

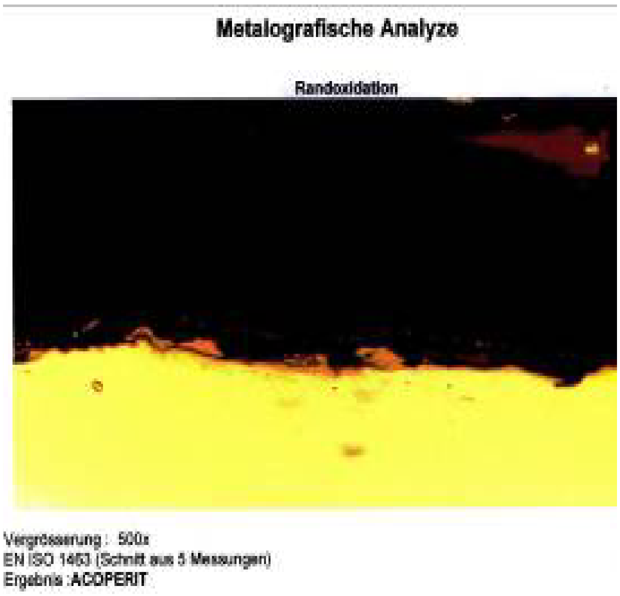

Fig. 6 Adherence between glass and bend’s metal

Wear endurance is tested according to ISO 6370-1 using bends in figure 7 and figure 8.

Fig. 7 Bend 90° 2D 168.3 x 4.5 mm steel P265GH, glass covered inside /outside

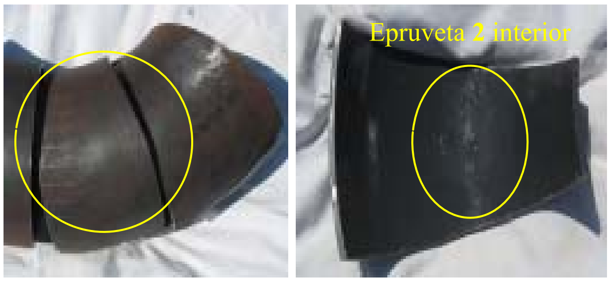

Fig. 8 Bend 90° 2D 168.3 x 4.5 mm steel P265GH, (without glass)

For testing wear endurance of bends, a TH-110 device manufactured by INNOVATEST Maastricht, Netherlands, with test results either displayed or printed (fig. 9), was used. TH-110 is a portable device for hardness testing, simple and accurate in a broad range of measurements. Suitable for testing the hardness of metals, has numerous applications in oil industry, chemical industry, energy etc. [4].

Fig. 9 TH-110 Universal hardness tester

Measurements results are presented in table

Wear endurance of bends **Table 4.**

Test	Sample 1 interior (fig. 7)			Sample 1 exterior (fig. 7)			Sample 2 interior (fig. 8)		
	Leeb Hardness [HLD]	Vickers hardness [HV]	Mohs hardness [HM]	Leeb Hardness [HLD]	Vickers hardness [HV]	Mohs hardness [HM]	Leeb Hardness [HLD]	Vickers hardness [HV]	Mohs hardness [HM]
1	508	415,28	5,22	510	416,91	5,23	335	273,86	4,54
2	518	423,45	5,25	532	434,90	5,30	336	274,67	4,55
3	502	410,37	5,20	529	432,45	5,29	316	258,32	4,45
4	520	425,09	5,26	532	434,90	5,30	316	258,32	4,45
5	528	431,63	5,29	535	437,35	5,31	305	249,33	4,40
6	553	452,07	5,37	529	432,45	5,29	341	278,76	4,57
7	533	435,72	5,31	528	431,63	5,29	281	229,71	4,29
8	507	414,46	5,22	518	423,45	5,25	306	250,15	4,41
9	-	-	-	515	421,00	5,24	-	-	-
Avg	**521**	**425,91**	**5,27**	**525**	**429,18**	**5,28**	**317**	**259,14**	**4,46**

5. CONCLUSIONS

Hardness of the interior surface of a normalised P 265GH steel bend is of 260 HV Vickers scale and 4.46 on Mohs scale, while the calco-sodium glass hardness is of 426 HV, namely 5.27 HM on Mohs scale. In such conditions the durability of the bends increases with approx. 68%.

External glass coating of the bend prevents the negative effects of natural steel corrosion.

The purpose was to protect the inside of metal products used for changing direction by applying a fritted glass coating which would eliminate an operational flaw of the liquid transport and distribution networks, creating an interior surface of very high hardness. Experiments revealed an inversely proportional relation between the adherence of frit ground to the metal surface of bends and the hardness of resulting coating. Also, the tearing and compression strength of frit enamel is inversely proportional to the hardness of resulting coating.

New technologies of bend manufacturing eliminate negative effects of defects occurring when bending pipes, such as: cross section ovalisation, wall thinning on the outer side of pipe bend, formation of creases and fissures on the inner side of pipe bend, arching or bending radius. Another defect occurring during operation is the thinning of the inside wall on the outer side of the arch, caused by friction generated by the fluid flowing through the installation.

It is important to increase the hardness of interior side in the wearing area to compensate the negative effects of friction by applying and fixating, by burning, a glass pellicle hardened with enamelling technology.

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POSIBILITĂŢI DE CREŞTERE A DURABILITĂŢII RACORDURILOR LA ŢEVI DE DIAMETRU MARE, PRIN ACOPERIREA CU STICLĂ A SUPRAFEŢELOR INTERIOARE

Rezumat: Durata de funcţionare sau durabilitatea unei piese, reprezintă timpul efectiv de funcţionare până ajunge la starea limită. Coturile sunt partea din instalaţiile de transport ale fluidelor care sunt supuse uzurii, eroziunea fiind principala cauză de degradare. Când direcţia de curgere se schimbă cu ajutorul coturilor, particulele nu vor urma fluidul ci vor lovi peretele curbei. Acoperirea suprefeţei interioare a coturilor s-a făcut prin folosirea tehnologiei de emailare prin aplicarea de frită produsă de firma Pemco BVBA din Brugge. Pentru coturi s-a utilizat un amestec de trei frite, astfel: 5%(R5750); 25%(R10) şi 70%(R25). Acoperirea cu sticlă a suprafeţei interioare a coturilor prezintă avantajul că, se reduce în mod substanţial frecarea dintre fluid şi suprafaţa interioară a coturilor, ceea ce măreşte durabilitatea coturilor în exploatare.

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