Means of Reducing Wear in Steel Pipe Connections
with Interior Glass Coating

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Increasing quality and durability of bent tubular parts requires new manufacturing technologies. By using bent pipes, the conditions for fluids flowing through installations are improved. New bending technologies 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 wrinkles and cracks on the inner side of pipe bend, or springback. 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 flow 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 fixing a glass pellicle hardened with enamelling technology.

Keywords: connections, bends, glass, frit, enamelling, chemical recipes, non-destructive methods

Bending is the technological operation of modifying the shape and size of parts without removing material. Parts subject to bending are: metallic sheets, bars, pipes, wires etc. while bending methods by the type of effort are manual or mechanical bending. Plastic bending methods classified by temperature are two – cold or hot plastic deformation.

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 medicinal applications. Hot deformation has the purpose of reducing the material deformation strength and increasing its deformation characteristics. At the temperatures used for hot deformation, material's strength is 10-12 times lower than the same material strength in cold state [2]. Given the technical progress of tools and devices, pipe hot bending is rarely used, for large diameters only, in the sanitary and thermal installations industry, as well as for transporting oil products, in particular for maintenance and repairs on the existing installations, where all types of hot formed bends, tapers are being used. By some authors [3], classification of steel pipe distribution networks for drinking water, heating and oil products, according to diameter Dn, is in small diameters (<Dn 100 mm) and large diameters (> Dn 100 mm).

Beneficiaries demands regarding the increase of quality in tubular parts, as well as the reduction of manufacturing costs, determine the manufacturers of bent tubular parts to continuously improve their technologies. When analysing the tubular parts created by plastic deformation, a series of problems may be noticed, which require mitigation or even elimination.

The main defects occurring when bending pipes are: ovalisation of cross section, wall thinning on the outer side of pipe bend, formation of wrinkles and cracks on the inner side of pipe bend. In addition, springback occurs in steel alloy and high grade steel alloy pipes, eventually causing unwanted modification of bending angle and radius. Pipe resistance against interior pressure is better as much as the pipe cross section is circular. Thinning of the outside wall causes a decrease in pipe durability [5]. Such thinning has unwanted consequences, since the inside wall of the outer side of bend is subject to wear by friction during operation, produced by fluid flowing through pipe. Veerappan and Shanmugan [8] noticed that ovalisation of cross section and wall thinning should be considered together in order to decide the acceptability of a bent part as regards the precision.

Bends are the parts of fluid transport installations subject to wear, where erosion is the main cause of degradation. When flow direction is changed with bends, the particles would not follow the flow but will impact the bend wall (fig. 1). Experiments showed that in case of complex isometric schemes, maxim erosion and its location may differ [1].
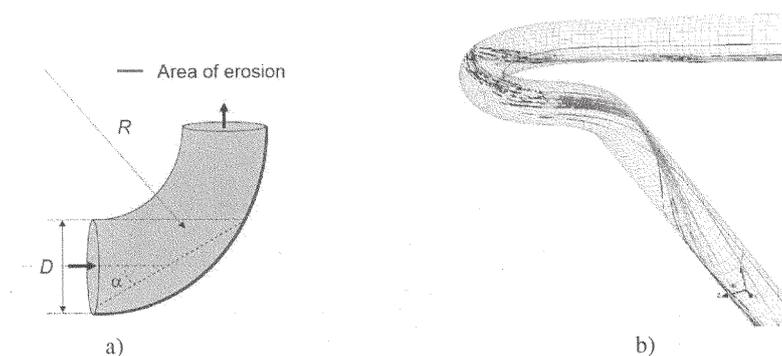

Fig. 1. Impact angle in a bend. a). Particles trajectory in a detailed isometric simulation in CFD; b) [1]

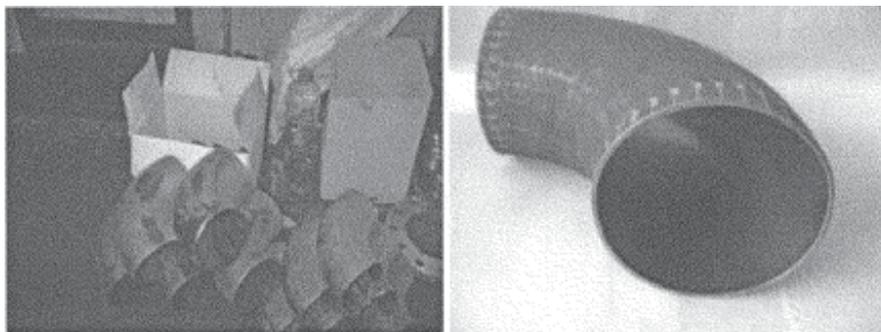** email: cristelmuresan@yahoo.com, Gheorghe.Achimas@tcm.utcluj.ro*

Fig. 2. Bends 90°, Dn 168.3 x 4.5 2D manufactured by *S.C. Tehnital S.R.L.,* Ploieşti

Therefore is important to investigate the protection of interior surface of direction changing elements against wear by friction caused by transported liquid, in order to increase durability, which consequently determines the increase of life span for the entire distribution or transport network.

Bend manufacturing technology by mandrel bending and pulling using induction heating is the most efficient method for manufacturing bends. It is the most accurate technology to create 45, 60, 90 and 180° bends with low energy consumption; the coil can be centred and adjusted horizontally and vertically, such as the product has no ovalisation; wall thickness is uniform, without thinning on the outside or thickening on the inside; minimum mandrel radius is of 1.5D, smaller than 2D provided in [10] [SR EN 10253-2:2008]; applying high advance speed (for Dn 168.3 bends the advance speed is of 300 mm/min) decarburation does not occur, while oxidation can be remedied by sand blasting and painting (fig. 2).

A basic analysis reveals that, without requiring a high level of accuracy, the product fulfils its function very well, compared to similar products made with other methods or technologies: interior ovalisation of 0.86%, exterior ovalisation of 0.57%, variation of pipe wall thickness between 12.65 and 15%, below the 17% occurring with other technologies.

Technologies for bending steel pipes

Pipe bending technology depends on the configuration, size and required accuracy, as well as the mechanical properties of material, production volume etc. Pipe bending can be performed with or without support, either from inside or outside. In cold state, without interior or exterior support, only the pipes with diameter below 10 mm can be bent.

Cold bending of pipes (cca. 20°C) with larger diameter (10 mm), in particular when the initial shape of cross section has to be maintained in the bending area, can only be performed by supporting the pipe, either from the inside or the outside.

For high production volume, it is recommended to support the pipe from the inside, in the bending area, with mandrels (fig. 3). Supporting mandrels can be spherical (fig. 3a) or spoon shaped (fig. 3b), the most used in practice. Such mandrel has a large contact area in the plastic deformation section of the pipe, providing good support and consequently a proper bending of the pipe. Care should be taken to periodically lubricate the supporting mandrels with a good quality lubricant.

Fig. 3. Shape of supporting mandrels for pipe bending

The most productive method for manufacturing pipe bends, in large quantity, is mould bending. Bends can be made by:
- bending pipes in moulds, without heating the pipe;
- hot moulding, with entirely heated pipes.

Hot moulding allows for bends in large diameter pipes (Dn ≥ 100 mm) and high accuracy of cross section.

Production of steel pipe bends with mandrel pulling using induction heating is the most effective method for bending large diameter pipes. The cinematic structure of bending equipment for 45; 60; 90; 180° is presented in figure 4 [3,].

This technology is particularly efficient and useful, generating high quality bends, with little arching, minimal ovalisation, no change of thickness in bending area and no creases. Drawbacks of this technology are the quite high expenses for purchasing the equipment and high wear of supporting mandrels.

For manufacturing bent pipes with complex configurations and in large quantities, specialised machines with digital operation are recommended.
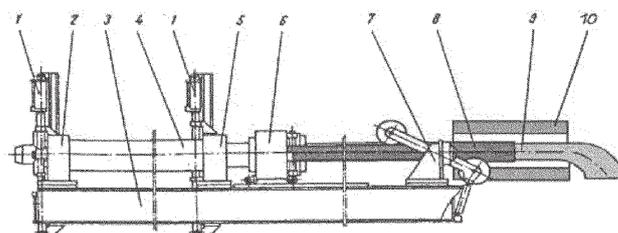

Fig. 4. Cinematic structure of bending equipment with mandrel pulling and induction heating: 1- hydraulic cylinders; 2 and 5- support bearings; 3- frame; 4- linear hydraulic motor; 6- pusher; 7- locking pawl; 8- pipe; 9- supporting mandrel; 10- heating coil

Experimental part

The value of theoretical research is increased when such research is applicable into industrial practices, providing a working tool for the specialists in the field.

Programs and tests presented in this paper, with appropriate adaptations, could receive proper use in industrial practices, helping specialists in solving problems occurring in production. All programs and tests were created for "bend" type pipe products.

Several recipes of calco-sodium glass have been elaborated for covering the interior surface of bent pipes, with the following characteristics:
a) high adherence to base layer;
b) dilation index the same as P 265GH steel (SR EN 10028-2:2004), which is 1.3×10^{-5} $[K^{-1}]$;
c) melting point 800-850 °C.

Solution I

Three recipes of calco-sodium glass have been elaborated, as presented in table 1, with their oxidic composition presented in table 2. Recipes were calculated for a 100 kg batch.

No.	Material	Unit	Frit 1	Frit 2	Frit 3
1	Hudeşti sand (SiO₂)	kg	51.675	51.282	53.254
2	Sodium oxide (Na₂O)	kg	29.296	30.055	29.839
3	Potassium oxide (K₂O)	kg	5.443	5.885	7.439
4	Calcium oxide (CaO)	kg	12.169	5.044	4.649
5	Lead oxide (PbO)	kg	-	6.725	-
6	Boron oxide (B₂O₃)	kg	0.417	-	-
7	Sodium sulphate (Na₂SO₄)	kg	1.000	1.009	1.014
8	Zinc oxide (ZnO)	kg	-	-	3.805

Table 1
FRIT RECIPES (SOLUTION I)

No.	Material	Unit	Frit 1	Frit 2	Frit 3	F1+F2+F3
1	Hudeşti sand (SiO₂)	%	64.697	62.008	64.183	63.630
2	Sodium oxide (Na₂O)	%	22.001	21.792	21.832	21.875
3	Potassium oxide (K₂O)	%	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 (B₂O₃)	%	0.190	-	-	0.098
7	Zinc oxide (ZnO)	%	-	-	4.640	1.554
8	RO₂	%	64.697	62.008	64.183	63.630
9	R₂O	%	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

Table 2
OXIDIC COMPOSITION (SOLUTION I)

For frits preparation (1, 2 and 3) a frit oven has been used, providing a temperature of about 1200°C as well as a ball crusher from the "CEROC" laboratory of "Babeş-Bolyai" University of Cluj-Napoca.

Recipes were prepared 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 B₂O₃ (boron oxide which fixes alkaline environment) and (nitrite) NaNO₂ 0.004 kg which fixes the slurry to the interior surface of the bend. Resulting dry mixture weighed 4.937kg. 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.

Solution II

Bend coating with glass using enamel technology was also studied using frit produced by *Pemco BVBA* company from Bruges, in stock at *S.C. Emailul S.A.* company in Mediaş. 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 bowls.

A mixture of the three frits was prepared: 5% (R5750); 25% (R10); 75% (R25); table 3 presents the composition of the three frits [6].

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 B₂O₃ (boron oxide which fixes alkaline environment) and 0.09% (nitrite) NaNO₂ 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 at *S.C. Emailul S.A.* Mediaş

Results and discussions

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.

Solution I

Frit recipes prepared for Solution I are calco-sodium glass recipes and have the same dilation coefficient with the pipe material (P 265GH), namely 1.30 . 10⁻⁵ [K⁻¹].

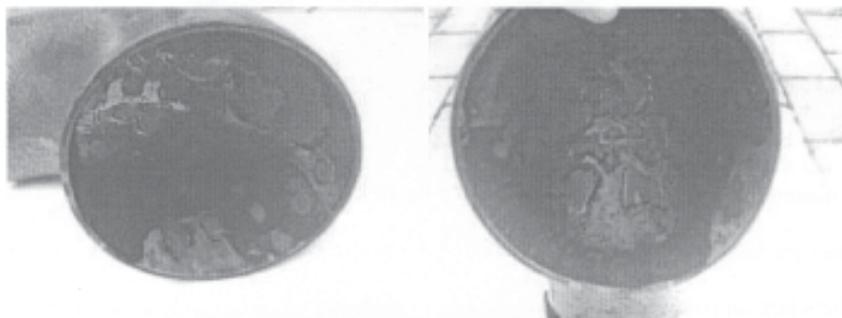|	Oxide	Unit	R5750	R10	R25	R5750 5%+R10 25%+R25 70%
1	SiO₂	%	30	33	50	44.75
2	B₂O₃	%	25	22	20	20.75
3	Na₂O	%	20	20	8	11.50
4	CaO	%	6	8	8	7.90
5	Al₂O₃	%	8	6	4	4.70
6	Fe₂O₃	%	-	-	0,3	0.10
7	MgO	%	2	2	-	0.60
8	P₂O₅	%	4	2	2	2.10
9	MnO	%	2	1	1	1.05
10	NiO	%	1	1	2	1.70
11	CuO	%	-	2	1	1.20
12	CoO	%	-	1	1	0.95
13	K₂O	%	-	-	3	2.10
14	BaO	%	2	2	-	0.60

Table 3
PEMCO FRIT RECIPE
(SOLUTION II)

All three recipes prepared for Solution I 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.

As seen in figure 5 and 6, the bends present defects in the application of ground enamel, with an uneven surface. The frit applied by glazing vitrified, however the adherence to the inside surface is improper and, in areas with thicker deposit, the vitrified surface became brittle.

Solution 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 at S.C. Tehnital S.R.L. Ploieşti, then sand blasted and lacquer coated (fig. 7a), glazed and dried (fig. 7b), fixed by burning (fig. 7c), in the oven at S.C. Emailul S.A. in Medias (fig.8).

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 [7]. This is a non-destructive method to determine values, ideal to compare two enamels against the average values of the enamels (table 4).

According to Winkelman and Schott [7], glass density can be calculated from its oxides with the equation:

$$\frac{100}{X} = \frac{a_1}{x_1} + \frac{a_2}{x_2} + \frac{a_3}{x_3} + ... + \frac{a_n}{x_n}, \qquad (1)$$

where:

$a_1, a_2, a_3, ... a_n$ are the percentual contents for various oxides;

$x_1, x_2, x_3, ... x_n$ are the corresponding density factors.

Factors indicated by Winkelman and Schott [7], checked and recalculated by Tillitson, Baillie, English and Turner, Kitangorodski, Gehlhoff and Thomas, as well as the value admitted by Stuckert [7].

Tearing strength or stretching resistance, compression strength, plasticity, hardness or puncture strength can be approximated based on glass composition using Winkelman and Schot factors [7] or Heimsoeth and Weining factors for hardness, with the following additive equation [7]:

$$X = a_1 \cdot y_1 + a_2 \cdot y_2 + a_3 \cdot y_3 + ... + a_n \cdot y_n, \qquad (2)$$

where: a_n percentual contents of various oxides; y_n are factors.

According to [7], Al_2O_3 increases compression strength, while all other oxides have no effect or decrease the strength. For regular types of technical glass, compression strength was measured between 80 and 100 daN/mm^2, and for quartz glass around 200 daN/mm² however all such measurements were performed on homogenous, carefully manufactured experimental pieces, different from usual

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	Hardness	-	1322.94	1136.46
6	Adherence	-	insufficient	good

Table 4
MECHANICAL PROPERTIES OF FRIT
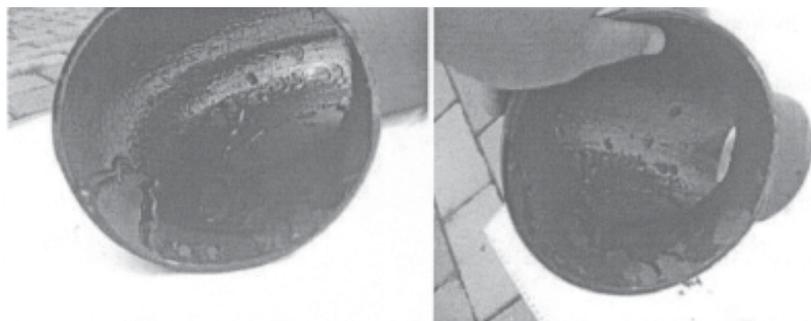RECIPES DEDUCED WITH ADDITIVE
RELATIONS

Fig. 6. Bend glazed on the inside
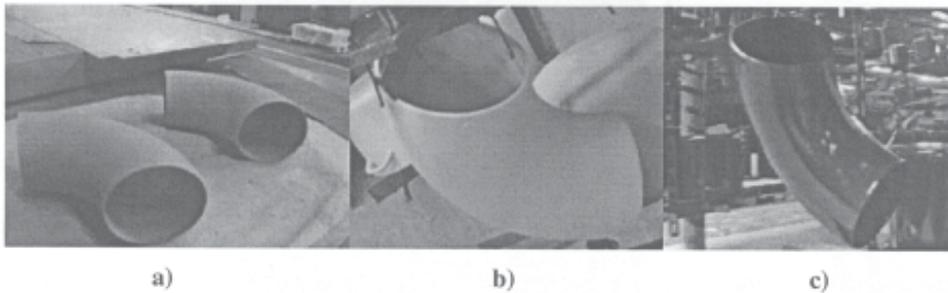(Solution I), made at *S.C. Emailul S.A,*.
Medias

Fig. 7. Bends 90°2D 168.3x 4.5mm glazed with frit combined according to Pemco recipe
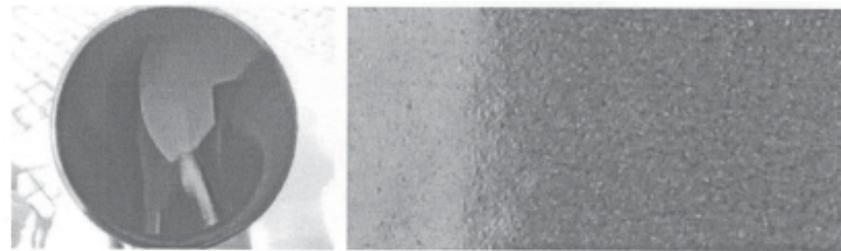

Fig. 8. Bend 90°2D 168.3 x 4.5 mm with combined PEMCO frit, general view and interior detail
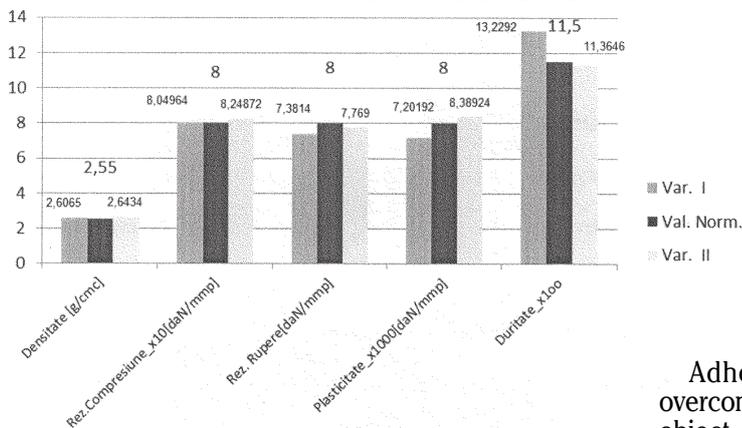

Fig. 9. Variation of mechanical properties of frit recipes

pieces due to impurities and flatting agents in the enamel which are not taken into account (fig. 9).

Breaking or stretching resistance for technical glass is of 7-9 daN/mm^2, while for drawn technical glass it increases to 20-50 daN/mm^2, for lead glass 4-6 daN/mm^2, for quartz glass 9 daN/mm^2. All such values correspond to glass without combination with metal support. Breaking or stretching resistance is only about 10% of the compression strength. Therefore the stretching should be avoided in case of enamelled parts, however the compression is allowed [7].

Elasticity, or extensibility defines the capacity of a body to restore the variation of length caused by extension or compression when the force ceases and thus reverts to the original shape. Enamel's elasticity is, without doubt, crucial for the durability and resilience of enamelling. Stuckert [7] showed that the elasticity acts against the tensions conditioned by the different dilation of metal and enamel and, furthermore, has to equalise the deformation forces which cannot be avoided in practice. The base enamel should present proper elasticity properties since the immediate proximity of metal generates the highest tensions.

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. Absolute hardness resulting from calculation with additive equation (2) is 525<**1136,46**<1150 which falls in the last position of hardness on Auerbach scale and corresponds to Class 9 Corundum on Mohs scale. The first solution of frit also has an absolute hardness higher than 1322,92 but still falls in Class 9 Corundum on Mohs scale.

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 [7] 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 in the composition.

Conclusions

Hardness of the interior surface of a normalised P 265GH steel bend is of 180-200 HB, while the calco-sodium glass hardness is of 600-700 HB, namely 6-7 units on Mohs scale. In such conditions the durability of the bends increases approx. 3-4 times.

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.

A software application may be designed to determine the optimal combination between the three proportionality relations verified with additive equations (1) and (2) and tables in [7] such as to be able to prepare not only optimal

enamel recipes for general use but also single-purpose enamel recipes for the chemical industry which would resist against acids, alkaline hydroxides (lye) or the weather.

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* * * SR EN 10253-2:2008 : Racorduri pentru sudare cap la cap. Partea 2: Oţeluri nealiate şi oţeluri aliate feritice cu condiţii de inspecţii specifice

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As a continuity of the previous IDS series, the ambition of IDS 2014 is to provide the most advanced global forum for disseminating new results and data in research development and applications in the field of drying/dewatering sciences and technologies. For this 19th IDS, we should like to have a general focus on energy savings and environmental issues with active participations coming from industry and R&D Centers.

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On behalf of the organizing committee, I have the pleasure to inform you about the opening of the conference web site at the following address:

http://www.ids2014.fr/en

Here you will find quite soon all the detailed information concerning your participation to this event (venue, transport, hotels, important dates, registration fees, social program, etc..).

Considering the economic crisis that we still have now in many parts of the world, I should like to point out just now that we have done our best for reaching registration fees as reasonable as possible with special fares for Ph.D. students, etc… while aiming a conference of high quality concerning the scientific programme and the accommodation aspects of your stay in Lyon. Hence, some comfortable hotels with good prices, at walking distance from the Conference venue, will be available (Cf our web site). Moreover, Lyon International Airport is connected by direct flights to most European capitals, operated by national or low-costs companies.

Otherwise, I should like to inform you that you have to submit your abstracts until December 15th, only by electronic way, at the following address:

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January 15, 2014: *Notification of acceptance.*
January 31, 2014: *Deadline for "early bird" registration.*
March 15, 2014: *Deadline for submission of manuscripts.*
May 31, 2014: *Deadline for "regular" registration.*
June 1, 2014: *Final notification of manuscript acceptance.*
July 1, 2014: *Final program and deadline for registration.*
July 15, 2014: *Final deadline for fees reception (the communications of authors who will not transfer the fees before this date will not be included in the final program and in the proceedings).*

We are looking forward to welcome you in the beautiful city of Lyon, the city of the Lights, a very modern and dynamic European city … also known as the capital of the French gastronomy!

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