

# INFLUENCE OF THE PRESSURE TANKS REPEATED ENAMELING ON THE BASIC MATERIAL DEGRADATION

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Pressure tanks with the enamel surfaces play an important role mainly in the food industry and pharmacy. As the best advantage of these enamels there is very good resistance against aggressive environment at keeping the required mechanical properties of low-alloyed steels which are used for these applications. Enameling is generally applied as several particular layers whereas every of these layers has to undergo the pre-defined temperature cycle. Because of increasing device service life there is very often applied repeated enameling. The paper deals with the monitoring influence of the temperature exposition on the change of mechanical properties and structure of the basic material P265GH regarding its initial properties. The aim was to identify whether and eventually how these repeated emailing can influence the basic material degradation and based upon this to determinate their possible maximal number.

## KEYWORDS

*enamel, steel, heat treatment, annealing, structure, mechanical properties*

## 1 INTRODUCTION

One of the possible protection against the corrosion in steel pressure tanks is an application of enamelling surfaces. Types of these surfaces distinguish by the type of used atmosphere and by the overall enamel thickness. Nowadays, this is used especially in chemical, food and pharmaceutical industries. The properties of enamelling surface depend on the composition of enamelling frit, the number of applied layers and the type of thermal cycle used for burning of each layer. Two kinds of frit are used during the enamelling process due to the adhesion of surfaces. The first kind is used for the primary protecting enamel layer, and the second one for the cover layer of enamel. Afterwards, all the deposited layers of enamel are dried and burnt. Also the thermal stress affects basic material throughout the burning process. The conditions of enamel burning process are defined by minimal burning temperature, real achieved interval of burning temperatures and holding time. Burning temperatures usually vary between 800 and 1000°C, and holding time on burning temperatures ranges from 5 to 30 minutes. [Mohyla 1995, Podjuklova 1997] This method is used to burn one layer of the primary enamel and the maximum of eight layers of the cover enamel. Due to the fact, that the enamel layer might contain defects, which occur during manufacturing or operation, it is essential to fix these defects by a process called 're-enameling'. This means that primary material is repetitively exposed to the aforementioned

thermal affection, since the internal regulations of companies enable the use of up to two re-enamels.

Steel plate dedicated to the production of pressure tanks with enameled surface has to fulfil requirements resulting from the manufacturing technology of each product and also from the enameling technology. For pressure tanks production are normally used non-alloy steels (e.g. P265GH, etc.), or eventually alloy noble steels corresponding to CSN EN 10028-2 standard. [CSN EN10028-2 2010] According to general principal, the steel used for enameling must contain a minimal amount of spurious element, non-metallic inclusions and gases. [Samiee 2007, Son 2015] Accompanying and alloying elements have to be spread equally. Apart from that, the aforementioned steels must contain guaranteed, or at least conditional, weldability. For the actual welding of pressure tanks with enameled surfaces, the fusion welding in shielded atmosphere (135, 141, according to ISO 4063) is usually used, eventually the technology of submerged arc welding, or plasma arc welding. [Pavlov 2007]

## 2 EXPERIMENT

The purpose of experiments is to specify the influence of temperature exposition during enameling, or more precisely, repeating thermal cycles on the change of mechanical properties and structure of foundation material with regard to its initial properties. Non-alloyed steel for pressure tanks P265GH, which is suitable also for enamelling, was used for the experiments. Samples of size 300 x 300 mm and thickness of 16 mm were removed from the aforementioned material. Afterwards, these samples were submitted to different number of cycles corresponding to repetitive enamel. Table 1 represents the chemical composition, and mechanical properties of this steel according to CSN EN 10028-2 standard are listed in the tab. 2.

Temperatures recommended for the thermal treatment, or annealing, vary between 890 and 950°C. Transformation temperature  $A_{C1}$  fluctuates between 710 and 720°C, and temperature  $A_{C3}$  ranges from 840 to 860°C.

The initial material delivered by supplier underwent the thermal treatment, annealing and was labelled as 'Series 1'. Labelling of other samples of steel plates depending on the temperature exposition conditions are listed in the table 3. The rest of the samples were firstly annealed in the same way that is applied on welded pressure tanks. They were heated up to 940°C, with 30 minutes holding time on this temperature, and then cooled down in an open oven (thermal cycle I). Afterwards, each sample was exposed to a different number of repetition of thermal cycle – heating up to 840°C, holding time 30 minutes and consequential cooling in the open oven (thermal cycle II), which corresponds to thermal cycle used in burning of each layer of enamel.

The structure and mechanical properties ( $R_m$ ,  $R_e$ ,  $A_g$ , A50, HV 10 a KV) were evaluated in all samples within this experiment. Series of samples for each experiment were prepared from every steel plate.

The structure of each sample was inspected on optical microscope Olympus DSX 500. The samples for metallographic evaluation were taken from samples for Charpy impact test. The samples for observing on the optical microscope were prepared by common metallographic procedure and to highlighted the structure there was used 3% Nital.

**Table 1.** Chemical composition of P 265GH steel according to CSN EN 10028-2

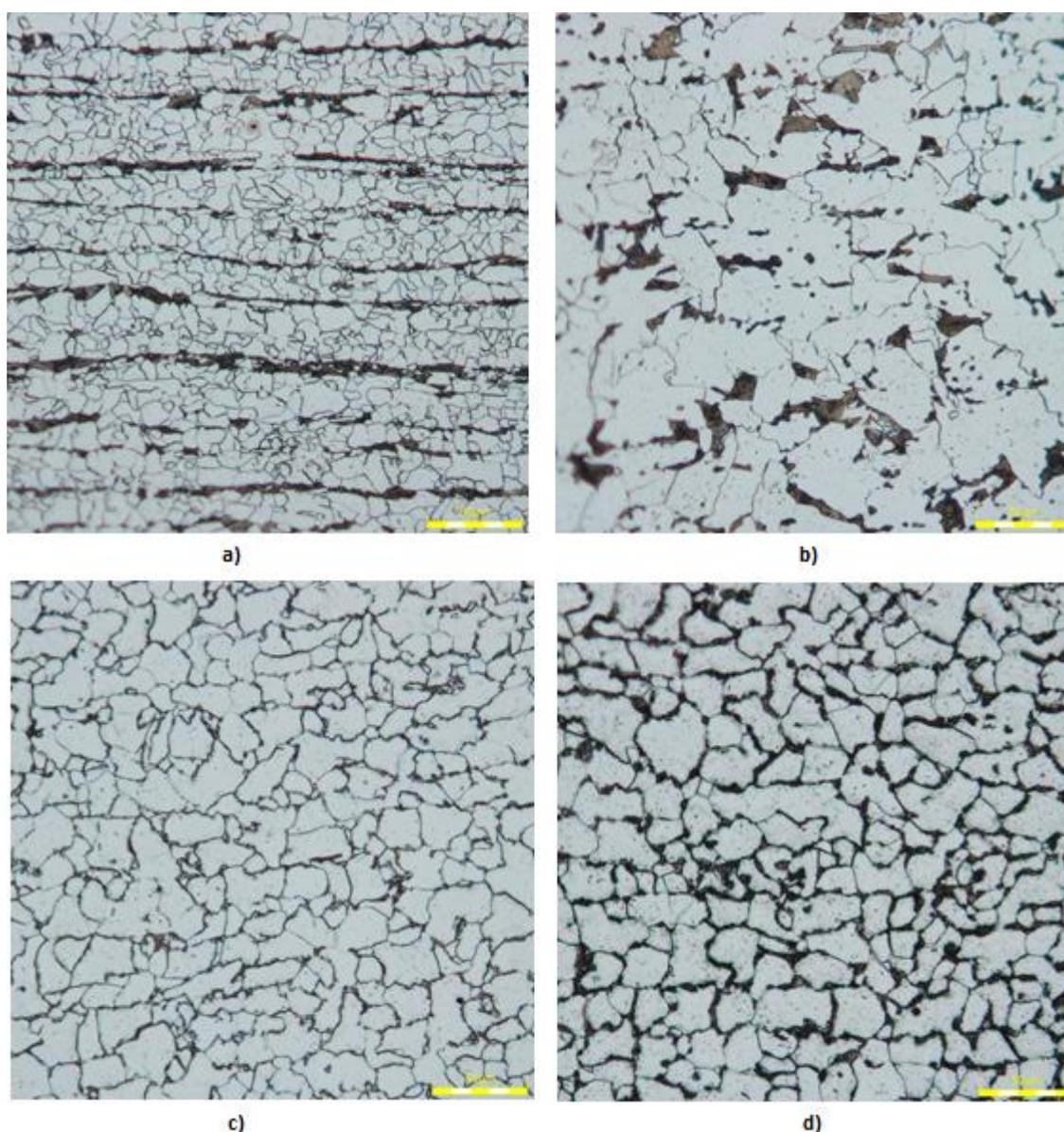
<b>C [%]</b>	<b>Si [%]</b>	<b>Mn [%]</b>	<b>P<sub>max.</sub> [%]</b>	<b>S<sub>max.</sub> [%]</b>	<b>Al<sub>celk.</sub> [%]</b>	<b>N [%]</b>	<b>Cr [%]</b>
≤ 0,20	≤ 0,40	0,8 - 1,4	0,025	0,010	≥ 0,020	≤ 0,012	≤ 0,30
<b>Cu [%]</b>	<b>Mo [%]</b>	<b>Nb [%]</b>	<b>Ni [%]</b>	<b>Ti<sub>max.</sub> [%]</b>	<b>V [%]</b>	<b>Other Cr + Cu + Mo + Ni [%]</b>	
≤ 0,30	≤ 0,08	≤ 0,020	≤ 0,30	0,03	≤ 0,02	≤ 0,70	

**Table 2.** Mechanical properties of P 265GH steel according to CSN EN 10028-2

Steel Labelling	Thickness [mm]	Upper yield strenght R <sub>eH</sub> [MPa] min.	UltimatesStrenght R <sub>m</sub> [MPa]	Ductility A [%] min.	Impact work KV [J]		
					-20°C	0°C	+20°C
P265GH	≥ 16	265	410 - 530	22	27	34	40
	16 < t > 40	255	410 - 530	22	27	34	40

**Table 3.** Experimental conditions and labelling of samples

	Series							
	1	2	3	4	5	6	7	8
<b>Thermal cycle I</b>	-	1x	1x	1x	1x	1x	1x	1x
<b>Thermal cycle II</b>	-	-	5x	10x	15x	20x	25x	30x



**Figure 1.** a) Original material, b) Series 2 – Annealing, c) Series 3 - Annealing + 5 thermal cycles of burning, d) Series 8 - Annealing + 30 thermal cycle

The structure of material received from producer is shown in the Fig. 1. There is seen the close-grained ferit-perlit steel with significant banding. In this material, the application of

annealing (shown in the series 2, Fig. 2) leads to moderate grain growth, and banding of structure disappears. When the

material undergoes other thermal cycles (thermal cycles used in enameling), then the ferrit-perlit structure equalizes.

In some cases, there is possible observe more moderate structure, and in the others, the structure is rougher. This fact is given by particular ambiguity in thermal cycle conditions (sample's cooling in the open oven). Strong effect of another repetitive thermal cycles on the grain growth was not proven, see Fig. 1.

Tensile test was performed on the experimental samples according to CSN EN ISO 6892 standard on TIRA test 2300 system.

The evaluating values were: lower yield strenght  $R_{el}$ , upper yield strenght  $R_{eh}$ , ultimate strenght  $R_m$ , ductility in strenght limit  $A_g$  and overall ductility  $A_5$ . Graphical representation of measured values is shown in the fig 2. From the obtained values is evident, that after the annealing cycle will drop the ultimate strenght from 483 MPa (initial material) to 437 MPa (Series 2), which corresponds to a decrease of 10% compared to the previous stage. The other thermal cycles do not cause any other significant changes. The value of ultimate strenght is corresponding to  $433 \pm 8$  MPa approximately. The same trends are seen in the yield strength cases. By contrast, ductility

increases after the annealing cycle by circa 10 %. Ductility does not highly change throughout the other cycles. The value of ductility is approximately  $37 \pm 1$  %. Charpy impact test, or measuring of used impact work, was undertaken on the Charpy's hammer 300 J. The trial sample was a prism with dimensions and V notch manufactured according to ČSN EN 10045-1 standards. The experiment was run at temperatures between  $20^\circ\text{C}$  and  $-30^\circ\text{C}$ . Graphical representation of obtained values of used impact work is depicted in Fig. 3. From the measured values is noticeable, that after a temperature of  $20^\circ\text{C}$ , in material after annealing cycle (Series 2), the used impact work increases from the original value of 207 J to 224 J, which corresponds to 8 % of the initial stage. The used impact work does not differ significantly with other thermal cycles, and generally reaches around  $240 \pm 16$  J. The experiment which was undertaken at the temperature of  $-30^\circ\text{C}$  shows similar trends. The used impact work given at  $-30^\circ\text{C}$  is 185 J in the original material, and increases after annealing process (Series 2). The other thermal cycles does not have strong impact on this value, and consequently, the used impact work is approximately  $224 \pm 25$  J. Differences between these values of each thermal cycle are within measurement errors.

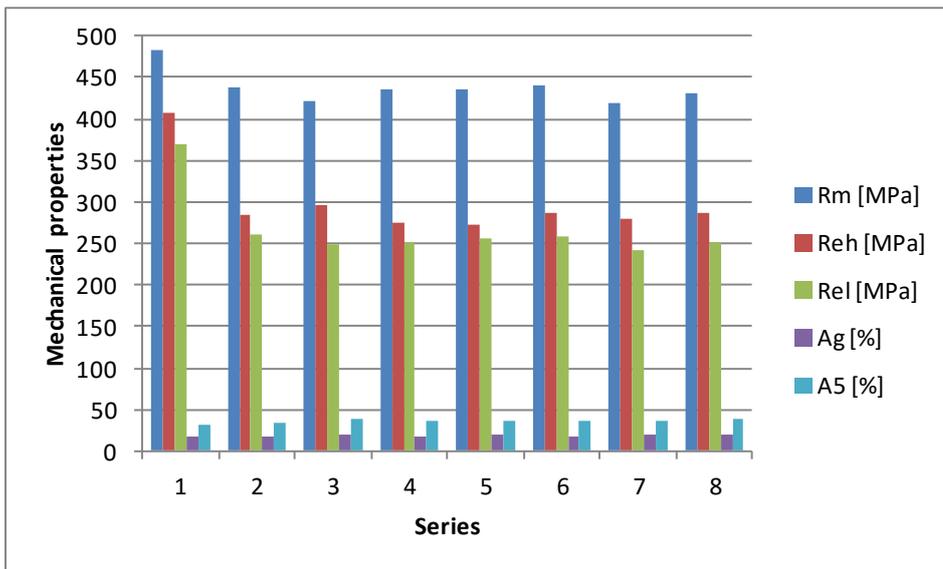


Figure 2. Graphical representation of the influence of thermal cycles on mechanical properties

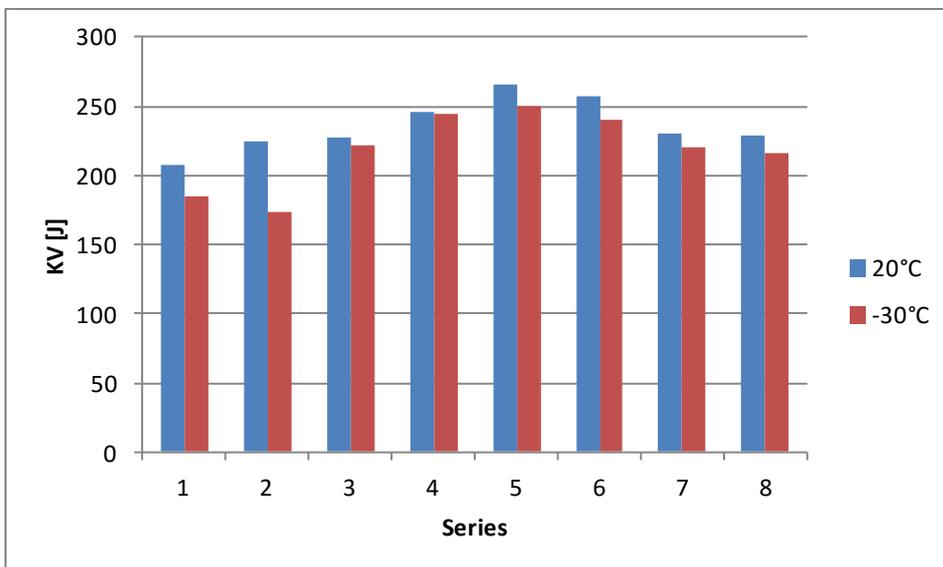


Figure 3. Graphical representation of the influence of thermal cycles on KV [J]

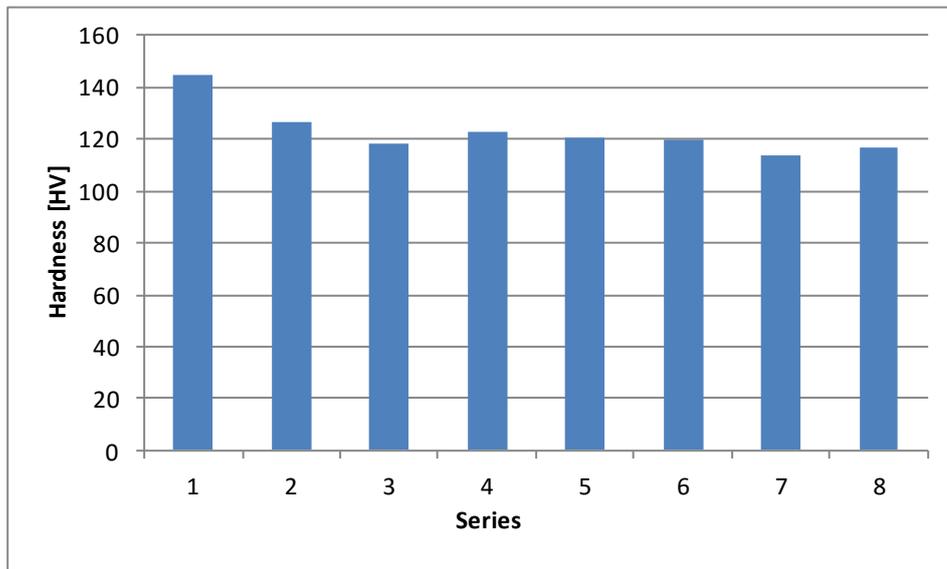


Figure 4. Graphical representation of the influence of thermal cycles on hardness according to Vickers HV10

The hardness HV10 (experimental strain 98,07N) was measured on metallographic samples taken from the samples used in Charpy impact test. The measurement of each sample was undertaken on 9 different places which were equally spread on the whole surface. The actual measurement was executed on hardness tester Q30A. Graphical representation of measured values of hardness HV10 is shown in Fig. 4. From the obtained values is evident, that after the annealing cycle (Series 2) hardness decreases from 145 HV to 127 HV, which corresponds to a decrease of 12% compared to the previous stage. The other thermal cycles does not have strong impact on the final hardness, which corresponds to an approximate value of  $119 \pm 5$  HV.

### 3 CONCLUSIONS

As it has been said already, enamels are repeated in enameled systems due to a demand of higher durability. During the manufacturing process, pressure tanks are firstly welded, and then annealing and enameled processes are applied. Each layer of enamel undergoes new thermal cycle during the burning process. The enamel is firstly removed by shot blasting, afterwards, new layers of enamel are applied gradually, and burning is applied according to prescribed thermal cycle. Nowadays, the maximum of two enamels are allowed according to the manufacturing regulations. The purpose of performed experiments was to find out, whether, or eventually how the applied thermal cycles affect changes of structure and mechanical properties of foundation material.

The aforementioned experiments has shown that the annealing process of close-grained ferrit-perlit P265GH steel leads to a moderate grain growth, and a banding of structure disappears. The repetition of thermal cycles used in the enamelling process does not have a significant impact on the structure. Mechanical properties ( $R_m$ ,  $R_{el}$ ,  $R_{eh}$ ) decrease rapidly after the tank is annealed, however repetitive thermal cycles used in enameling do not affect the material furthermore. Fracture limit in bend decreased after annealing process by circa 10 % compared to

the initial stage. Same trends were seen at the yield strength. On the other hand, ductility  $A_5$  increased by 10 % when annealing cycle was applied, and does not change noticeably with other thermal cycles. Used impact work KV at a temperature of 20°C goes up after annealing by 8 %, compared to the original stage, and hardness HV goes down by 12 %, compared to the initial stage. The use of more thermal cycles did not cause any degradation of obtained values.

According to the obtained results, it is possible announce that repetitive enameling in material P265GH does not significantly affect changes in the structure and mechanical properties of the original material, and therefore this method can be recommended for the aforementioned systems.

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