

## PLASTIC DEFORMATION OF METAL BY PULSATION FORMING

### SUMMARY

*Pulsation forming of metallic materials (also referred to as stresscycling) is a novel forging method based on the application of a variable pulsation frequency during the metal forming process. This paper presents some new results obtained after pulsation forming of steel grade Cr18Ni10. The experimental works suggested that the value of summary deformation of 25% (at the pulsation frequency of 30 Hz) was obtained with the very good compromise of yield strength ( $R_{p0,2}$ ), tensile strength ( $R_m$ ), elongation ( $A_5$ ) and contraction ( $Z$ ). The results were given with respect to the effect of deformation temperature (from 850 to 920°C) and deformation time (from 2 to 10 sec.) at constant heating temperature (1100°C), constant pulsation frequency (30 Hz) and variant frequency from 10 Hz to 40 Hz on mechanical characteristic ( $R_{p0,2}$ ;  $R_m$ ;  $A_5$ ;  $Z$ ) of stainless steel grade Cr18Ni10.*

**Keywords:** *pulsation forming, pulsation frequency, deformation temperatures, deformation times, mechanical properties*

### PULSACYJNA METODA OBRÓBKII PLASTYCZNEJ METALI

*Formowanie pulsacyjne metali jest nowatorską metodą opierającą się na zastosowaniu zmiennej częstotliwości drgań w trakcie obróbki plastycznej metali. Artykuł prezentuje wybrane rezultaty badań uzyskane w trakcie obróbki plastycznej stali typu Cr18Ni10. Z przeprowadzonych doświadczeń wynika, że dla 25% całkowitej sumy odkształceń (dla częstotliwości drgań 30 Hz) uzyskano bardzo dobrą zależność pomiędzy granicą plastyczności ( $R_{p0,2}$ ), wytrzymałością na rozciąganie ( $R_m$ ), względnym wydłużeniem ( $A_5$ ) i przewężeniem ( $Z$ ). Wyniki otrzymano z uwzględnieniem wpływu efektów cieplnych deformacji (od 850 do 920°C) i czasu formowania (od 2 do 10 s) przy stałej temperaturze nagrzewania (1100°C), dla stałej częstotliwości drgań (30 Hz) oraz zmiennej częstotliwości drgań (od 10 Hz do 40 Hz) na parametry wytrzymałościowe ( $R_{p0,2}$ ;  $R_m$ ;  $A_5$ ;  $Z$ ) stali typu Cr18Ni10.*

### 1. INTRODUCTION

Pulsatory forming, as one of non-conventional forming methods, can be classified into the category of technological processes where the energy of vibration systems with a frequency effect utilized. It is a process where a tool applies a force to a formed material, while the immediate value of the force oscillates around a mean value, which can remain constant or can increase or decrease during the process. The idea of applying pulsatory forming resulted from looking for a new bulk forming method with the aim to increase the technological formability of material, which is in common forming processes limited by conventional conditions of technology. The pulsation frequency and amplitudes during pulsatory forming are new technological parameters using which we can influence both important processes taking place in the formed metal (recrystallization, grain growth, transformation processes) as well as the contact area between the formed metal and the forming tool (the character of friction and related impacts on the deformation course and the formability). Controlling the force values during pulsatory forming (decreases and re-increases) can promote and speed up the course of recrystallization [1]. The grain size – the most important structural factor – can also be activated by pulsatory forming, resulting in finer-grained microstructures, while the recrystallization kinetics (its higher intensity) and the grain refinement have a positive effect on the material plasticity and formability [1, 2]. The

cyclic decrease and increase of stress on the contact areas between the formed metal and the forming tool improves the conditions for elementary slips, which must take place in material flowing in the desired direction [2]. During pulsatory forming, the course of recrystallization processes is promoted, but, on the other hand, a high density of high-strength micro-areas is also promoted because of repeated “peak” stresses in the process. This has an effect on the course of transformation, for example in steel, where austenite is transformed into ferrite-carbide microstructures. According to [1], the strengthening character of carbon steels during pulsatory forming increases the austenite stability in relation to its transformation into bainite or martensite, but, on the other hand, it speeds up the formation of pro-eutectoid ferrite. Consequently, in the resulting structure the shares of ferrite and residual austenite are promoted at the expense of the bainitic or martensitic microstructural shares, which is an important factor from the viewpoint of material plasticity and formability.

Pulses can be generated by different mechanisms of hydraulic, electromagnetic, or mechanical principles. The pulsator was installed at the Department of Metal Forming, Technical University in Košice is working on mechanical principle [3, 4, 5], as shown in Figure 1. The paper presents research results made on an installed pulsator. The evaluation of the pulsatory forming results was focused on investigation of pulsation frequency and hot plastic deformation conditions on strength and plastic material characteristics as well as structure development.

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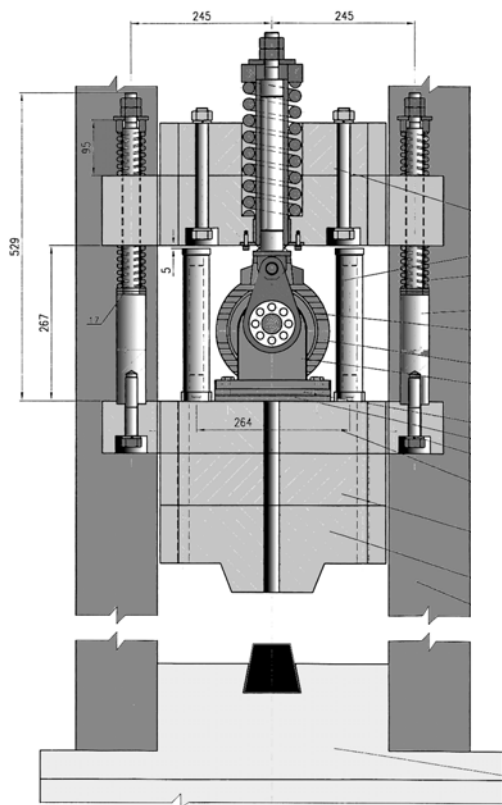


Fig. 1. Pulsator

## 2. MATERIAL AND EXPERIMENTAL METHODS

Cylindrical specimens with the dimensions  $h_0 = 30$  mm,  $d_0 = 20$  mm were used for experimental works. Chemical composition of the experimental steel is shown in Table 1. The experimental conditions are summarized in Table 2.

Table 1. Chemical composition of steel grade Cr18Ni10 [mass %]

Steel	C	Mn	Si	Cr	Ni	Ti	P	S
Cr18Ni10	0.03	1.2	0.5	18.6	10.8	0.26	0.008	0.023

Table 2. Experimental procedure

Heating temperature [°C]	Deformation temperature [°C]	Pulsation frequency [Hz]	Note
1100	850	10	The specimens after pulsatory forming were water quenched
		20	
		25	
		30	
		35	
		40	
Heating temperature [°C]	Pulsation frequency [Hz]	Finishing pulsation temperature [°C]	Note
1100	30	920	The specimens after pulsatory forming were water quenched

Only one short testing specimen ( $d_0 = 5$  mm,  $l_0 = 5$  mm) for static tensile strength tests were cut from pulsating samples. The static tensile strength tests were performed at room temperature by ZWICK 1387 equipment in accordance with STN 420310 (STN EN 10002-5) standard. The metallographic analyses were performed on pulsating samples by using of optical light microscopy as well.

## 3. EXPERIMENTAL RESULTS AND DISCUSSION

The summary deformation and deformation per one blow achieved during the pulsating of cylindrical specimens from experimental steel and also for comparison from aluminium as a function of the pulsation frequency are shown in Figures 2 and 3.

From figures is resulting that on localization of deformation maximum has not influence of material kind. The biggest summary deformations were obtained at frequency 30 Hz and biggest deformations per one blow at frequency 20–25 Hz.

The influence of pulsation frequency on strength and plastic properties is given in Figures 4 and 5. The best strength values were achieved for pulsation frequency 30 Hz and best plastic data were reached for pulsation frequency 20 and 25 Hz.

The influence of pulsation frequency on average austenite grain size (AGS) is given in Figure 6 and effect AGS on strength properties is illustrated in Figure 7. The minimum value of AGS was made by pulsation frequency interval 25–35 Hz. The best strength values were achieved for minimal  $d_{AGS} = 40$   $\mu$ m.

From obtained relations is resulting that optimal pulsation frequency value for achieved maximal strength and plastic values and minimal AGS rate is 30 Hz. The pulsation frequency 30 Hz is response to summary deformation  $\epsilon = 27\%$ .

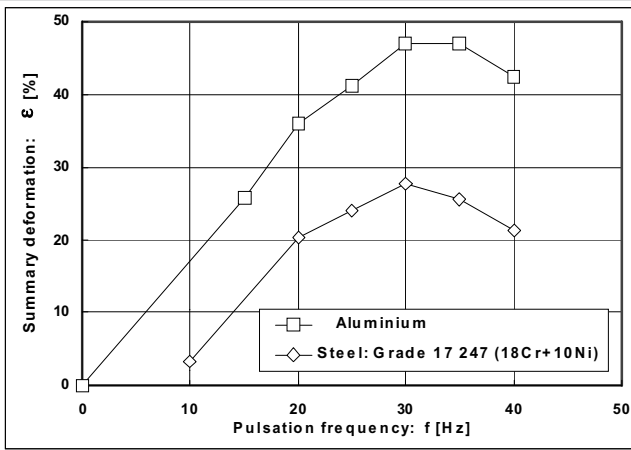


Fig. 2. Summary deformation as function of pulsation frequency (Al – cold forming, Steel –  $T_{finished} = 850^{\circ}C$ )

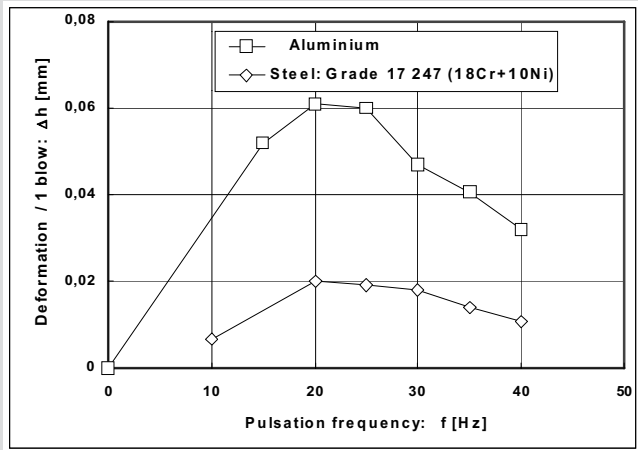


Fig. 3. Deformation / 1 blow as function of pulsation frequency (Al – cold forming, Steel –  $T_{finished} = 850^{\circ}C$ )

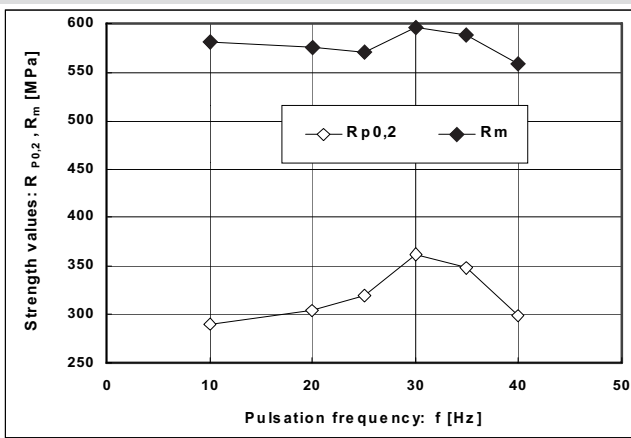


Fig. 4. Strength values as function of pulsation frequency (Steel –  $T_{finished} = 850^{\circ}C$ )

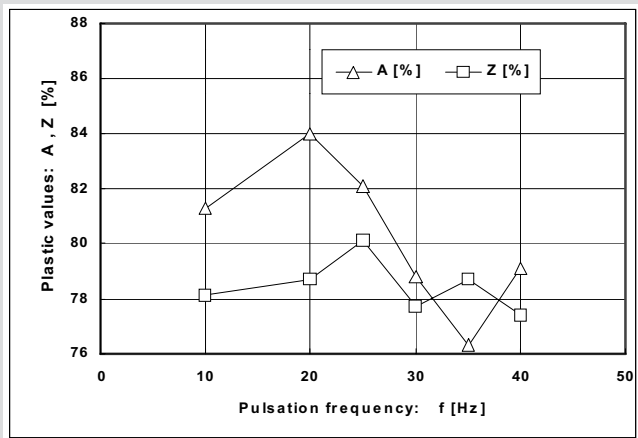


Fig. 5. Plastic values as function of pulsation frequency (Steel –  $T_{finished} = 850^{\circ}C$ )

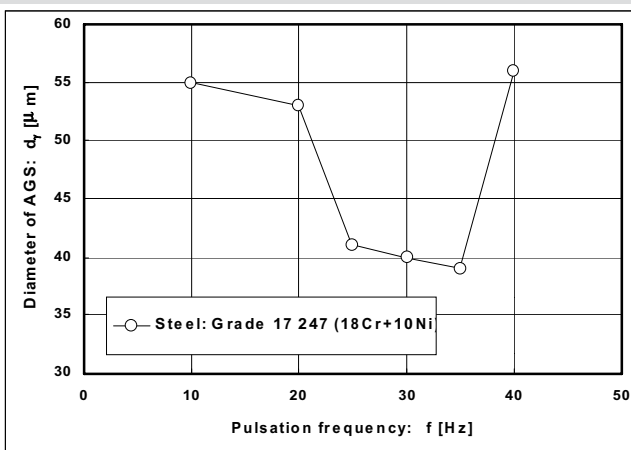


Fig. 6. Diameter of AGS as function of pulsation frequency (Steel –  $T_{finished} = 850^{\circ}C$ )

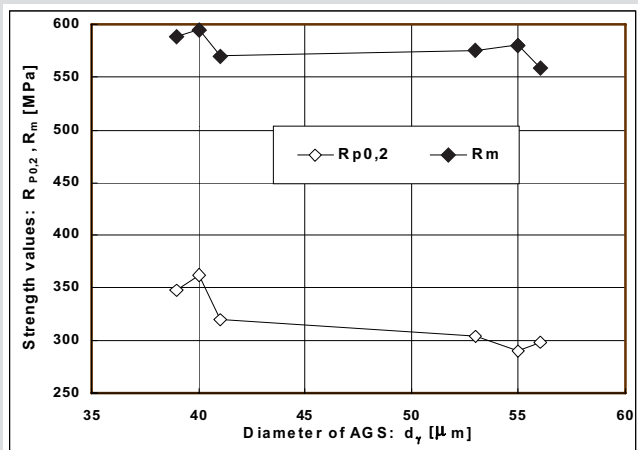


Fig. 7. Strength values as function of AGS diameter: (Steel –  $T_{finished} = 850^{\circ}C$ )

The effect of summary deformation on strength properties is documented in Figure 8 and on plastic properties is illustrated in Figure 9. From figures is resulting that the best properties were achieved for summary deformation  $\epsilon \approx 23\%$  which response to pulsation frequency 25 Hz. The strength and plastic values as function of deformation

temperature at pulsation frequency  $f = 30$  Hz are shown in Figures 10 and 11. The yield strength is decreasing after achievement of deformation temperature level  $890^{\circ}C$  because of recrystallization is starting. Full recrystallization was achieved at  $920^{\circ}C$  about what sit development in plastic properties as well.

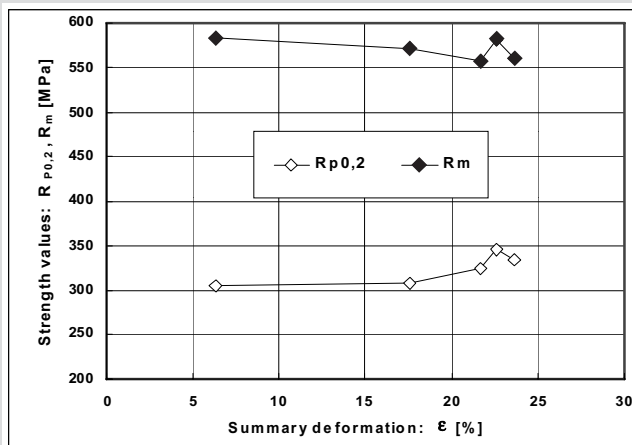


Fig. 8. Strength values as function of summary deformation (Steel:  $f = 30$  Hz)

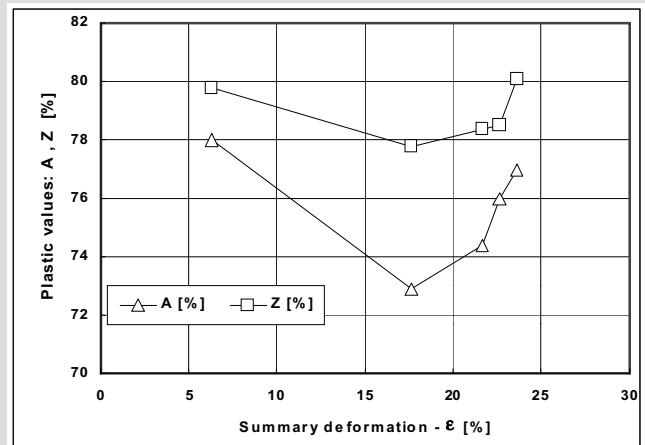


Fig. 9. Plastic values as function of summary deformation (Steel:  $f = 30$  Hz)

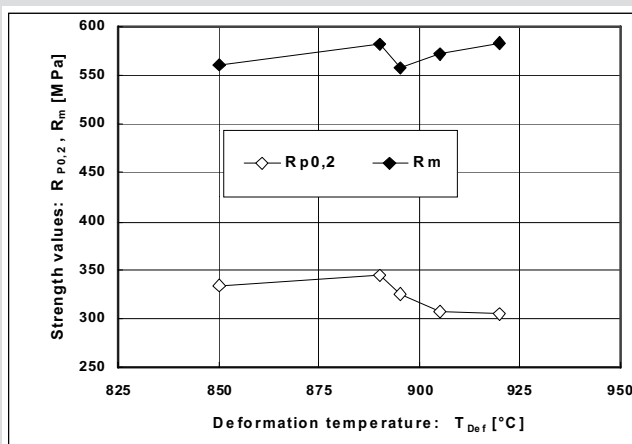


Fig. 10. Strength values as function of deformation temperature (Steel:  $f = 30$  Hz)

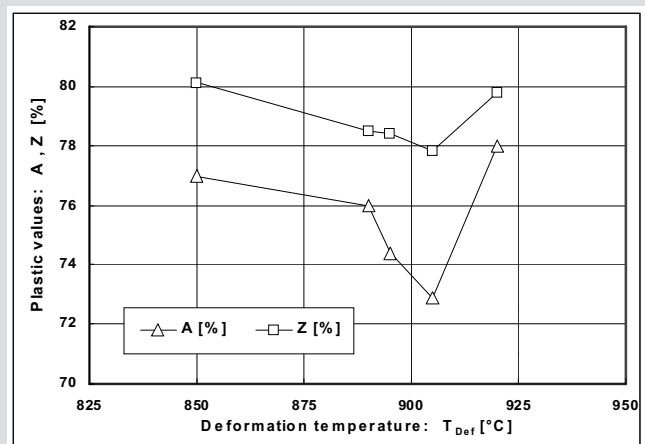


Fig. 11. Plastic values as function of deformation temperature (Steel:  $f = 30$  Hz)

#### 4. CONCLUSION

The best strength values ( $R_{p0.2} = 362$  MPa,  $R_m = 596$  MPa) were achieved by pulsation frequency  $f = 30$  Hz which response to summary deformation  $\epsilon = 27\%$  and diameter austenite grain size  $d_{AGS} = 40 \mu\text{m}$ .

After application of the pulsation frequency of 30 Hz at further defined conditions (heating temperature, deformation temperatures, deformation times and quenching of samples after pulsation forming) the following mechanical properties were achieved:

- Yield strength ( $R_{p0.2}$ ) from 304,8 to 345 MPa;
- Tensile strength ( $R_m$ ) from 557,5 to 583,7 MPa;
- Elongation ( $A_5$ ) from 72,9 to 78%;
- Contraction ( $Z$ ) from 77,8 to 80,1%.

The available strength values ( $R_{p0.2} = 345$  MPa,  $R_m = 558$  MPa) at deformation temperature  $890^\circ\text{C}$  and deformation time 8 sec was achieved with work hardening structure.

#### Acknowledgements

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