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MECHANICAL PROPERTIES OF FORGINGS DEPENDING ON THE CHANGES IN SHAPE AND CHEMICAL COMPOSITION OF INCLUSIONS

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The article deals with mechanical properties of forgings used for special technology in cannon barrels production. The forgings are treated by elctroslag remelting technology (ESR) to enhance its plastic properties and yield point. Described experiments are focused on mechanical properties and metallurgical quality (microstructure) of steels from which are the forgings made. The article includes microstructure photographs and description of inclusions located in examined steels. Experimental results compare forgings treated by ESR and next ones without ESR.

Key words: medium alloyed steel, ingot, forging, electroslag remelting, quality, mechanical properties, non-metallic folds

Mehanička svojstva otkivaka u ovisnosti od izmjene oblika i kemijskog sastava uključaka. Članak daje prikaz mehaničkih svojstava otkivaka koji se rabe pri posebnoj tehnologiji za topovske cijevi. Otkivci su tretirani elektro pretaljivanjem pod troskom glede povišenja plastičnih svojstava i granica razlučenja. Eksperiment se fokusira na mehanička svojstva, mikrostrukturu i metaluršku kakvoću materijala otkivka. Rezultati eksperimenta uspoređuju otkivke sa i bez pretaljivanja pod troskom.

Ključne riječi: srednje legirani čelik, ingot, otkivak, pretaljivanje pod troskom, mehanička svojstva, nemetalni uključci

INTRODUCTION

Enlargement of quality requirements in metallurgical semi products used in cannon barrels production (forgings) has resulted in substantially increased number of defective products. The main issues are poor quality of plastic properties and yield point of processed materials. Careful analysis of forgings technology and adaptation of its constituent phases has not resulted in the quality enhancement of the forgings. Consequently, the issue is searched in metallurgical phase of production technology. [1-3].

Table 1 **Characteristics of examined steel** [4]

Chemical composition (wt. %)				
C	Ni	Cr	Mo	Si
0,35	3,0	1,0	0,25	0,30
Mn	P_{max}	S_{max}	Cu_{max}	
0,40	0,025	0,025	0,030	
Mechanical properties				
$R_{p0,2}$ / MPa /	Z / % /	KCV / J/cm^2 /		
873	25	34		

MATERIAL AND METHODS USED IN EXPERIMENT

The experiment is aimed at the quality of bar shaped steel forgings of large dimensions with diameter 350 mm and length 8500 mm. The forgings are made of medium alloyed steel with chemical composition and mechanical properties according to Table 1.

Cannon barrel steels have a favorable relation between plastic and strength properties and high hardening capacity (over 150 mm). These conditions make steel suitable for forgings of large dimensions [3, 5].

Methodology of testing is performed according to the following steps:

- Testing mechanical properties on samples from defective forgings prepared of originally used steel
- Detailed analysis of solid phase on samples from originally used steel and following evaluation of its metallurgical quality
- Enhancement of metallurgical quality of originally used steel by application of ESR (Electroslag Remelting)

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- Testing mechanical properties on samples made of steel improved by ESR.
- Comparing results gained in the process of analyzing technologies employed (by ESR and without ESR)

SOLID PHASES ANALYSIS

The solid phase is analyzed via the fractures surface testing employing electron microscopy on the samples from tensile strength test and Charpy impact test of ESR and non ESR steel. Also the qualitative analysis of the unfamiliar particles located on the samples fracture surfaces is realized [6].

Inclusions on the fracture surfaces are classified into various different types but only two types of non-metallic particles are of the high priority. The first type is fanout aligned baculiform particles (Figure 1). Chemical analysis confirms the presence of the manganese sulfide MnS (Figure 2) [2]. The second type of the inclusions consists of small cumulated particles segregated in lines, strips or clusters (Figure 3). Polyhedral particles are angular and in some cases are almost formed into a regular hexagon. Chemical analysis by EDAX system confirms presence of the complex chemical compounds comprising O, Si, Ca, Al, Ti, S, Mn (Figure 4) [2, 3]. These compounds are complexes of sulfide oxides separated by strip of metallic base.

The highest number of defective products was occurred in those forgings where fanout aligned baculiform folds were detected.

ENHANCING METALLURGICAL QUALITY OF STEEL

Detailed analysis of fracture surfaces indicates clearly that the way of enhancing the tested product quality means affecting the inclusions in the melting phase of the production process.

The primary liquid alloy could not be affected on a large scale during the casting process of ingot. Therefore testing is focused on secondary melting as a product of electroslag remelting of the ingot to the forged electrode. The electrode was forged using hydraulic jack

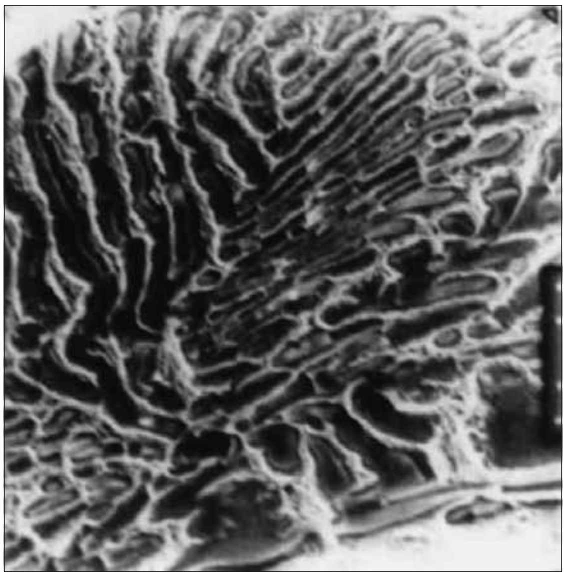

Figure 1 Fanout aligned baculiform folds –magnification 600x

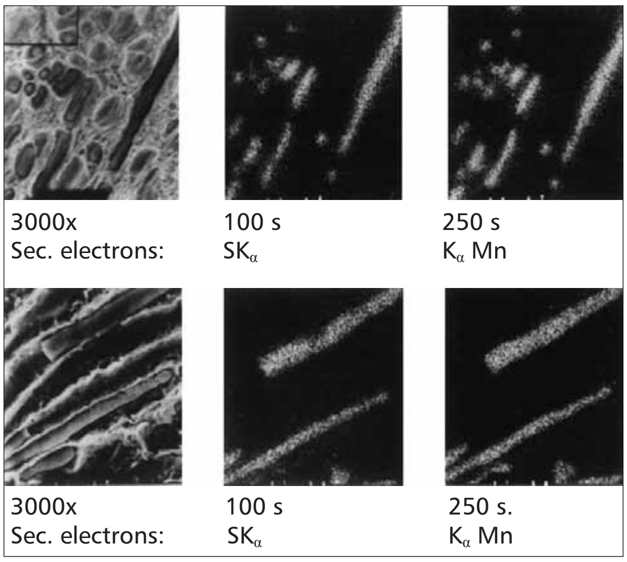

Figure 2 Area distribution of characteristics X-radiation K_α Mn and S in folds of baculiform shape

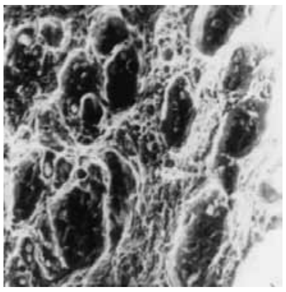

Figure 3a Polyhedral shaped clusters and rows of folds - magnification 600x

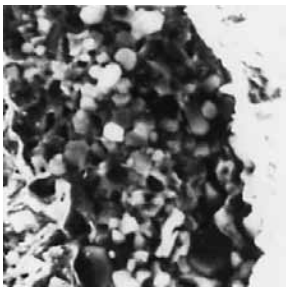

Figure 3b Polyhedral shaped clusters and rows of folds - magnification 2000x

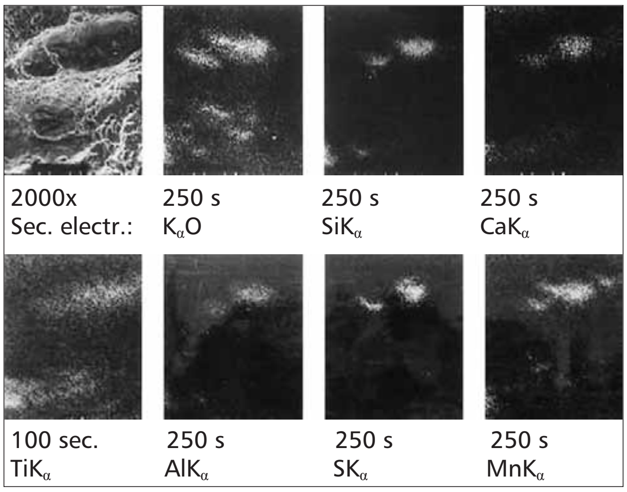

Figure 4 Area distribution of characteristics X-radiation $K_\alpha 0$, Si, Ca, Ti, Al, S, Mn and S in folds segregated in clusters

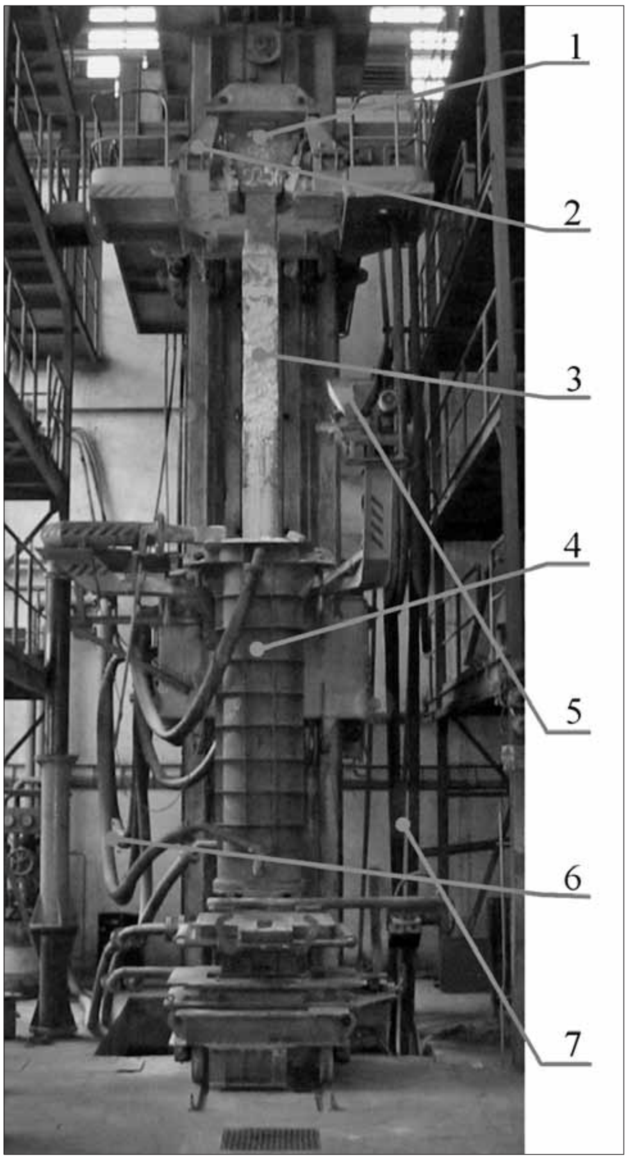

Figure 5 Equipment for electroslag remelting of steel [3]
1 – Inventory head
2 – Seating clamps
3 – Electrode (forged and remelted product)
4 – Crystallizer
5 – Feeding device
6 – Cooling of crystallizer
7 – Input power

CKV – 2500 and remelted in the electroslag device (Figure 5) under the refining slag with composition of 70% CaF_2 a 30% Al_2O_3.

The principle of ESR technology is described in more details in lit. [6].

Ingot made by ESR is annealing for stress relieving, forged and finally heat treated.

RESULTS COMPARISON - ESR AND NON-ESR STEEL

Samples are prepared from each of forgings (with ESR and without ESR) to be tested for tensile strength and to carry out Charpy test. The samples are taken from places in transverse direction to forging line of forgings. Tensile strength test is realized according to the standard STN EN 10002-1 and Chapry test is carried out in line with the standard STN EN 10045-1 [4,7].

Five samples are prepared from each of forgings and final values of its mechanical characteristics (Table 2 and Table 3) are arithmetic mean.

Results gained in mechanical values of originally used and enhanced steel show significant differences as it is stated in Table 2 and Table 3 [1, 3].

Table 2 **Results in mechanical properties acquired from remelted steel**

Forgings No.	$R_{p0,2}$ /MPa/	Z / % /	KCV / J/cm^2 /
4742	958	26,4	48
4743	974	30,9	52
4744	959	29,7	51
4745	964	24,6	54
4832	866	19,5	43
4833	909	18,6	42
4834	886	19,3	42
4835	953	21,2	42
5748	982	21,3	40
5749	915	30,5	48
5751	945	22,1	42
5752	1001	27,8	42
5753	922	35,9	48
5754	1013	32,2	40
5756	947	28,0	50
5757	947	34,9	58
5758	953	36,7	54
5759	962	36,6	51
Average value	947	27,5	47

Table 3 **Results of mechanical properties acquired from non-remelted steel**

Forgings No.	$R_{p0,2}$ /MPa/	Z / % /	KCV / J/cm^2 /
6395	1182	42,6	61
6396	1165	43,2	62
7482	1187	44,3	67
7483	1092	44,7	68
Average value	1131	43,2	64,5

Comparison of both types of steel unambiguously shows the increase in all mechanical characteristics of re-melted steel.

Absolutely different types of non-ferrous inclusions on the fracture surfaces of ESR steel are found if compared to the fracture surfaces of steel without ESR. Inclusions are dispersed in steel, not segregated in any clusters and they have almost globular form as it is shown in Figure 6. The inclusions were identified as a complex sulfide oxide by chemical microanalysis (Figure 7) [8].

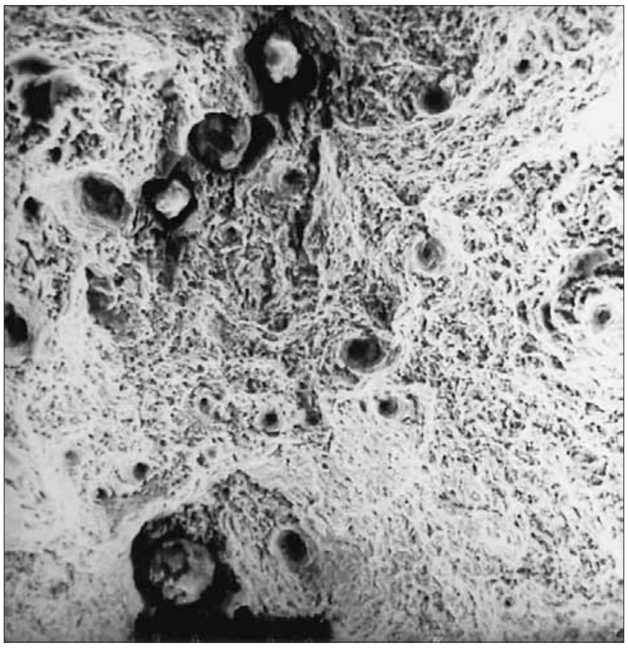

Figure 6 Typical folds of ESR forgings

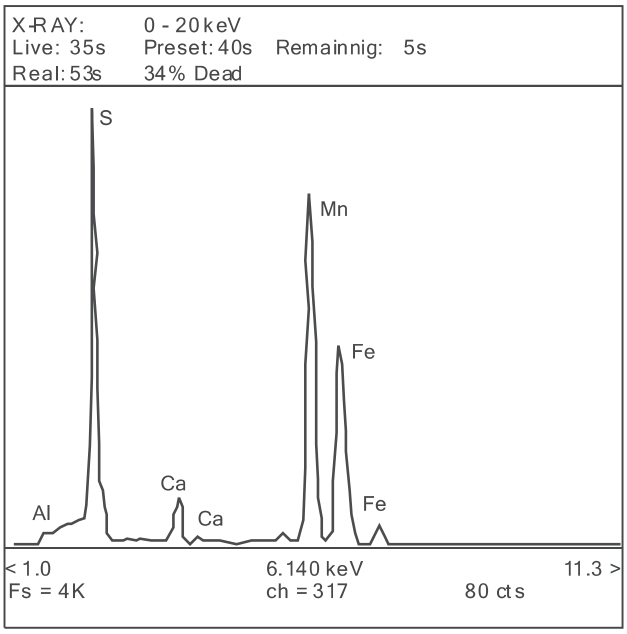

Figure 7 Chemical microanalysis of folds in ESR forgings

CONCLUSIONS

The presented results show that the electroslag remelting forgings have significantly higher values of mechanical characteristics than the values of requirements recommended. Therefore steel produced in arc furnace and then refined by ESR technology follows to its conditions suitable for the designer to design products with better utility properties.

An important benefit of ESR technology lies in plastic properties distribution homogenously through volume of forging. The plastic properties of ESR forgings are also significantly higher at high yield point level than the properties of forgings without ESR. This positive effect of ESR to steel forgings is due to distribution of non-ferrous inclusions in the steel. Forgings without ESR has inclusions segregated in cluster but this effect did not appear in ESR forgings. The refinement effect causes that some inclusions got stuck in the slug (a third of them according to analysis) and the rest, breaking off the slug, are segregated individually in the liquid. Individual segregation of inclusions does not affect mechanical properties of steel in a negative way if compared to inclusion segregated in clusters.

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Note: English translation corrected by: Mária Igazova, TnU, Trenčín, Slovakia