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Faculty of Mechanical Engineering
Department of Materials Engineering

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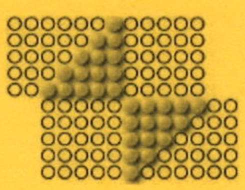
Dean of the Faculty of Mechanical Engineering of the University of Žilina



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PROCEDURE FOR REPLACING THE MATERIAL FOR MANUFACTURING THE RESPONSIBLE WELDED STRUCTURE

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1. Introduction

In the engineering industry, one of the basic raw materials for production is steel. The lack of this very important raw material, both on the domestic and world markets, can have a significant negative impact on the business of various companies since the lack of materials leads to delays and the impossibility of delivering the agreed products within the agreed deadlines. To avoid the consequences of such delays (payment of penalties), it is necessary to find replacement material on the market.

When choosing the appropriate replacement material, certain criteria must be met. When it comes to less responsible parts and constructions, it is necessary to choose a material that has similar or better mechanical properties than the original one. However, in the case of responsible parts, and especially in the case of responsible welded structures, besides the basic criteria, related to the mechanical properties of the new material, it is necessary to carry out a more detailed analysis that includes examination of other important factors influencing the output properties of a structure [1].

As the most important factor, which should be examined, is the influence of the heat released during the welding on the output properties of the welded joint. It is known that the heat leads to deterioration of the mechanical properties of welded structures. For the output properties of a structure to be as good as possible, it is necessary to prescribe the appropriate technology of welding, as well as of the heat treatment.

This paper presents a detailed procedure for selecting the appropriate replacement material, as well as an evaluation of the heat treatment impact during the responsible structure (part of the artillery tool) manufacturing on a practical example of an exceptionally responsible structure that operates under conditions of extremely impact-dynamic loads

2. Comparative analysis of properties of the used and replacement materials

The original raw material, used thus far for production of this extremely responsible part (structure) was steel 25CrMo4. Its mechanical properties are shown in Tab. 1. Due to known reasons, this steel has become scarce on the market in Serbia. To continue production, a decision was made to select an adequate replacement material, after appropriate tests.

Based on the analysis of material availability on the market and the experience of the authors of this work, the 42CrMo4 steel was proposed as a replacement. Its mechanical properties are shown in Tab. 1 and chemical composition in Tab. 2. Both steels (original and replacement) belong to the group of low-alloy chromium-molybdenum steels. In addition, according to their purpose, these steels belong to the group of steels for tempering. By comparing the mechanical properties of these two steels, it can be clearly concluded that the 42CrMo4 steel has significantly better mechanical properties. Thus, the criterion related to mechanical properties is fulfilled.

To be fully convinced that the proposed material is to be used as a replacement in production, it was necessary to carry out additional tests that include testing of the chemical composition, assessment of weldability, prescription of appropriate welding technology, as well as the heat treatment.

Tab. 1 Mechanical properties of 25CrMo4 and 42CrMo4 steels

Property/Steel	***25CrMo4***	***42CrMo4***
Yield stress [MPa]	*min 400*	*900*
Tensile strength [MPa]	*560-650*	*1100-1300*
Elongation [%]	*21,5*	*10*
Contraction [%]	*59,6*	*40*
Impact toughness [J]	*min 45*	*35*

Tab. 2 Chemical composition of the 42CrMo4 steel, %

Elements	***C***	***Si***	***Mn***	***Cr***	***Mo***	***P***	***S***
[wt. %]	*0.38-0.45*	*max 0.40*	*0.60-0.90*	*0.90-1.20*	*0.15-0.30*	*0.025*	*0.035*

Based on the composition of the steel, it is possible to calculate its weldability using the chemical equivalent carbon (CE). In the considered case, using the appropriate formula [2], the CE value obtained was 0.815 %. This value is higher than the limit value of 0.45 %, so the considered steel 42CrMo4 can be considered as conditionally weldable. Accordingly, it is necessary to check the tendency of this steel to cold cracks. An analysis carried out according to well-known formulas for assessing the proneness of steel to cracks' appearance, it was found that this steel is prone to the appearance of cracks, especially the cold ones and that it is necessary to apply preheating prior to welding.

The Seferian formula [3] was used to calculate the preheating temperature. In the specific case, the adopted preheating temperature T_p was 300 °C.

Since these are the parts and cross-sections of large dimensions, which require the preparation of welds of large volume, to achieve the highest possible productivity, the decision was made to apply the MIG/MAG (Metal Inert Gas/Metal Active Gas) welding methods. To determine the optimal welding technology, laboratory tests were performed on specially prepared samples. Sample preparation included welding of 42CrMo4 steel plates using appropriate procedures, additional materials and regimes.

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Considering that this is a responsible tool, which works under conditions of intensiv impact-dynamic loads, it is necessary to take all the measures, to obtain the greate possible impact strength of the welded joint. The proposed technology meant that the fir (root) pass was applied with an electrode wire of high impact toughness, while the oth (filling welds) were executed with an electrode wire of similar chemical composition an properties as the base material. For the root pass, the electrode of the manufacturer "S Jesenice" (Slovenia) was chosen, which has the designation MIG 18/8/6 and for the fill welds, the MIG 75 electrode of the same manufacturer was chosen. Chemical compositic of used electrodes, their mechanical properties and the welding parameters are shown i Tables 3, 4 and 5, respectively.

Tab. 3 Chemical composition of the used electrodes, [wt. %]

Commercial designation	Designation according to EN ISO	C	Si	Mn	Cr	Ni	Mo
MIG 18/8/6	G 18 8 Mn	0.080	0.800	7.000	18.500	9.000	-
MIG 75	Mn3Ni1CrMo	0.080	0.600	1.700	0.250	1.500	0.500

Tab. 4 Mechanical properties of used electrodes

Commercial designation	Designation according to EN ISO	R_p [MPa]	R_m [MPa]	A [%]	KCV [J]
MIG 18/8/6	G 18 8 Mn	> 380	560-660	35	at 20 °C 40 J
MIG 75	Mn3Ni1CrMo	> 690	770-940	>17	at 40 °C > 47 J

Tab. 5 Welding parameters

Commercial designation	Designation according to EN ISO	Current, I [A]	Voltage, U [V]	Welding speed, [cm/s]	Driving energy, q_l [J/cm]	$t_{8/5}$ [s]
MIG 18/8/6	G 18 8 Mn	180	21	0.20	16065	18
MIG 75	Mn3Ni1CrMo	240	25	0.35	14571	15

The driving energy, as well as the time $t_{8/5}$, were calculated using known formulas. Figu 1 shows the CCT diagram with entered cooling times $t_{8/5}$. The cooling curve obtained l applying filler welds is marked as #1, while the cooling curve obtained by applying ro welds is marked #2.
Analyzing the state shown in the diagram, based on the time $t_{8/5}$, one can clearly obser that the applied welding parameters generally produce a bainite-ferrite structure. Tl combination of structures gives good characteristics of strength and plasticity. Since it

an extremely responsible construction, the microstructure was recorded, as well as the hardness was measured in the corresponding zones [3].

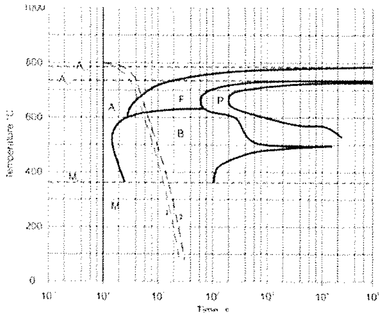

Fig. 1 The CCT diagram for the 42CrMo4 steel

To be completely sure that the output properties of the 42CrMo4 steel construction are satisfactory, it was necessary to apply the appropriate heat treatment. It consisted of the steel tempering, with prior normalization. Quenching was executed at 850 °C in oil and high temperature annealing at 600 °C, Fig. 2.

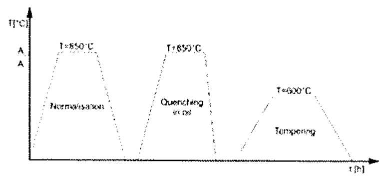

Fig. 2 The proposed heat treatment regime

Tests related to the heat treatment effect included comparative material characteristics tensile and impact toughness tests, the latter according to the Charpy method, as well as metallographic investigations. By comparing the values obtained from the tests, it was possible to assess the heat treatment influence on the most important mechanical properties. The tests of the material's mechanical properties were conducted on the steel samples in the delivered state (annealed state), as well as in the heat-treated state.

3. Results and discussion

3.1 Tensile tests

The samples were cylinders, with the measuring part of a diameter d_0 = 8 mm and length l_c = 80 mm ($10 \cdot d_0$). The schematic and real appearance of samples are shown in Fig. 3.

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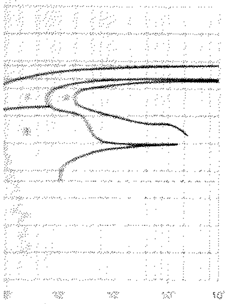

gram for the 42CrMo4 steel

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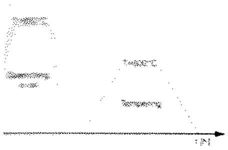

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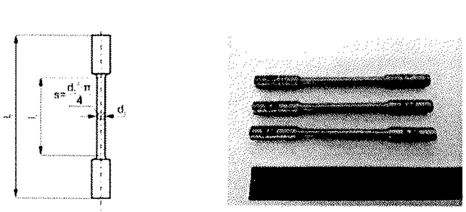

Fig. 3 Test samples: schematics (left); real appearance (right)

The tensile test of the prepared samples was performed on a Shimadzu unive hydraulic tensile testing machine (tensile tester) according to the SRPS ISO 6892-1:2 standard. The deformation rate was 1.5 mm/min. The test was performed both normalized and tempered samples, with three samples for each material condition. The results are shown in Tab. 6 and the stress-strain curves in Figs. 4 to 9.

Tab. 6 The tensile tests results

Property	Normalized state			Tempered state		
Sample #	1	2	3	1	2	3
R_m, [MPa]	760	746	755	880	880	880
R_p, [MPa]	360	360	346	700	700	700
A, [%]	18	15.33	16.67	12.5	11.7	12.67
Z, [%]	42	44	51	58	62.5	59.36

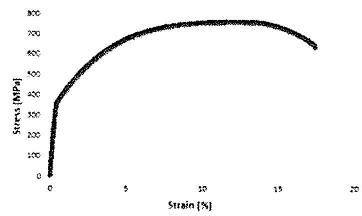

Fig. 4 The (σ-ε) diagram for the normalized state sample # 1

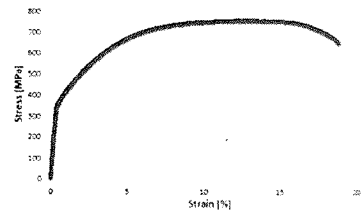

Fig. 5 The (σ-ε) diagram for the normalize state sample # 2

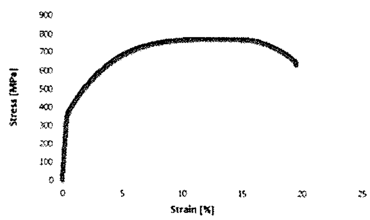

Fig. 6 The (σ-ε) diagram for the normalized state sample # 3

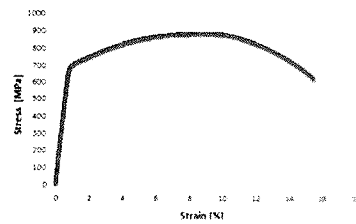

Fig. 7 The (σ-ε) diagram for the tempered state sample # 1

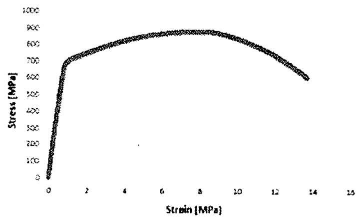

Fig. 8 The (σ-ε) diagram for the tempered state sample # 2

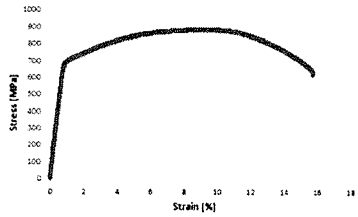

Fig. 9 The (σ-ε) diagram for the tempered state sample # 3

By analyzing the obtained stress-strain diagrams for normalized and improved states' samples, it can be clearly concluded that by applying the previously described heat treatment procedure, the strength of the material in the tempered state is significantly increased with respect to the normalized state. The tensile strength of the tempered samples was 880 MPa, which is 125 MPa (16.55 %) higher than the value of the normalized samples. The yield stress of the tempered samples was higher than that of the normalized samples for about 350 MPa (97.75 %). The increase in strength occurs due to the phase changes and the appearance of an unbalanced bainite structure. The plasticity properties (elongation and contraction) are somewhat reduced for the tempered samples at the expense of increased strength.

3.2. Impact toughness tests

Appropriate samples (six for each state - normalized and tempered) were prepared for the impact toughness testing according to the SRPS EN ISO 148-1 standard. Fig. 10 schematically shows the appearance of the sample for the impact toughness test using the Charpy method, while Fig. 11 shows the real impact toughness test samples before and after the test. The test results are shown in Tab. 7 and Fig. 12.

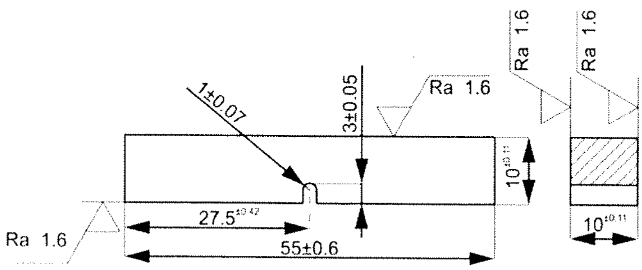

Fig. 10 Schematic representation of samples for impact toughness testing

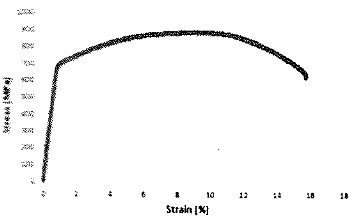

Fig. 9 The (σ-ε) diagram for the tempered state sample # 3

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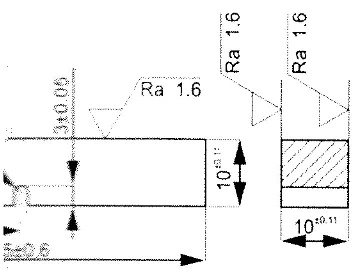

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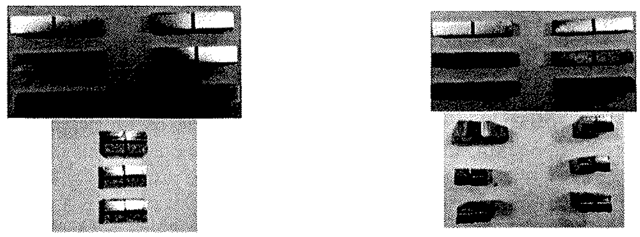

Fig. 11 Samples for impact toughness tests: normalized state (left) and tempered state (right)

Tab. 7 Impact toughness of steel samples

Sample state	Normalized state						Tempered state					
Sample #	1	2	3	4	5	6	1	2	3	4	5	6
KCV [J]	24	26	24	24	16	16	42	38	42	42	44	44

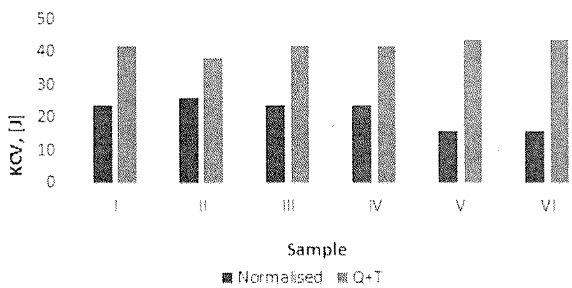

Fig. 12 Graphic presentation of the impact toughness test results

Analyzing the results, one can see that the normalized samples have a relatively l... toughness (16 to 26 J), but that it was significantly increased by application of temperi... (38 to 44 J). The reason for this should be sought in the structure of the material obtain... by tempering (ferrite + bainite).

4. Conclusions

To find an adequate replacement for a material, it is necessary that the new one meets t... appropriate requirements. The conditions that need to be fulfilled are usually related t... most important mechanical properties, while in this case the chemical composition w... very important, as well (due to weldability, heat treatment etc.). In this case, the steel t... needed to be replaced was 25CrMo4, while the steel 42CrMo4 was chosen as t... replacement material.

When a potential replacement steel was chosen, it was necessary to carry out appropri... tests. As part of the test, an analytical assessment of the weldability of 42CrMo4 steel w... performed. Since this is an extremely responsible part, it was necessary to experimenta... verify the analytical-empirical assumptions made that it was the adequate replacement. T...

appropriate metallographic and hardness tests were performed on test-welded samples. The samples were welded using two electrodes manufactured by "SI Jesenice" (Slovenia) with the commercial markings MIG 18/8/6 - for the root welds and MIG 75 - for the filler welds. As it is a responsible part of the artillery tool, it was necessary to improve the quality and output properties of the welded and heat-treated construction to the greatest extent possible. That is why a decision was made to prepare appropriate samples/models of the 42CrMo4 steel and perform test test-weld on them; then to compare the properties of the heat-treated steel with the properties of the steel in the delivered (annealed) state.
The tensile strength of the tempered samples was 880 MPa, which is 125 MPa (16.55 %) higher than the value of the normalized samples. The yield stress of the tempered samples was higher than that of the normalized samples for about 350 MPa (97.75 %). The increase in strength occurs is a result of the phase changes and the appearance of an unbalanced bainite structure. The plasticity properties (elongation and contraction) are somewhat reduced for the tempered samples at the expense of increased strength.
The impact toughness tests' results have shown that the normalized (as delivered) samples had a relatively low toughness (16 to 26 J), which was significantly increased by application of tempering (38 to 44 J). The reason for this should be sought in the structure of the material obtained by tempering (ferrite + bainite).
Finally, it is important to emphasis that the problem of replacing materials needs to be carefully approached, especially if the responsible parts that work in demanding conditions are to be produced. Then, in addition to the mechanical properties, it is very important to consider the influence of consequences of appropriate production procedures on the final output properties of the realized structure.

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