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# Výber adekvátnej výrobnej technológie na produkciu masívných a kritických častí strojov

## *Selecting the adequate manufacturing technology for producing the heavy and critical machine parts*

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**Abstrakt:**

Pri výbere technológie výroby masívneho a/alebo kritického strojného dielu je potrebné zvážiť všetky dôležité parametre, vrátane vlastností materiálu, jeho ceny a dostupnosti na trhu, ako aj vlastných technologických možností a obmedzení postupov. Poznanie všetkých týchto faktorov je veľmi dôležité, pretože majú veľký vplyv na výslednú kvalitu vyrábaných dielov. Strojný diel, uvažovani v tomto výskume, vyrobený z ocele Q+T (kalenie + temperovanie) 42CrMo4 a z liatej ocele G42CrMo4, bol najprv vyrábany liatím, čo bolo považované za adekvátnu technológiu vzhľadom na zložitú geometriu dielu. Nedeštruktívne testy novovyrobeného dielu odhalili veľké množstvo defektov. S cieľom vyhnúť sa týmto chybám bol navrhnutý alternatívny výrobný proces pozostávajúci z kombinácie obrábania a zvárania. Diely vyrobené touto technológiou nevykazovali žiadne chyby, preto bol navrhnutý na sériovú výrobu.

***Abstract:***

*When selecting a production technology of a massive and/or responsible machine part, all the important parameters, including material properties, its price and availability on the market, as well as own technological capabilities and procedure limitations, need to be considered. Knowing all these factors is of a great importance, due to their great influence on the produced parts' final quality. The machine part, considered in this research, made of the Q+T (quenching + tempering) steel 42CrMo4 and cast steel G42CrMo4, first produced by casting, which was considered as adequate technology due to part's complex geometry. The non-destructive tests of the newly manufactured part have revealed a large number of defects. To avoid those defects, the alternative production process was proposed, consisting of combination of machining and welding. The parts produced according to this technology did not exhibit any defects, so it was proposed for the batch production.*

## 1. Introduction

When the constructors are realizing a new project, it is common that, after the part's design is finished, they deliver blueprints, as well as the CAD models of a designed part to the technology department. There, the engineers have to conduct an in-depth analysis of part's geometry, tolerances, loads, required mechanical properties, and other requirements. After that, they ought to be able to propose several methods for the part's production.

The described procedure is also used in the case of designing and producing the so-called responsible, i.e., the critical parts, which are subjected either to intense dynamic and impact load, or variable thermal loads and/or aggressive working environment.

The part, considered in this research, is of the very complex geometry and of large dimensions, Figure 1. It is used as a part of the gun barrel mount. Due to its large dimensions, it was considered that it should be suitable to produce it by casting.

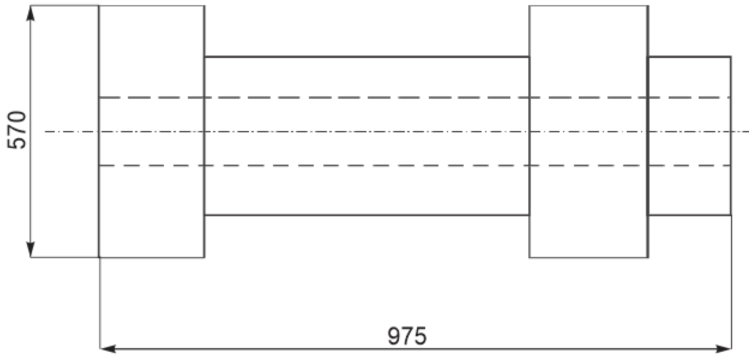

*Fig. 1. Schematic view of the analyzed machine part*

## 2. Material properties

The material selected for casting of the studied part was cast steel G42CrMo4. Chemical composition and mechanical properties of this material are shown in Tables 1 and 2, respectively, [1].

*Tab. 1. Chemical composition of G42CrMo4, wt%*

| Chemical composition | C | Si | Mn | Cr | Mo | P | S |
|---|---|---|---|---|---|---|---|
| Standard | 0.38-0.45 | max. 0.40 | 0.60-0.90 | 0.90-1.20 | 0.15-0.30 | 0.025 | 0.035 |

*Tab. 2. Mechanical properties of steel G42CrMo4 (normalized)*

| Mechanical properties | $R_{eH}$, MPa | $R_m$, MPa | A, % | Z, % | KV | HB |
|---|---|---|---|---|---|---|
| Standard | 350-700 | 650-1000 | 10-12% | 60 | 16-31 | 150-200 |

The mechanical properties of the selected material had to be confirmed through the tensile and impact toughness tests. Test specimens were machined to adequate dimensions from the prepared casted material. The requirement for the yield strength $R_{eH}$ was set, according to constructor's calculations, at a minimum permissible value of 230 MPa. The tensile test specimens and their geometry are shown in Figure 2

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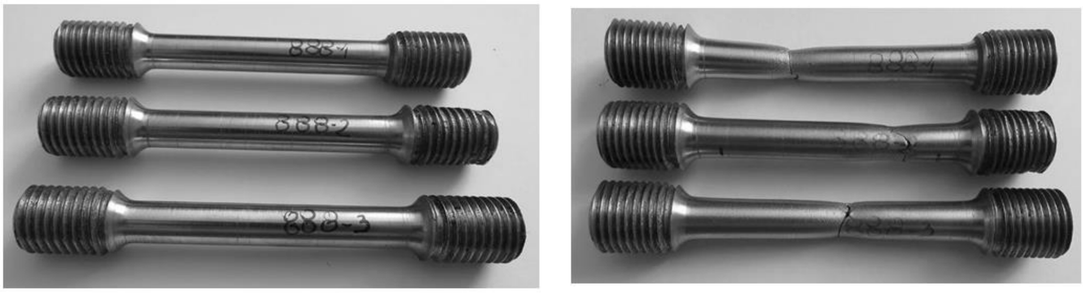

a) b)

*Fig. 2 Tensile test specimens before (a) and after the tensile test (b)*

The tensile tests were conducted on ZWICK/ROELL Z100 testing machine, shown in Figure 3, The maximum load capacity of the machine was 100 kN (10 t). The test results are shown in Table 3.

*Tab. 3. Results obtained during tensile test [1]*

| Specimen number | $R_{eH}$, MPa | $R_m$, MPa | A, % | Z, % |
|---|---|---|---|---|
| 1 | 324 | 566 | 27 | 47 |
| 2 | 320 | 559 | 24 | 38 |
| 3 | 329 | 567 | 25 | 45 |

As can be seen from Table, 3 the set minimum requirement for the yield strength was met for all the three specimens. That also implies that additional heat treatment of the selected material was not necessary.

The impact toughness tests were conducted according to the Charpy method [2], using the V-notch specimens, shown in Figure 4. Tests were conducted at 20 °C and – 20 °C. Specimens for Charpy test bellow 0 °C were cooled in a mixture of dry ice and alcohol. The test results are presented in Table 4.

*Fig. 3 Display of testing machine ZWICK/ROELL Z100*

a) b)

*Fig. 4 Charpy impact test specimens before (a) and after (b) test*

*Tab. 4. Results of Charpy impact test*

| Specimen number | KV20, J | KV-20, J |
|---|---|---|
| 1 | 41 | 18 |
| 2 | 38 | 25 |
| 3 | 40 | 22 |

## 3. Sand casting

Due to the part’s large dimensions, it was considered that the sand-casting would be the adequate manufacturing technology. After verification of the selected material mechanical properties, the sand mold for pouring in the molten metal was constructed, the schematic view of which is shown in Figure 5. The additional grooves, which can be noticed on the mold, are required for positioning the specially prepared core, so the inner holes can be properly casted [1, 3].

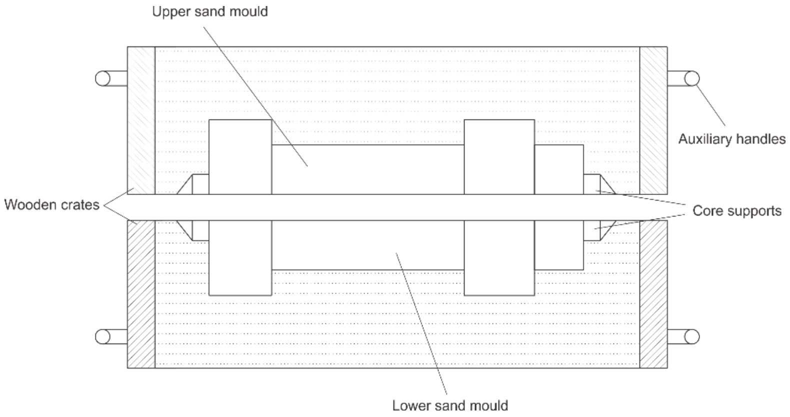

*Fig. 5 Schematic view of upper and lower sand molds*

After the first batch of cast-parts was produced, the non-destructive tests were performed to check their quality. The tests were performed by visual inspection and by the penetrant liquid method. Both types of tests were executed by the certified laboratory personnel. The performed control tests have revealed a multitude of severe and unrepairable defects on the produced parts. The defects could be classified as porosity and surface cracks. The main cause for appearance of porosity actually were the part’s large dimensions, which implied that the volume of the sand mold had to be large, as well. Large dimensions of the prepared sand mold had led to more intensive heat conduction from the poured liquid metal. Therefore, the less time has remained for the dissolved gasses to escape from the casted material [1-4]. On the other hand, the reason for crack appearance was related to the heat conduction, as well. The difference appeared between the cooling rates of the molten metal on the surface of the cast part and the core of the part, thus, which meant that the values of residual tensile stress could potentially exceeds material strength, resulting in cracks' appearance. Some of the observed defects can be seen in Figure 6.

Only a few produced castings could have been repaired, so that they could have been installed in the final product. Much larger number of castings were classified as inadequate and/or irreparable, and were sent to scrap.

As a conclusion, the selected production technology – casting, turned out to be inadequate and needed to be replaced by the more adequate one.

a) b)

*Fig. 6 Display of some detected flaws: worm-like porosity (a), cracks (b).*

## 4. Machining plus welding

The newly proposed technology consisted of machining and welding. Since the part in question had large dimensions, one possibility was to make it from three separate parts, which would afterwords be joined together to form a whole. The original part was divided into three smaller sections, two prismatic and one cylindrical. The parts were machined individually by conventional milling and turning operations. After the producing of those three parts was done, they were joined by the welding procedure (MIG/MAG). The parts were manufactured from the same material as the cast piece, the 42CrMo4 steel, the chemical composition and mechanical properties of which were presented earlier (Tables 1 and 2, respectively).

Since the mechanical properties of the selected material were satisfying the construction requirements, the next step was to check how the welding process could be conducted. The first step was to check the materials weldability. The calculated carbon equivalent of this material has the value of 0.815 %, which is bigger than the limiting value for this material, which amounts to 0.5 % [5]. That implies that the special measures were necessary for the successful execution of the welding process, which include the pre-heating, as well as the post weld heat-treatment [3, 6]. The calculated preheating temperature had to be above 200 °C (the temperature of 205 °C was applied), [7, 8]. This technology was proposed according to earlier experience of the authors. The applied technology assumes that the root welds have to be executed using the austenitic filler material, while for the filler welds, the wire of higher strength has to be applied. According to the set criterion, the filler materials of SIJ Elektrode Jesenice were selected. Tables 5, 6 and 7 present the chemical composition, mechanical properties of the filler materials [9] and the applied welding parameters [10], respectively.

*Tab. 5. Chemical composition of filler materials, wt %*

| Filler metal mark by producer | Filler metal mark by ISO EN | 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. 6. Mechanical properties of filler materials*

| Filler metal mark by producer | Filler metal mark by ISO EN | $R_{p0.2}$, % | $R_m$, % | A, % | KV, J |
|---|---|---|---|---|---|
| MIG 18/8/6 | G 18 8 Mn | > 380 | 560-660 | 35 | (T=20°C) 40 |
| MIG 75 | Mn3Ni1CrMo | > 690 | 770-940 | > 17 | (T=-40°C) 47 |

*Tab. 7. Welding parameters*

| Filler metal mark by producer | Filler metal mark by ISO EN | I, A | U, V | $v_z$, cm/s | $q_l$, J | $t_{8/5}$, s |
|---|---|---|---|---|---|---|
| MIG 18/8/6 | G 18 8 Mn | 180 | 21 | 0.20 | 16065 | 18 |
| MIG 75 | Mn3Ni1CrMo | 240 | 25 | 0.35 | 14571 | 15 |

For the given parameters the cooling time between 800 and 500 °C was calculated both for the root weld and filler welds. For the calculations Ito and Bessyo formula was used, as it was proven that their formula gives precise results for massive parts [7]. Obtained time was inserted in the CCT (Continuous Cooling Transformation) diagram for the 42CrMo4 steel [4], with inserted cooling rates, Figure 7. Based on $t_{8/5}$, the expected microstructure of HAZ was a combination of ferrite and pearlite microstructures. Expectations were later confirmed by metallographic investigation [4].

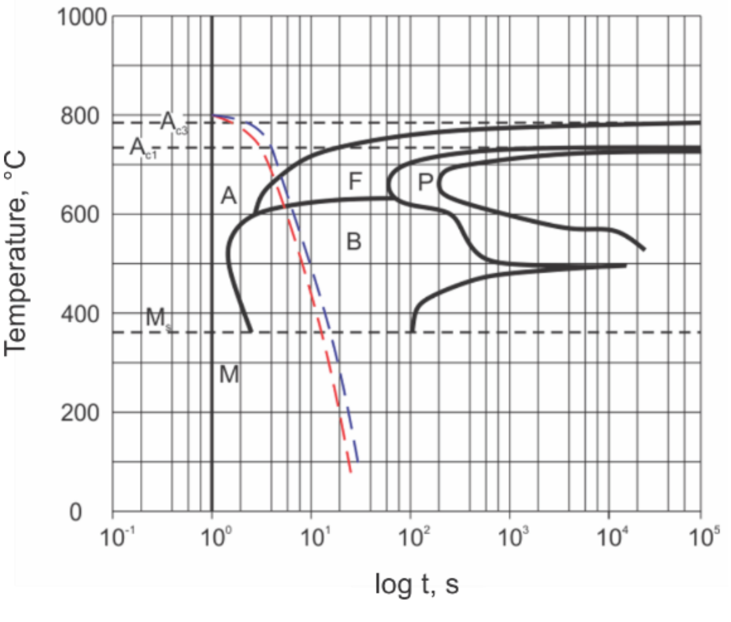

*Fig. 7 The CCT diagram for 42CrMo4 steel*

After the parts machining and assessment of adequate welding technology, the assembly was prepared for welding. The schematic view of the assembly for welding, and the welding scheme are given in Figs. 8 and 9, respectively, [4]. To achieve the good properties of a final product, the pre-heating, as well as the post welding heat-treatment were needed. Welding was followed by normalization annealing (at 800 °C). After the annealing, quenching (from 800 °C cooling in the oil) and tempering at (600 °C) were conducted.

After the welding of the first parts was finished, and the heat treatment was successful, the parts were subjected to non-destructive tests, same as for the casted parts. No major flaws were observed.

Fig. 10 displays an example of a good weld. The welded part was also tested in the operating conditions and it exhibited very good performance under the intense impact load.

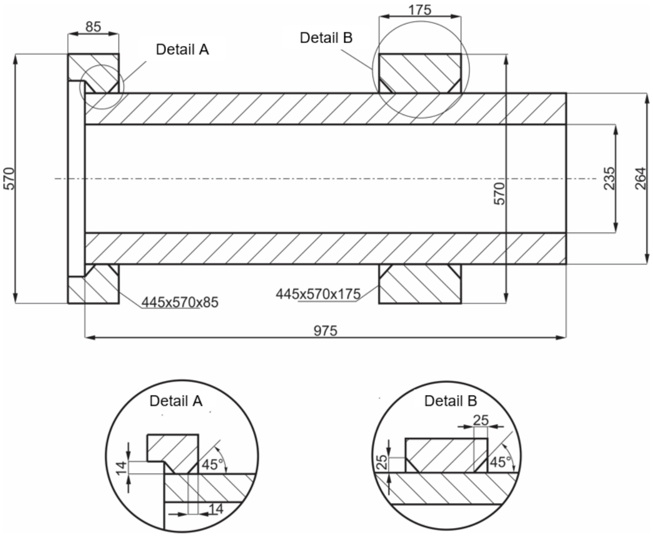

*Fig. 8 Scheme of assembly prepared for welding*

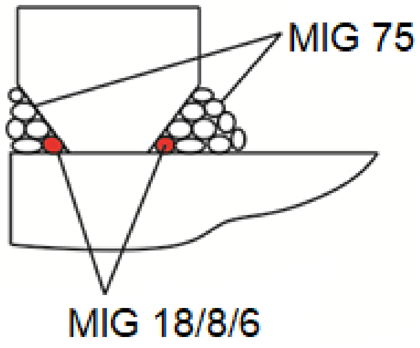

*Fig. 9 Scheme of welding layer deposition*

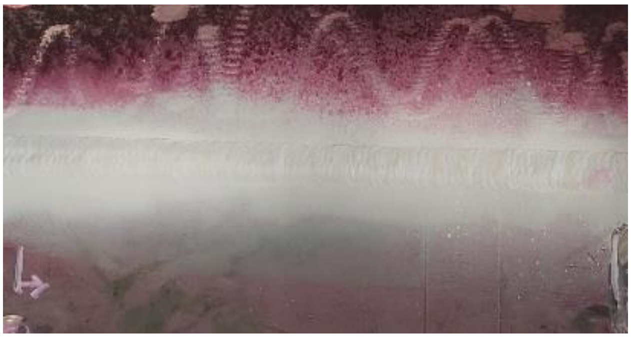

*Fig. 10 An example of a good welded bead on the produced part*

## 5. Conclusions

When selecting the adequate production technology, many factors need to be taken into consideration, available materials on market, own technological capabilities and etc. When the production technology for responsible parts is to be prescribed, much more attention needs to be paid to each detail of all the operations.

Selection of the adequate production technology of a massive and responsible machine part, subjected to dynamic impact load, is presented in this paper. Due to complex geometry and large dimensions of the analyzed part, the primary selected production technology was sand casting. However, since after the first batch production numerous defects were noticed on the finished parts, it was decided to apply the alternative technology, which consisted of splitting the part to two prismatic and one cylindrical part, which were joined together by welding.

The welding procedure, filler materials and additional pre and post heat treatments were defined for joining of the three machined parts. The same type of tests as for the sand casted parts were applied after the production. No major defects were noticed and the parts were sent to batch production. The proper functioning of thus manufactured parts was verified in the operating conditions.

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