TRENDS IN MECHANICAL PROPERTIES ENHANCING OF STEELS USED FOR GUN BARRELS PRODUCTION

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Abstract

The paper is focused on recent trends in mechanical properties enhancing of the steels used for sport or army guns barrels. Special conditions are required for these steels including high tensile strength R_m, surface hardness HV (HRC) as well as yield point $R_{p0.2}$ or impact value KV (KU). The strength could be improved by choosing some of new progressive materials as are Maraging, TRIP, TWIP or TMT steels. Some of these materials, their chemical composition, properties and strengthening methods are mentioned in the paper. Next part is focused on short description of howitzer or cannon barrel production and its heat treatment. Besides that, effect of electro slug remelting process (ESR) used as a method for barrels quality improving including experimental comparison of ESR treated and non-treated semiproducts is described in the paper.

Keywords: high strength steels, tensile strength, yield point, hardness, Maraging steels, Trip and Twip steels, Electro slug remelting, gun barrels production

1 Introduction

The armament production and progress in this field is one of most fastest developing industry. New materials and methods for their production and treating are developing, including abrasion resistance and reliability increasing with using of surface treatment as are chromizing, nitriding or PVD and CVD coatings.

This science and technology progress brings new requirements on materials used for barrel production. Materials with tensile strength Rm = 1000÷1150 MPa were used for gun barrel production during world war two, but nowadays, current tensile strength (Rm) for tank barrel is about 1400 MPa and for howitzer barrel is it 1600÷2000 MPa. Also the values of yield point and impact energy are increased [1].

Common steel do not meet these demanding high criteria, therefore advanced high strength steels (AHSS) as are Maraging, TMT (thermo-mechanically treated), TRIP or TWIP steels must be used. Properties and strengthening effect of these steel are described in following subchapters.

2 AHSS Steels with ultra-high strength values

2.1 Thermo-mechanically treated steels

Thermo-mechanically treated (TMT) steel achieves its high strength by application of the controlled combination of phase transformation (austenite to martensite) and plastic deformation caused by rolling or forging (see fig. 1).

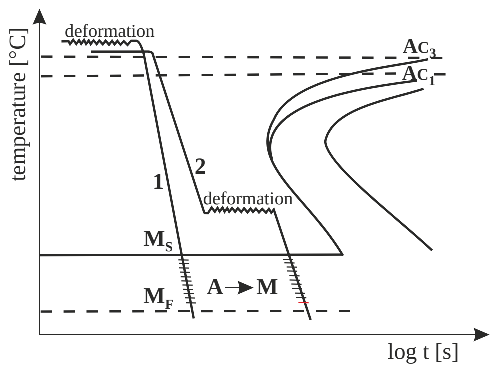

Fig.1 *Scheme of thermo-mechanical treatment*

1 – high temperature TMT, 2 – low temperature TMT [2]

TMT processes are best classified according to the order in which plastic deformation and phase transformation are carried out. The plastic deformation is mostly applicated before the transformation, but its application during (isoforming) or after the transformation (thermo-mechanical tempering) is also possible. There are exist two TMT processes with deformation before the transformation, which are most used in praxis.

High temperature thermo-mechanicall treatment (HTMT) occurs if the deformation is carried out at high temperature above A_{c3} line in the area of stabile austenite (see line 1 in fig.1). The ratio of deformation is in range 40÷90%. The quenching process starts immediately after TMT. The steel reaches the strength values about 2500 MPa after application of this process.

Low temperature thermo-mechanicall treatment (LTMT) occurs if the deformation is carried out after rapid cooling to the temperatures range 500÷600°C (see line 2 in fig.1)., what is the area of metastabile austenite. The ratio of deformation is about 50%. The steel reaches the strength values up to 3000 MPa after application of this process.

Steels suitable for TMT process are typically low or middle allyoed (mainly by Cr, Mo, V, Ni) with carbon content 0.4÷0.6 wt. %.

2.2 Maraging steels

Maraging are one of most strength steels. The steels are high alloyed with nickel (12÷25 wt. %) and with very low content of carbon (about 0.03 wt. %). Besides Ni and C, combination of Mo-Co-Ti or Ti-Al-Nb is required to achieve ultimate stregth. Contrary to the standard steels, Maraging steels must have very high chemical purity (Mn, Si<0.1 wt. %; P,S<0.01 wt. %).

Maraging is the combination of the words “Martensite” and “Aging” what describe the effect of strengthening in these steels. Final strength of Maraging steels is reached by hardening of martensite matrix by precipitation of Mo-Co-Ti or Ti-Al-Nb alloying elements and its values are about 2000÷2700 MPa. Final microstricture of Maraging steel is shown on fig. 2.

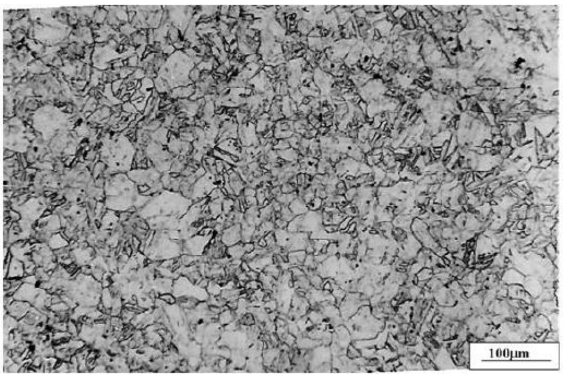

Fig.2 *Microstructure of Maraging steel [3]*

Basic mechanical properties of selected maraging steels are shown in Table 1. Several Maraging steels are known under commercial names as are 18Ni250grade, Vascomax 250, Nimar 110, Alnar 18-250, Marvac250, Republic RSM-250, Murphy 1 and others.

Table 1 *Mechanical properties of selected Maraging steels [4, 5]*

Steel	Tensile strength R_m [MPa]	Yield point $R_{p0,2}$ [MPa]	Elongation A [%]	Hardness HRC	Producer
18Ni400	2720	2680	5	62	USA
18Ni350	2500	2470	8	59	USA
3NiCoMoTi19-10-5	2150	2000	4	55	ČR
18Ni300	1990	1960	10	54	USA
N18KBM5T	1760	1730	12	50	RU
N18K8M3T	1460	1450	15	45	RU

Maraging steels are quenched from temperatures about 800÷900°C after austenitization period of 30 minutes. These conditions cause the dissolution of alloyed element particles in austenite and also the relaxation of potential stresses. Quenching is carried out on air or in the water. The cooling velocity is not important because of high content of the Nickel. The Carbon-free nickel martensite is created after quenching which have high plasticity, relatively low hardness (30÷35 HRC) and strength up to 1000 MPa. Next step is the ageing usually at temperatures in range 450÷550 °C for a period of 3 hours.

Advanced high strength steels (AHSS) of Maraging type (W1.2709 – DIN X3NiCoMo18-9-5) are very suitable for machine guns and automatic rifles productions. These materials should be treated by hard chromizing to improve abrasive resistance what is used for BVP-2 gun barrel surface treatment.

2.3 TRIP and TWIP steels

TRIP and TWIP steels are ultra-high strength steels characterized mainly by their excellent plastic properties. The difference between both groups is in the mechanism which caused the high plastic properties.

TRIP steels (Transformation inducted plasticity) are metastable steels with austenitic structure stabilized by Ni, Mo and N content. The steels are hardened by plastic deformation in area of metastable austenite to allow precipitates creation and consequently the hardening effect. Martensitic transformation is caused by the applied deformation only and not by thermal changes (cooling) as usual. Chemical composition of TRIP steel is designed according to this condition whereby the M_s temperature is shifted below zero to the negative temperatures.

Treatment of TRIP steel (see fig. 3) consist of dissolve annealing at temperature about 1150°C and then the deformation in area of metastable austenite at temperature 450°C and ratio of deformation 80%. Final tensile strength is about 2000 MPA, elongation is 25÷30% and thougness is 40 J.cm^{-2}. Schceme of typical microstructure of Maraging steel is shown on fig. 4.

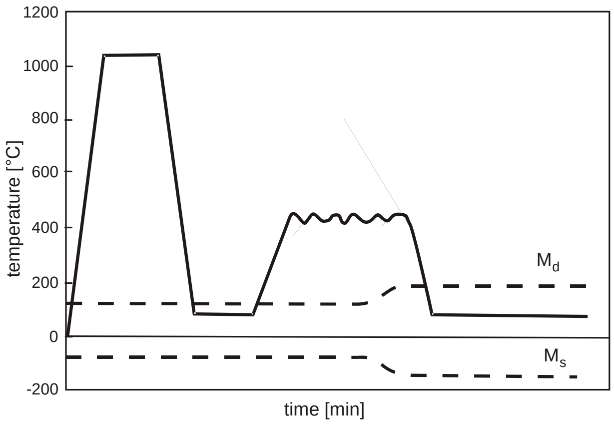

Fig.3 *Treating of TRIP steel [4]*

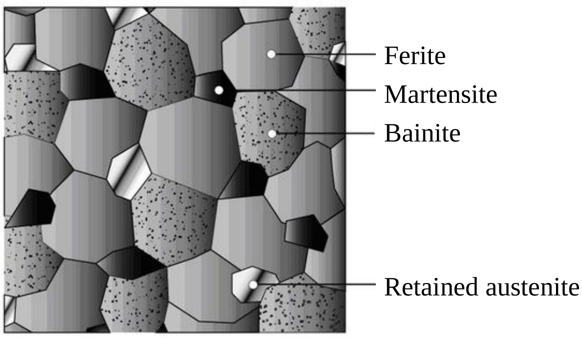

Fig.4 *Typical microstructure of TRIP steel [6]*

Treatment of TRIP steel (see fig. 3) consist of dissolve annealing at temperature about 1150°C and then the deformation in area of metastable austenite at temperature 450°C and ratio of deformation 80%. Final tensile strength is about 2000 MPA, elongation is 25÷30% and thougness is 40 J.cm^{-2}.

TWIP (Twinning induced plasticity) steels have even better plastic properties than TRIP but with relative lower strength. Elongation of these steels may reach up to 125%, yield point up to 1400 MPa and tensile strength up to 1500 MPa. TWIP steels are high alloyed by Mn (17÷30%) and Cr (up to 20%). Their hardening come from stabile austenite microstructure and dominant twin induced deformation mechanism in the austenitic grains. Contrary to the TRIP steels, austenite in TWIP steels is not deformed but its crystal lattice orientation is changed by twins creation.

Both TRIP and TWIP steels are relatively new and progressive materials and the research of their possible applications or properties improvements still continue.

3 Production of gun barrel and improving its quality by ESR

As is stated above, ultra high strength steels of Maraging type are suitable to produce barrels for automatic and machine guns where the barrels are surface treated by nitriding or hard chromizing. Barrels with smaller diameters for pistols, air rifles or rook rifles are hardened by swaging of surface and hole at the same time with using of GFM: SHK6–SHK10 device and the process is fully controlled by computer.

There is the list of recently used materials in Slovak Republic for some types of gun barrels in the table 1 where the tensile strength is mentioned too.

Table 2 *Materials recently used for gun production in Slovak republic [1]*

Type of gun barrel	**Used material**
Air rifle	Free-cutting steel STN 11107 a STN 11109
Rook rifle	STN 11500.8 or 15230.7
Pistol	STN 13242.9 ; 15230.9 ; 16341.9 ; OCHN2MFA, SAE-4145-HS (STN 16440.9) , with tensile strength $R_m = 900 \div 1140$ MPa
Machine or automatic rifle	32CHN 2 MFA with tensile strength $R_m = 1150 \div 1250$ MPa
Howitzer	OCHN 3 MFA 0-80 , OCHN 3 MFA 0-100, (STN 16440, 16445) with tensile strength $R_m = 1350 \div 1600$ MPa

Production difficultness of the barrel drilling led to the application of special equipment as are single-purpose deep drilling machines, reaming machines, machines for cartridge chamber drilling, honing machines and special purpose machines for screw groove breaching to make uniform or progressive twist of rifling [7].

3.1 Production process and heat treatment of large-sized gun barrels

The production process of large-sized gun barrel used for howitzers or cannons starts with casting of an ingot of required chemical composition in the vacuum or arc furnace. The ingot is then forged to needed dimensions by machined smith forging where automatic manipulator is used to move and turning it. Directly after forging, the electro-slug remelting process (ESR) of the ingot is carried out to improve its mechanical and plastic properties. ESR causes homogenization of chemical composition in ingot volume what brings positive changes in microstructure and consequently improving of the properties of ingot. The experiment describing the improving effect of ESR is presented in next chapters [8].

After ESR is the ingot forged again but with using of hydraulic press and vehicular manipulator. A final dimension of gun barrel semiproduct is calculated by STN 129011 standard with appropriate additions required by some step of production process. The gauge samples are taken in all these production steps to control whole process including heat treatment [2].

Quenching and tempering of the semiproduct are very important steps to achieve final needed mechanical properties. Interrupted quenching is used in large-sized barrels production as follows:

After heating up to austenitization temperature given by CCT diagram of used steel, the semiproduct is moved by crane above the water tank and it is quickly dipped to the water with temperature 35°C (but not by free fall) and then moved vertically up and down to remove the bubbles. One third of semiproduct is moved out of the water after 15 minutes and then in defined time lapses, second and consequently third part is moved out of water. Then, the semiproduct is moved above the oil tank and it is dipped to the oil with temperature 40÷60°C to finish whole interrupted quenching process. Next step is the cleaning of the semiproduct in flushing tank to remove the oil. Last step of semiproduct heat treatment is tempering in deep electric furnace at temperature in range 400÷ 440°C.

3.2 Possitive effect of the ESR evaluation

The experiment is focused on comparison of mechanical properties between ingots processed by ESR and ingots made without ESR. Basic material of ingots is structural nickel-chrome-molybdenum steel 36CrNiMo4 which chemical composition and basic mechanical properties are shown in table 3.

Table 3 *Chemical composition and basic mechanical properties of 36CrNiMo4 steel*

C	Ni	Cr	Mo	Si	Mn	P_{max}	S_{max}	Cu_{max}
0,35	3,00	1,00	0,25	0,30	0,40	0,025	0,025	0,30
Minim. Yield point			Minim. Impact value			Minim. contraction		
873 MPa			34 $J.cm^{-2}$			25 %		

For these parts used in large sized gun barrels a suitable strength-plasticity features ratio is required so that these products absorb combine stress, which is generated in form of pressure, heat, collision, shear and flexion [8, 9].

The mechanical properties of forged pieces were analyzed after their heat treatment, where mainly contraction often did not achieve the specified values. In table 4 there are shown particular data measured out on forged pieces from manufacturing production, from which it can be seen, that three from eight analyzed semi-products did not achieve the specified parameters for contraction.

Table 4 *Mechanical properties of selected ingots made without ESR*

Forged piece Ser.	**Yield Point [MPa]**	**Contraction [%]**	**Impact value [J.cm^{-2}]**
4742	958	26,4	48
4743	974	30,9	52
4744	959	29,7	51
4745	964	24,6	54
5748	982	21,3	40
5749	915	30,5	48
5751	945	22,1	42
5752	1001	27,8	42

A part of forged pieces manufactured with an increased amount of desoxydation agent was recast under slag composed of 70 % CaF_2 + 30 % Al_2O_3, in a crystallizer with dimensions 510 x 510 mm. Recast forged pieces achieved significantly much higher values, as it is shown in table 5.

There are shown the level of properties improvement after ESR on fig 5. The yield point was increased about 13%, Impact value about 18% and Contraction even about 48,4% on ESR treated ingots in comparison with ingot without this treatment. Mean values of the properties of both ingot groups calculated from table 1 and table 2 were compared in graph on fig. 5.

Table 5 *Mechanical properties of selected ingots processed with ESR*

Forged piece Ser.	**Yield Point [MPa]**	**Contraction [%]**	**Impact value [J.cm^{-2}]**
6395	1182	42,6	61
6396	1165	43,2	62
6397	1025	36,3	48
6398	1084	34,7	45
7482	1087	44,3	67
7483	1092	44,7	68
7484	1032	34,6	47
7485	1029	36,2	48

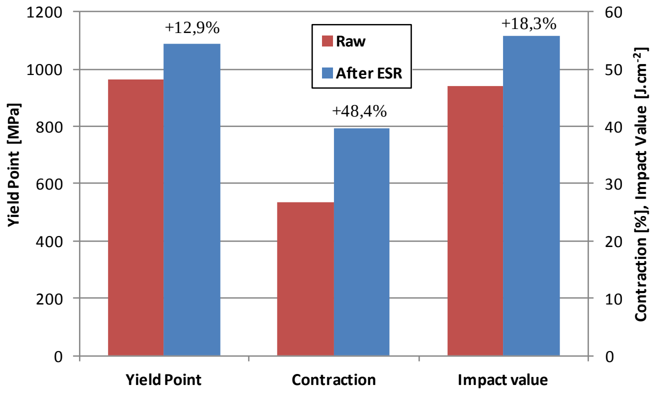

Fig.5 *Improvement of mechanical properties by ESR*

After recasting the forged pieces have almost globulitic inclusions, no separately excluded manganese sulphides were found at all neither clumps nor were lines of oxides noticed in precast forged pieces. The content of sulphur in steel was ranging up to 0,011 %.

4 Conclusion

There are several possibilities how to improve the quality by enhancing the mechanical properties of steel used for extra-sized gun barrels production. One of possible ways is to use on of new progressive materials as are Maraging steels, TMT steels, TRIP or TWIP steels. Basic properties and strengthening mechanism of these steels is described in the paper.

Another possible way is to improve the values of mechanical properties by some of metallurgical process as is electro slug remelting. Described experiment proves the increase of contraction mainly but yield point and impact value to in remelted ingots.

Application of materials and methods stated above brings important and noticeable increasing of reliability, durability and usage effectiveness in extra-sized gun barrels productions.

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