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HIGH SPIN ROCKET MOTOR STRUCTURAL DESIGN CONSIDERATION

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Abstract: *Design of modern high spin solid propellant rocket motors is based on application of materials with high mechanical strength, structural design with low ratio of passive weight of the rocket motor and propellant grain weight and production technologies which ensure appropriate product quality with resonable costs. This paper comprises a review of materials for rocket motor structure and their physical and mechanical properties, which are interesting for, design engineers, trend of structural design and review of modern technology proceedings of rocket motor cases production. A part of research results prepared by the authors has been presented and comparison with published results of other authors has been also performed.*
Key words: *solid rocket motor, design, high spin, flow forming.*

1. INTRODUCTION

Generally, structure of high spin solid propellant rocket motor consists of motor case, bottom, nozzle and grate. Depending on solid propellant grain form, internal surface of motor case can be exposed to combustion gases with very high temperature between 2000 and 3000 K. In this case a protection thermal layer on the internal surface of motor case is used, so the strength analysis being based on assumption of isothermal conditions at a considering region. Nozzle is exposed to influence of high temperature gas flow so thermal analysis must be used when it is designed.

Design of the solid propellant rocket motor and a whole projectile generally includes selection of appropriate material, all necessary calculations and analyses, workmanship technology selection, preparation of corresponding quality control procedures and methods and obtaining an optimal ratio cost-quality for a developing rocket projectile. Application of modern prediction methods for calculation of dimensions for elements of the rocket motor structure, weight optimization, determination of envelope, safety and reliability etc. are required for successful design of a new rocket motor.

2. MATERIALS USING FOR MOTOR STRUCTURE

Depending on purpose of a new developing rocket, strains appearing in the walls of the rocket motor case during the burning of the propellant grain, propellant type and grain form, but also on design solution of the rocket motor, selection of suitable material is perform. Since the beginning of 1960th design process has been focused on the application of materials with high tensile strength and reduction of passive weight of rocket motor structure. Reduction of the passive weight of solid propellant rocket motors is followed through decreasing of structure weight coefficient, which defines ratio between the passive weight of the motor structure m_s and the propellant weight $m_{p.}$

The structure weight coefficient depends on kind of the used material, applied technology for workmanship of the structure and design solution of the rocket motor. Trend of design of high spin solid propellant rocket motors has been focused on use of quality material for structure elements, as are steels with high tensile strength, titan and aluminium alloys.

Steels as SAE 4130, SAE 4340 and maraging steels are used preferably for production of rocket motor cases, while titan and aluminium alloys are not used for production of this type of rocket motors because of high costs and/or limited envelope of rocket motors.

Properly selection and application of appropriate material is exceptionally important for successful design of nozzles. Conditions within the nozzle as high temperature and flow velocity of the combustion gases and their erosion influence (chemical and dynamic) during their flow through the nozzle lead to very strict and complex requirements for selection of material. Extremely loaded part of the nozzle by heat is a zone close to the nozzle throat. Materials using for this part of the nozzle are pyrolithic graphite characterized by anisotropy of heat conduction (which provide control of heat conduction by crystal orientation and crystal grain dimension) or tungsten or molybdenum (both of them are heavy metals, which are expensive and sensitive to cracks appearance). The last mentioned materials are not used for structure of high spin rocket motors due to expensive and complex insert assembling into the block of nozzles (consisted of several nozzles within unified block part).

As a thermal insulator for prevention an intensive heat transfer to the rocket motor bottom and through it to the projectile warhead, ablative plastic material (rephrasil, phenol asbestos, impregnated phenol fabric, graphite) which have a very low thermal conductivity, but they are characterized by pyrolysis and high rate of erosion. Insulation covers made of ceramic are also used for thermal protection of rocket motor structure.

3. TECHNOLOGIES FOR CASES WORKMANSHIP

Selection of technology for solid propellant rocket motor case is determined by rocket mission, design solution, available materials and technological and economic capacities of a producer. It is important to know how the production process affects on mechanical properties of the used material and operability of the rocket motor. For more complex rocket systems it is necessary to work out in detail a special program which must take into consideration mechanical properties of raw material, influence of production proceedings on mechanical characteristics, corrosion resistance of material while the rocket motor being hydro–pressure tested. A particular issue is selection and application of methods for mechanical properties testing (including non-destruction and destruction tests) for the chosen production technology. Rocket motor cases of the modern high spin solid propellant rocket motors are usually manufactured by machining of tubes, by hot extrusion of hollow forms, by flow forming and by flow forming under conditions of austenitic hot hardening. During the period from 1960 until 1980, for production of solid propellant rocket motor cases, basic production technology was machining of tubes, and in the beginning of 1980 application of flow forming technology has started. Production technology of hot forging is applied for rocket motor cases with low slenderness.

Rocket motor case workmanship ***by machining of tube*** is a production technology which is used long time and this technology is currently used in countries with low degree of technological development and for less complex projectiles.

Proceeding of ***hot extrusion of hollow forms*** is based on plastic deformation at hot conditions with high rate of deformation. Geometric form determines structure integrity and surface finish quality during the extrusion.

At proceeding of ***flow forming*** there are two methods, forward flow forming where the case material flows in the direction in which the rollers are moving and reverse flow forming where the material flows at opposite direction of the moving direction of the rollers. As a result of this method of cold deformation, the crystal structure of the material is being changed (Fig. 1).

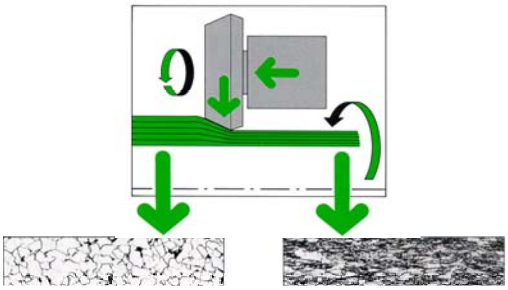

Fig. 1 Crystal grain structure before and after flow forming

Besides the change of grain structure, the tensile strength increases (total degree of deformation can be even more than 90%). Research performed at Vareinigte Edelstahlwerke Aktiengesellschaft, Voest-Alpine Gruppe which was aimed to establishing the variation of tensile strength as a function of degree of cold deformation for several types of steels, shows that the relative rise of tensile strength is more considerable for steels with lower initial tensile strength than others with higher initial tensile strength. This proceeding provides a workmanship of complex axis symmetrical parts. According to, proceeding of flow forming can increase the tensile strength up to 25% for soft steels, up to 15% for "maraging" steels and up to 10% for aluminium alloys.

Flow forming under conditions of austenitic hardening uses company Metal Spezial Rohr GmbH and this proceeding ensure a considerable increase of tensile strength and keeps elasticity of the material. In this way increase of hardness up to 60 HRc, tensile strength up to 2.800 MPa, yield strength up to 2.300 MPa and vibration durable strength, and rupture elongation of 5% are achieved, but plasticity and elasticity are not increased. Compared with the standard proceeding of hot treatment improvement, tensile strength is larger in 600 MPa, yield strength is at little bit lower level and elongation values are same.

4. EXPERIMENTAL RESEARCH

Research on influence of deformation level and initial mechanical characteristics on final mechanical properties at flow forming proceeding for two types of steels were performing.

Degree of deformation of the workpiece was 55% for the first case and in the other case degree of deformation was 66,5%. Tests of influence of initial mechanical characteristics on the final mechanical performances of motor case, for both types of steels, using flow forming preceeding, were performing. Results of the research are shown in Fig. 2 and 3.

To be determined the erosion rate at the nozzle throat zone the steels W. No 1.0501, W. No 1.0601 and W. No 1.7707 have been tested. Results have shown that the mechanical erosion of the material at the nozzle were intensified after 45% of the total burning time and the throat diameter was increased in 22-25%.

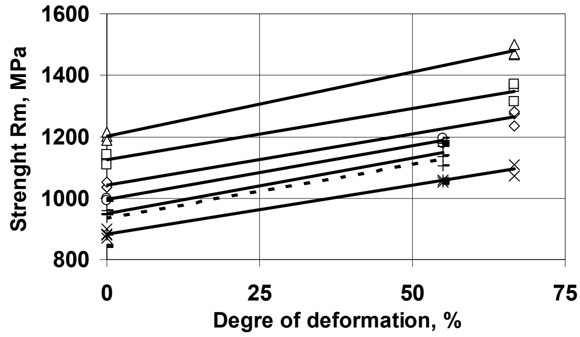

Fig. 2 Tensile strength versus degree of deformation for steels SAE 4130 and W. No 1.1157 (punctual line)

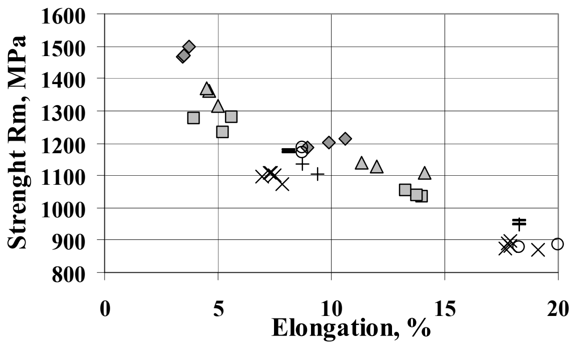

Fig. 3 Tensile strength versus elongation for steels SAE 4130 (full points) and W. No 1.1157

5. CONCLUSION

Tensile strength variation follows change of degree of deformation approximately in accordance with a linear function and those results correspond with results published by other authors. Elongation variation is in accordance with tensile strength variation for a given degree of deformation.

Application of flow forming technology and materials with improved mechanical properties and new solid propellant grain design can create conditions that a new rocket motor design obtains a lower passive weight of the rocket, greater rocket velocity and extended range up to 50 % [Zecevic, 1996, 1999].

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