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Analysis of Resistance of Clad Composite of Structural Steel and Tombac to Stress at Elevated Temperature

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Abstract : Technological operations, where the temperature gradient significantly affects the thermal expansion of the material, require care in the choice of thermal stress with respect to the material used. A high temperature gradient can result in an increase in thermal stresses, which can result in plastic deformation of the material or even its failure. Clad materials are generally very sensitive to thermal stress. Especially if it is a composite material composed of layers with very different coefficients of thermal conductivity and thermal expansion, in our case structural steel and tombac. The aim of this study is to use the finite element method to simulate the maximum allowable thermal stress of a rolled clad composite composed of layers of tombac (CuZn90/10) and a core of structural steel S235JR + N, when there is no plastic deformation.

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1 Introduction

The subject of the research project was the development of an innovative GMCS (Gilding Metal Clad Steel) production technology, which is described in this introductory chapter. GMCS production technology is a partial part of the complex technology of production of sheets and strips from Cu and CuZn alloys. The design of GMCS production technology is based on the conclusions of tests and development activities and contains basic procedures that must be subsequently modified and fine-tuned within the production process. The aim was to develop and verify a production technology in which brass plates (Ms90, CuZn10) and a steel core are joined. The resulting sheet should have a thickness of 1 mm after cold rolling.

The preparation of GMCS cartridges (packets) includes all activities leading to the production (cold) of the output product or. GMCS, which is the input material for the subsequent hot rolling technology on the DUO reverse rolling mill. The GMCS cartridge is a package of three layers of sheets wrapped and enclosed in a protective steel package.

The individual layers are stored in a protective packaging as follows:

• Bottom layer - sheet CuZn90/10 (Tombac).

• Middle layer - Steel block.

• Top layer - sheet metal CuZn90/10 (Tombac).

GMCS preparation includes the following basic activities:

a) one-sided surface grinding of CuZn90/10 sheets on a grinding machine,

b) blasting of steel blocks on a blasting machine,

c) cutting and pre-bending of the protective steel casing on sheet metal shears and a manual sheet metal bender,

d) application of separating coating,

e) storage of individual layers in a protective package, including its packaging and sealing on a packaging machine.

The protective cover of the GMCS cartridge is used to:

• As protection of CuZn90/10 sheets (tombac) when heated in a heating furnace (step furnace) to a temperature of 930-960°C (melting temperature CuZn90/10 is 1025-1045°C)

• As a connecting element, preventing the individual layers from shifting before the connection of the steel block to the tombac sheets after the first removal during hot rolling on the DUO rolling mill. The following image is an illustrative photograph of a rolled GMCS sheet.

1.1 Protective cover

The protective cover of the GMCS cartridge serves:

• As protection of CuZn90 / 10 sheets (tombac) when heated in a heating furnace (step furnace) to a temperature of 930-960°C.

• As a connecting element, preventing the individual layers from shifting before the connection of the steel block to the tombac plates after the first resp. the second removal during hot rolling on a DUO rolling mill.

Requirements for chemical composition, mechanical properties resp. other requirements for see above cladding materials (Chapter 2.1, indent 1) and 2)), are defined in DEF STAN 95-11 / Issue.

Figure 1 is an illustrative photograph of a rolled GMCS sheet. This is an innovative technology for the production of ammunition for firearms for military purposes, therefore the detailed specification is not public.

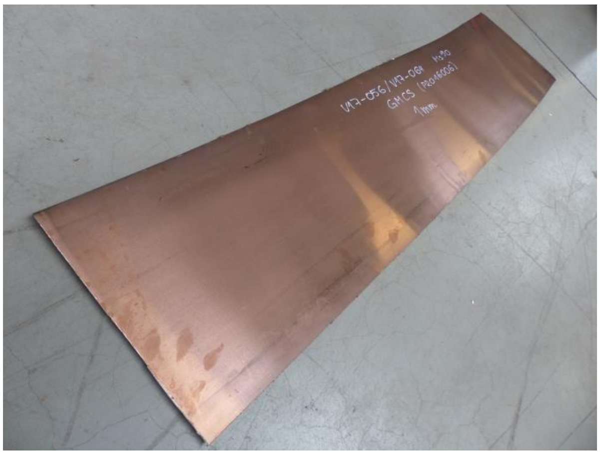

Figure 1 Photo GMCS plate

Based on previous operations, the final forming operation of the composite will take place - cold rolling. As it is a technology that combines several different technological processes, the resulting product is subjected to mechanical tests, which are preceded by mathematical analyzes.

2 Analysis of resistance to thermal stress

The presented analysis deals with the resistance of clad material made of structural steel S235JR + N and tombac CuZn90/10 to the effect of elevated temperature. The material is in the annealed state after cold rolling. The composite material consists of two 0.1 mm thick top layers of tombac and a 0.8 mm thick core of structural steel (Figure 1). The total thickness of the clad material is thus 1 mm. Due to the very different thermal expansion, it is necessary to determine the maximum temperature at which there is no plastic deformation due to thermal stresses. The finite element method was used for the determination. The computational model was performed in 3D SW ANSYS.

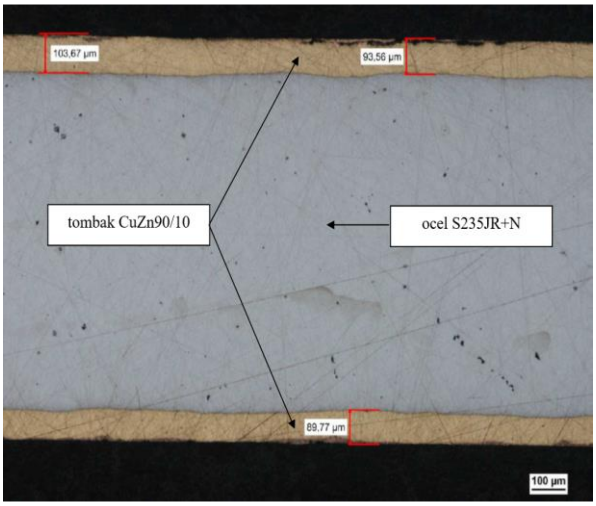

Figure 2 Image of metallographic cut of clad material with indication of thickness of rolled layers

3 FE simulation

The computational model consists of twenty-node quadratic elements SOLID186 (Figure 2). For the purpose of calculating the thermal stress alone, a multiple symmetric boundary condition was preferably chosen (Figure 3). The temperature is entered unitally. The problem is solved as stationary, because test calculations with a non-stationary temperature field due to the high thermal conductivity of both metallic materials are meaningless.

The material behavior model is homogeneous isotropic nonlinearly elastic. The nonlinear dependence of all material properties is the temperature dependence, where the required intermediate values are obtained by interpolation. The mechanical-physical properties of the CuZn90/10 tombac could not be obtained for higher temperatures. For this reason, the properties of pure copper were used, taking into account the ratio of the mechanical properties of pure copper and tombac at a temperature of 20°C. Used mechanical-physical properties of steel, (tombac) are listed in Table 1, resp. in Table 2. Most values are drawn from the literature [1] and [2]. Unfortunately, the possible strengthening of steel or tombac cannot be included in the calculation model, because the changes of mechanical-physical properties of the finished clad material after the last technological operation of the production of clad material are not known. Likewise, small deviations of the mechanical properties in the rolling direction and perpendicular to the rolling direction can be expected. Since the technological process also includes rolling at elevated temperatures, it can be assumed that the residual stresses are at most at the level of the yield strength at a temperature equal to the rolling temperature. Such a residual stress would be insignificantly small. The insignificance of residual stresses is also supported by the fact that the finished clad semi-finished products do not show any deformation, such as surface undulation.

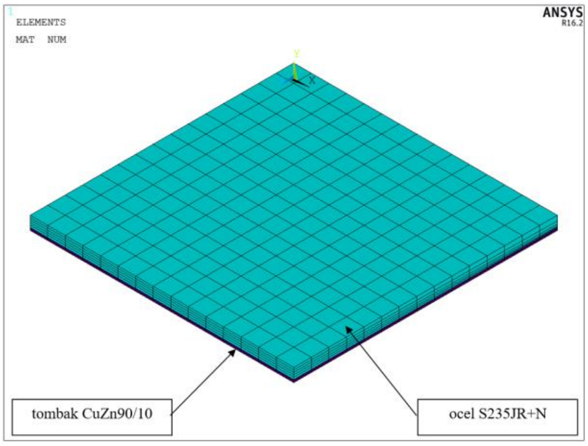

Figure 3 Computational model - finite element network

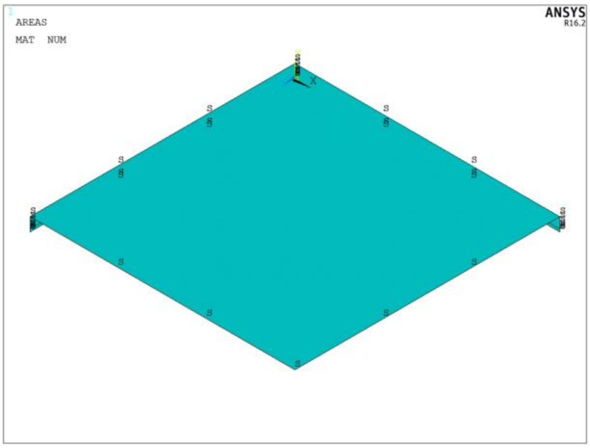

Figure 4 Computational model - symmetric boundary conditions

The network of finite elements and boundary conditions of the mathematical model were adapted to the dimensions of the actual product and the predicted type of load.

Table 1 Mechanical properties of steel S235JR + N

μ = 0,30 [-], ρ = 7850 [kg/m³]					
T [°C]	E [MPa]	$\alpha.10^6$ [1/K]	λ [W/m.K]	c [J/kg.K]	Re [MPa]
20	200000	11,5	51,7	472	196
100	195000	11,9	51,1	496	196
200	190000	12,5	48,5	525	196
300	180000	13,1	44,4	565	157
350	175000	13,4	43,5	586	135

Table 2 Mechanical properties of tombac CuZn90/10

μ = 0,34 [-], ρ = 8960 [kg/m³]					
T [°C]	E [MPa]	$\alpha.10^6$ [1/K]	λ [W/m.K]	c [J/kg.K]	Re [MPa]
20	129800	15,4	15,3	383	211
100	125500	16,2	16,3	398	205
200	120000	16,9	17,6	408	182
300	114500	17,7	18,9	417	126
350	112000	18,1	19,5	421	95

The mechanical properties of both investigated materials show an indirect relationship between the modulus of elasticity and the longitudinal expansion.

4 Results

The result of the computational modeling for the temperature of 350°C is shown in the form of a stress field. In Figure 5-7 the reduced stress according to the Tresca condition in MPa is presented. The results of all calculations are summarized in the form of a graph in Fig. 8. The stresses σINT_tombak are calculated for a given temperature, σY_tombak represents the yield strength of the tombac for a given temperature, σY_steel represents the yield strength of the steel for a given temperature. In all standards, a limit is set for a simple membrane stress, usually 2/3 of the yield strength for a given temperature. This limit ensures safety against reaching the plastic deformation limit state. The voltages σ_tombak represent the limit for a given temperature at the tombac. The stresses σ_steel represent the limit for a given temperature for steel.

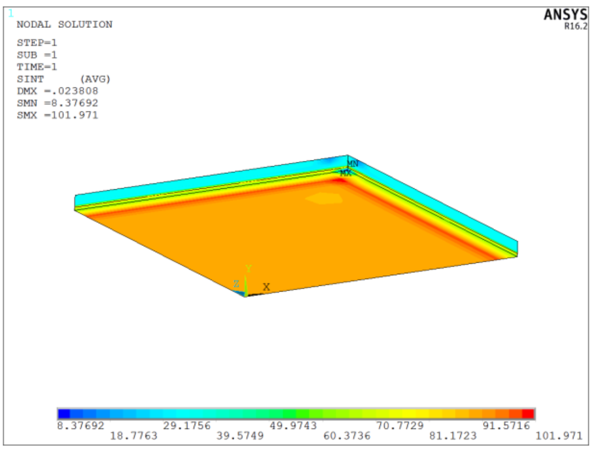

Figure 5 Stress according to Tresca condition at 150°C

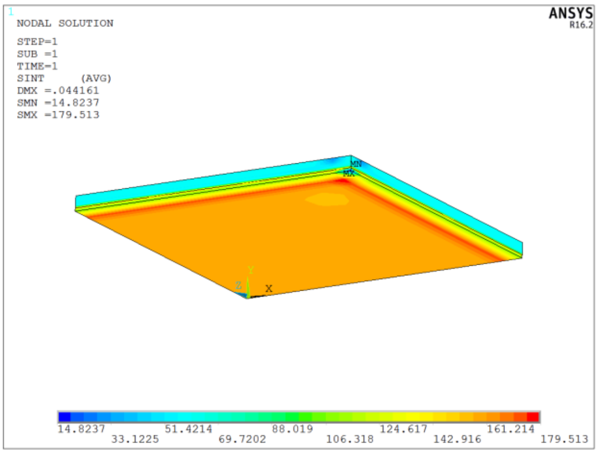

Figure 6 Stress according to Tresca condition at 250°C

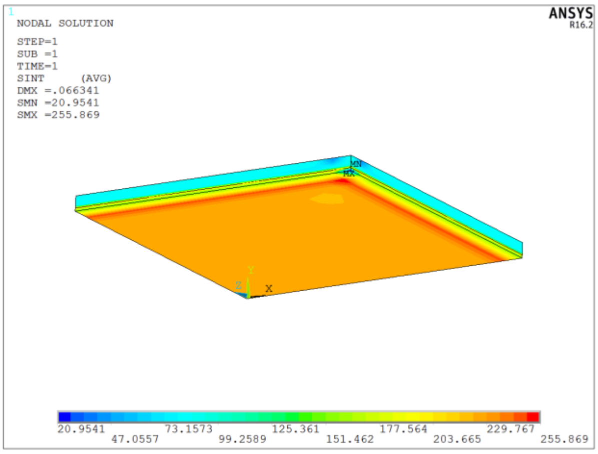

Figure 7 Stress according to Tresca condition at 350°C

On the color scale of Figure 5-7 we see the difference in the stress field of the individual layers, declared above in the longitudinal expansion of both materials in Tables 1 and 2 (column 3). The modulus of elasticity is thus a determining parameter for the prediction of plastic deformation.

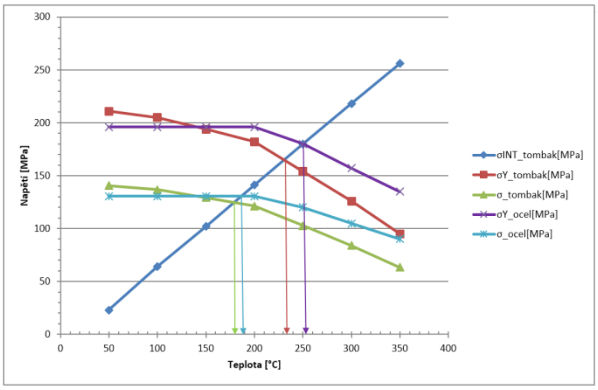

Figure 8 Summary of results

The results of mathematical modeling show that the yield strength and safety limits do not deviate from the predicted values declared by the standard. Based on a mathematical model, plastic deformation at the joint of both materials should occur after the temperature exceeds 250°C.

5 Concusion

The computational analysis shows that the clad material made of steel S235JR + N with a thickness of 0.8 mm with double-sided rolled tombac CuZn90/10 with a thickness of 0.1 mm is not suitable for exposure to higher than about 250 °C. Above this temperature, due to the different thermal expansion of steel and tombac, plastic deformation of the clad material as a whole is likely to occur. At temperatures up to approx. 230°C, no plastic layer is deformed. When exposed to temperatures up to approx. 190°C, the clad material has only 2/3 of the yield strength exhausted, which is the limit value for the membrane stress in commonly used standards for calculations and assessment of vessels and structures. Temperatures up to 180 °C appear to be the most suitable from the point of view of the production of clad material, which was the subject of computational modeling. At the indicated temperature, the yield strength of the tombac layer is 1/3 of the yield strength value for the given temperature. A temperature higher than 230°C can lead to plastic deformation associated with a permanent change in shape. At the same time, it is desirable that the clad material is not exposed to a temperature higher than 230°C before the last technological step.

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