Modeling of Stressed State during the Processing of Laminated Surfaces

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Abstract – **Based on the elasticity theory methods the task to describe the stress condition of the layered system in machining is set. The finite element model with the non-uniform mesh of finite elements is formed by Workbench ANSYS. The load is set as distributed over the tool/workpiece contact patch. The equilibrium conditions are described as a fixation of the developed surfaces in space.**

The deformation model of the environment is represented as linear model of the elastic deformation for each layer. The model performance is tested on the example of the layered system "metal – polymer composite – metal" linear turning. It is demonstrated that strains may exceed the limited layers for material resulting in the defects formation.

Key words – **turning, grinding, stress, composite materials.**

I. Introduction

The operational purpose of the parts in the machine industry implies conformity to certain accuracy and quality requirements for actuating surfaces of such parts. For example, parts and assemblies often operate under wear conditions therefore the rubbing parts materials shall meet the specified requirements to ensure the adequate reliable operation of such assemblies. They should provide wear resistance and faultless operation. Generally the wear-resistant materials have high hardness that complicates their processing. They are also quite expensive, so they can not be used as basic materials. The way out of this situation is the creation of the wear-resistant coatings on the work surface of parts.

There are many traditional ways of generation of surface layers with increased wear resistance. Among these are well-known methods of local and surface hardening, thermochemical treatment. In recent years, methods based on the parts surface layers treatment by particle fluxes are increasingly used. It is ion deposition and doping, plasma and laser sputtering methods etc.

In case of elevated vibrations and under aggressive medium the coats made from dispersed- strengthened, composite materials and metal-polymer based on thermoplastic and thermosetting polymers worked well in practice.

Thus, all methods of the surface layers modification provide the parts work surfaces with specific properties, thereby forming a layered structure.

The layered system forms the work surface of the part. To ensure the surface accuracy and quality layer systems are exposed to the finish machining. The most effective methods of finish machining are turning and grinding. The processing by such methods is associated with force impacts and thermal effects on the treated workpiece.

As it is well known from practice, the defects such as separation or destruction of the layer are often formed in the processing of the layered system under intensive cutting modes [1–6]. The difference of material properties included in the layer system has their impact here. The mechanical properties of polymer composites (PC) are next lower order than that of traditional construction materials [7]. Besides, there is limit adhesion strength between layers. Each material of any of the layers has its maximum allowable tensile strength (eg, the resistance to direct pull from steel of the PC layer is 5 ... 50 MPa), which will influence on the cutting modes purpose in the layered system processing.

In addition, the deformation properties of the polymer composites are significantly different from the properties of metals. Such difference predetermines the complex stress state arising from the cutting forces effect. Consequently, the stress analysis of the whole system under the cutting forces is crucial.

II. Task description

The source of the stress state during the layered system production is the cutting force P that acts in the course of processing on the treated layer of the system.

The cutting force is an active factor that generates the stress state. There is a reaction due to equilibrium of the technological system. The reaction is determined by the workpiece positioning on the machine.

As a rule, the accurate surfaces of layered systems are cylindrical. Therefore, it is reasonable to assume the layered system as the body of rotation during the object formation for stress analysis.

During the stress state simulation it is necessary to describe the factors that generate the stress state of the workpiece when it is machined. The load is distributed over the tool/workpiece contact patch. The operative direction of

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power load is assumed as arbitrary in space. It will enable to describe any cutting scheme.

Thus, we arrive at the design model (Fig. 1) consisting of the following elements:

– *object:* a set of embedded into each other cylinders, each of which consists of different materials with different strength properties;

– *load:* load ($\bar{p}\{p_x; p_y; p_z\}$) is applied on the upper processed cylinder (working layer) distributed over the contact patch;

– *fixation:* the system is fixed in space depending on the workpiece mounting method on the machine.

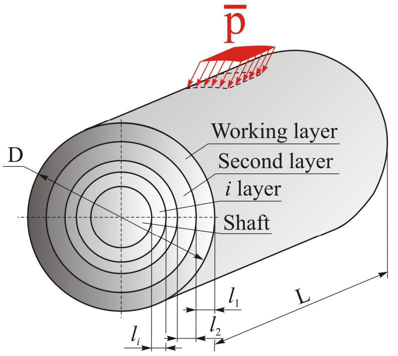

Fig. 1. Analytical model of loading of layer system
D – layer system diameter, *L* – length of layer system,
l_1 – thickness of processed layer, l_2 – thickness of second layer,
l_i – thickness of *i* layer

The design model takes into account the layered system design and the basic technological factors: load and fixation method.

III. Numerical Implementation of the Solution

In order to solve this problem the Workbench module included in the ANSYS software package and describing such problems in three-dimensional formulation is used.

Description of the object geometry and its physical properties is reduced to a solid model. To generate a 3D-model of the layered system the Solid-Works CAD-system has been used. Further the model was transferred to the ANSYS software package solver.

There is a possibility to set the body with variable strength and deformation properties in the ANSYS environment. Therefore, we consider a layered system as a single body with discretely varying physical properties by layers. In the developed model the forces action in the layered system extends through layers without losses.

It is necessary to superimpose the finite element mesh in order to apply the finite element method.

In this structure, the weak element will be a layer of polymer composite. Therefore, in the construction of the finite element mesh it is advisable to make the elements sizes irregular. It is reasonable to make the elements smaller in the area close to the deformation zone but bigger with the increase of distance from the cutting zone (Fig. 2).

Description of the system fixation. The equilibrium conditions in the Workbench PC ANSYS module are set in the form of fixation in the constructed surfaces space. All chuck surface movements as well as in the front center are forbidden. On the back center surface of the rotation about part axis is left free.

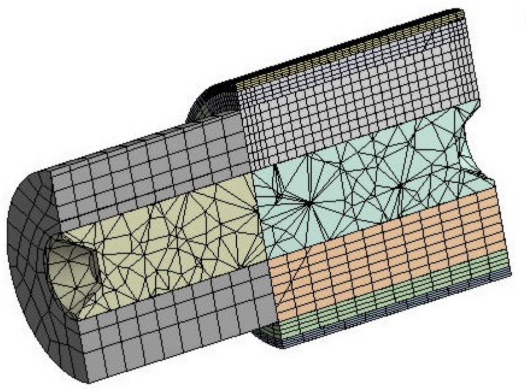

Fig. 2. Solid model of layer system while axial turning
with table of finite elements

Load. The point of load application -cutting forces- is the tool/workpiece contact patch (see Fig. 1).

Environment model. One of the crucial issues of the finite element method simulation is the environment model. The linear model of elastic deformation is used in the elastic zone. However, the rupture stress value should also be considered.

The finite element model formed in this way is transferred from Workbench to the ANSYS solver where the stress analysis in the nodes of each element is made.

IV. Calculation Data Presentation

The calculation data are stresses and displacements at the nodes of each element. The nodal stress and displacement re-calculation gives the principal, normal, tangent and equivalent stresses fields in the layered system as a whole and separately by layers of the system, the total deformation of the layered system from the cutting forces action. The stress fields and deformations are presented in the form of level lines (Fig. 3). The stress level value is specified by color. The color scale with stresses values is placed automatically on the left from the calculated field stresses.

V. Calculation Data Analysis

The solubility demonstration is carried out by the example of three-layer system if the used machining method is linear

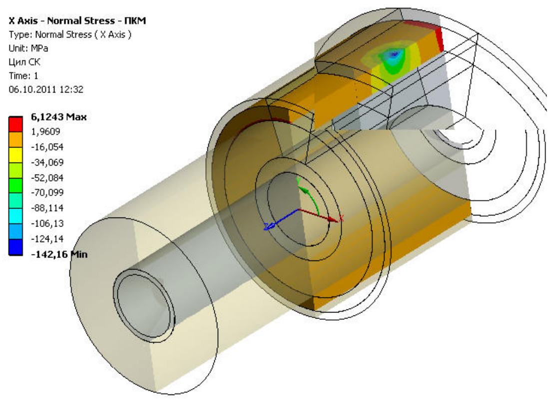

Fig. 3. Fields normal stresses σ_X in layer PC
of layer system of type "metal – polymer composite – metal" when turning

turning (Fig. 3-8). The stress diagrams developed according to the calculated stress fields are presented in the Fig. 7-8.

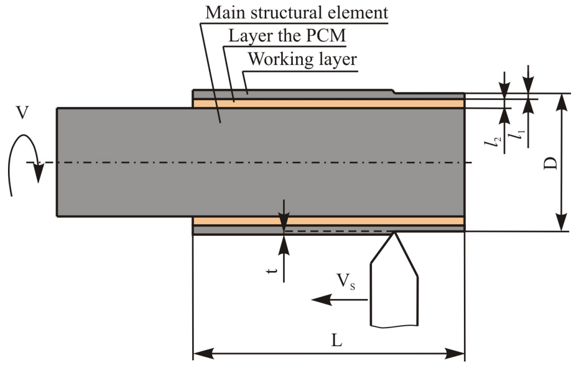

Fig. 4. Construction of layer system of type "metal – polymer composite – metal", technological conditions of processing: PC – diamant MM Stahl 1361 (E=14 GPa), metal – steel (E=200 GPa), D=30 mm, L= 30 mm, l_1=1 mm, l_2=2 mm. Turning, method of work piece fixing in patron, t=0,75 mm, V_S=0,3 mm/turnover, V=210 m/min, P_x=830 N; P_y=835 N; P_z=2275 N.

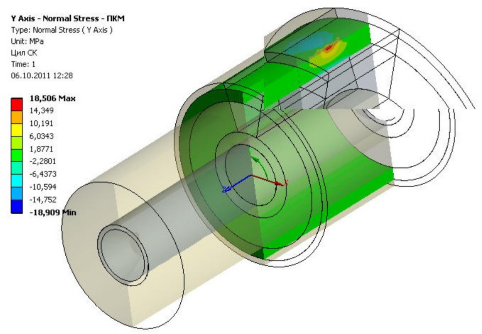

Fig. 5. Fields normal stresses σ_Y in layer PC of layer system of type "metal – polymer composite – metal" when turning

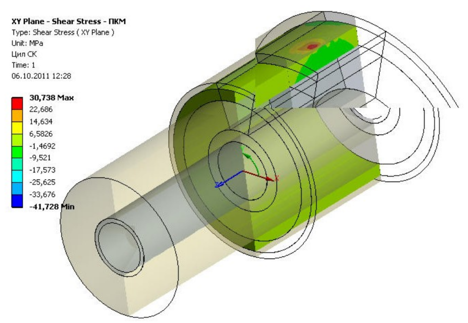

Fig. 6. Fields shear stresses σ_{XY} in layer PC of layer system of type "metal – polymer composite – metal" when turning

Let's consider the stress state of the layered system which design and technological conditions are shown in Fig. 4. The maximum normal stresses σ_x, σ_y (along axis X and Y respectively) and the shear stresses τ_{xy} in the layered systems processing reach the high values in terms of limiting strength PC characteristics. Let's consider the stress state of the layered system by layers in order to determine in which layer the maximum stresses occur and whether they will be critical in terms of defect formation.

PC layer. As Fig. 3, 5-8 shows, the peak value of compressive stresses σ_x are in the deformation zone. The peak values of tensile stresses σ_x are outside the workpiece range on the edge of the layered system where the PC layer is as if in the free state. Under the tool pressure it can be squeezed out between the metal layers forming the separation defect.

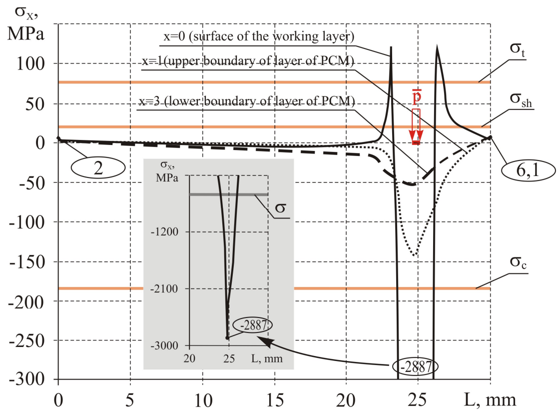

Fig. 7. Stress distribution along axis of layer system of type "metal – polymer composite – metal" when turning: σ – ultimate strength; σ_t – ultimate tensile strength; σ_{sh} – ultimate shear strength; σ_c – ultimate compressive strength

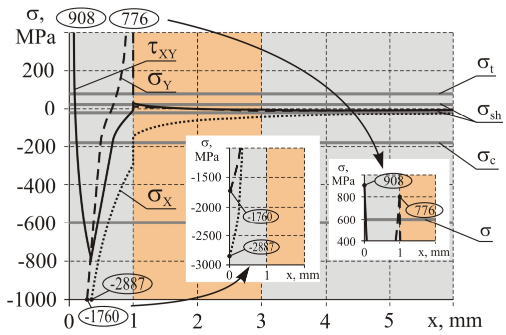

Fig. 8. Stress distibution along depth of work part in zone of load application

The peak values of σ_y stresses are on the boundary of working layer and PC layer. The tensile stresses are concentrated in the processing area and compressing stresses are located outside this area. Values are close to the limit stresses under normal fracture for the material under consideration (20 MPa).

The peak values of shear stresses are located in the deformation zone. Their value (30,74 MPa for tensile stresses and 41,73 MPa for compressive stresses) exceeds the limit values for this material (22 MPa), for this reason there may be the layered system destruction.

VI. Conclusion

These examples show that stresses in machining may exceed the limits for the polymer composite. Besides, the peaks of these stresses are in different zones (on the processed surface and layers boundaries) that can be critical in the design of machining process.

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