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The test stand calculations of the research station of sub-atmospheric pressure press with implementation of the finite element method

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Summary. This article presents the application of CAD systems with the use of the finite element method (FEM) in calculations of parameters of the research station of sub-atmospheric pressure press. The obtained results of calculations have been shown as numerical maps, tabular statements and charts. The proposed method of research shall be practically used for fulfilling orders for the needs of agricultural machinery and device industry, building industry, defense industry.

Key words: computer aided design, finite elements method, contact stress, sub-atmospheric pressure press.

INTRODUCTION

The test stand of a sub-atmospheric pressure press is intended for laboratory tests of the construction of a press which is used for adhesion process of large-size and multi-ply composite elements. The composite elements are used for production of self-supporting container constructions of various use. The composite wall elements are used for cold store constructions and erecting of farm compartments in agricultural technology.

In this paper, the following problem has been discussed: numerical modeling and strength calculations of the major test station components of the large-size press intended for sub-atmospheric adhesion of multi-ply composite panels and non-standard size constructions. The framework of the test stand functions is based on utilization of a sub-atmospheric effect (vacuum) generated between the suitable shaped surface of the work table and a rubber membrane covering elements of the panels which are to be adhered. It is the value of the sub-atmospheric pressure generated which plays the most important role in admissibility of the holding down degree of the adhered elements of a multi-ply panel. The sub-atmospheric effect is output within implementation of a correctly selected vacuum pump which sucks the air off the space between the work table and the rubber membrane.

The work over the project on the test stand calculations of a sub-atmospheric pressure press has been co-supported financially by the European Regional Development Fund within frames of the Innovative Economy Programme.

Within the limits of the realized work, a digital model (3D) of the press has been made, with implementation of a solid modeling method of the CAD systems. Over the next stages of the assigned work, strength-stiffness calculations of the major components and parts constituting the supporting structure of the test stand with utilization of calculating instruments of the CAD systems (a frame analyzer, a finite element method) were done. The final effect of this work was the press test stand construction which enables verification of numerical calculations based on empirical research.

Fig. 1. The test stand of the sub-atmospheric pressure press - practical realization

THE DIGITAL MODEL OF THE SUB-ATMOSPHERIC PRESSURE PRESS WORK UNIT

The digital model of the construction of the sub-atmospheric pressure press test stand has been completed

in the 3D Autodesk Inventor modeling technology. The model contains all the features of the real object (to the scale): geometric, material and dynamic ones. The characteristics of these constructive features have been defined in two aspects - both qualitative and quantitative.

The major element of the digital model of the sub-atmospheric pressure press work unit is the frame, designed of structural steel sections.

The inter construction of the supporting frame latticework was made of beams, welded perpendicularly to the frame side members. Perpendicularly to the outer beams and the inter beams, two-row-placed struts were welded; the struts were welded in a particular way so that they make, together with the frame side members and the cross-bars, a uniform surface on which work panel unit was placed.

The model of the work panel of the sub-atmospheric pressure press was placed on the leveled surface of the supporting frame. This model consists of two layers of laminated panels arranged in a particular way so that the bonds of the lower layer were placed in the scope of axes of the inter beams of the supporting frame and in crosswise axes of the upper layer of the laminated panels. The prop steel legs, which were allocated in three rows, bear the supporting frame of the sub-atmospheric pressure press.

The air-duct, which was modeled with suitably matched structural sections and joined with use of welding technology, was the further constructional element of the digital model of the test stand.

The rubber membrane is a complement to the sub-atmospheric pressure press work unit. The membrane (a rubber oilproof plate) whose dimensions are longer than length and width of the work table is intended for air-tight closure of the sub-atmospheric pressure chamber in which the whole adhesive process is completed. The dimensions of the membrane are dependent on the height of the adhered elements.

Completion of the digital model of the sub-atmospheric pressure press work unit has been the basis for MES strength calculations.

THE MES STRENGTH CALCULATIONS OF THE PRESSURE PRESS WORK UNIT

To obtain calculations of forces which are loading the frame of the pressure press work unit, the MES method was applied (the finite element method). Creation of the model of cooperation of a unit of components (a steel frame, panels, a multi-ply composite panel, a rebate, a rubber membrane), taking contact stresses between deformable objects into account, was the central objection to the main stage of assigned work. This task was put into practice by modeling the contact zone with application of the "surface-to-surface" method in the following steps:

- creation of the geometrical model of the discussed object,
- selection of the material characteristics,
- definition of the contact zone,
- assignment of the contact type,
- creation of the finite element network,
- application of the boundary conditions,
- realization of the calculations,
- analysis of the calculation effects - assignment of the reactive forces which are loading individual elements of the frame.

The analysis of the deformable body contact belongs to nonlinear problems, and usually requires considerable analytical inputs and an efficient numerical model of the model being researched. The contact zone is not exactly known and depends on the following factors:

- loading,
- material characteristics,
- boundary conditions.

The contacting surfaces of the bodies can come into interaction and lose it in unpredictable way. Friction is an additional factor which introduces nonlinearity and it can also produce difficulties in convergence of an iterative process. There are three basic ways of realization of this contact:

- node-to-node,
- nod-to-surface,
- surface-to-surface.

To obtain the strength analysis of the unit, arranged in a particular way as board-rebate-composite panel- rubber, the "surface-to-surface" method was applied. The Autodesk Inventor System, working in automatic mode, detected 138 contact pairs between particular elements in the digital model. All the contact pairs were qualified by the system as "bound".

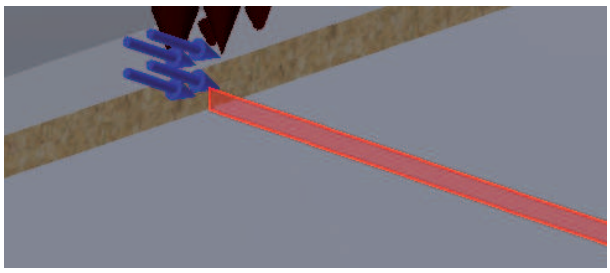

Fig. 2. Sample of a bonding (an adhesive-joint-model) between two chip panels

The digital model was subdivided into 227 259 elements, in which 466 848 nodes were separated. The number of the elements was determined by the iterative process of the network consolidation, which was carried on up to the moment when successive steps of the consolidation did not change the value of the calculated stresses.

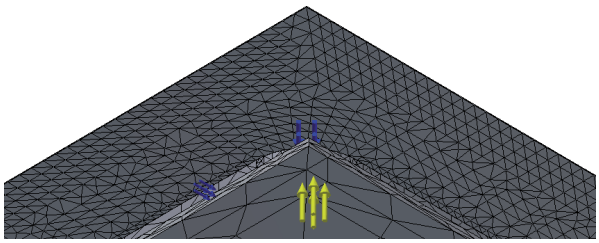

Fig. 3. The detailed section of the work unit with the finite element subdivision

The boundary conditions were defined by application of loading values to the system and by determination of the bearing props (a place and kind). The loadings were defined by application of working pressure values for selected surfaces of the press work unit.

The 400 hPa sub-atmospheric working pressure, used for the adhesive process, was put on the surfaces of the inter elements of the press work unit, on the contrary, the 1000 hPa atmospheric-corresponding pressure was put on the surfaces of the outer elements.

The bonds (deprivation of degree of freedom of the unit) were put on the surface of the contact of the press frame with the lower surface of the chip panels. 55 permanent bonds for the contact surface of structural sections of the press frame with the lower surface of the laminated chip panels were generated. For surfaces, margins or tops, the bonding of permanency was used. The bonding of permanency eliminates all degrees of freedom between selected components, which is in concord with technology of adhesion of the lower chip panel layer to the upper surface of structural sections which constitute the carrying frame of the sub-atmospheric pressure press.

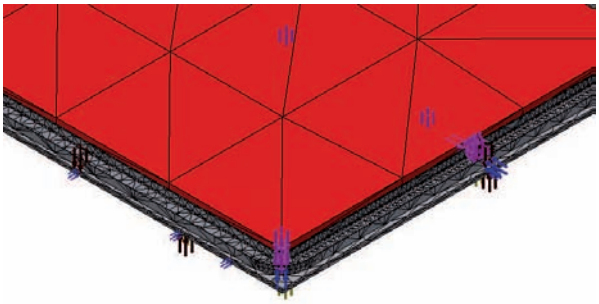

Fig. 4. The detailed section of the work unit press - a view of pressures applied

For the needs of further research on the digital model of the prototype press, in the whole scope of the MES calculating process, basic values which enable to carry on the strength analysis of particular elements of the press were registered. Strength values, reduced in agreement with the von Mises (Huber) hypothesis, were determined. The strength values had been settled on by the computer system, according to the following relation:

$$\sigma_{red} = \sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2 - \sigma_x\sigma_y - \sigma_y\sigma_z - \\ -\sigma_z\sigma_x + 3\tau_{xy}^2 + 3\tau_{yz}^2 + 3\tau_{zx}^2}$$

where:

$\boldsymbol{\sigma}_x$ – the component of a vector of normal stresses along with the X-axis of the accepted frame of reference,

$\boldsymbol{\sigma}_y$ – the component of a vector of normal stresses along with the Y-axis of the accepted frame of reference,

$\boldsymbol{\sigma}_z$ – the component of a vector of normal stresses along with the Z-axis of the accepted frame of reference,

$\boldsymbol{\tau}_{xy}$ – the component of a vector of tangential stresses in the XY plane of the accepted frame of reference,

$\boldsymbol{\tau}_{yz}$ – the component of a vector of tangential stresses in the YZ plane of the accepted frame of reference,

$\boldsymbol{\tau}_{zx}$ – the component of a vector of tangential stresses in the ZX plane of the accepted frame of reference.

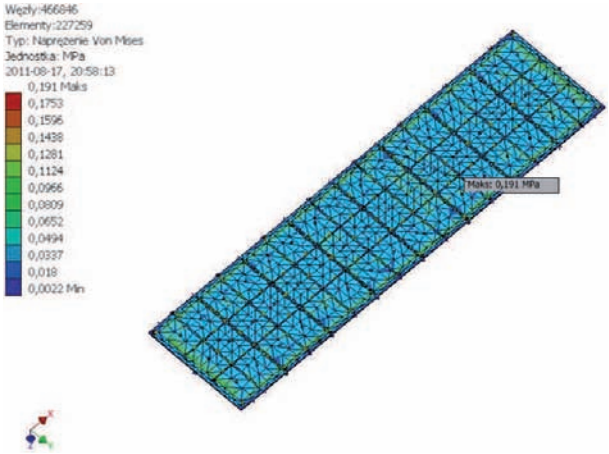

Fig. 5. The distribution of stresses in a layout of chip panels

Table 1. The summary of the calculation results of the reduced stresses

The name of the element	The value of maximal reduced stresses σ_{red} [MPa]
chip panels	0,1910
steel rebate	28,0100
composite panel	0,0534
rubber membrane	1,5590

The minimal value of the factor of safety was: 7,39; in connection with the above, the strength condition, with reference to the whole unit, has been fulfilled.

THE DIGITAL MODEL OF THE SUB-ATMOSPHERIC PRESSURE PRESS FRAME UNIT

The condition for the strength analysis of the construction of the frame unit of the test stand of the sub-atmospheric pressure press was completion of its digital model. The model has been completed with implementation of the "generator of frames" module of the Autodesk Inventor system. The basic carrying element of the sub-atmospheric pressure press prototype is the steel frame made of 55 steel structural sections.

With help of the „frame analyzer" module set in the AutoDesk Inventor system, the skeleton model of the frame was generated; the model consisted of 174 nodes and 64 stiff bonds between the bends. The bends were put out at the end of all the structural sections constituting the frame. The stiff joints between the nodes correspond to the welded joints which were configured in the digital model of the frame. The frame unit was supported with

51 permanent hinge props, whose allocation corresponds to the position of the prop steel legs bearing the press. In the nomenclature of the Autodesk Inventor system, these props are named „fastened bond". The way the fastenings are allocated is shown in the picture below.

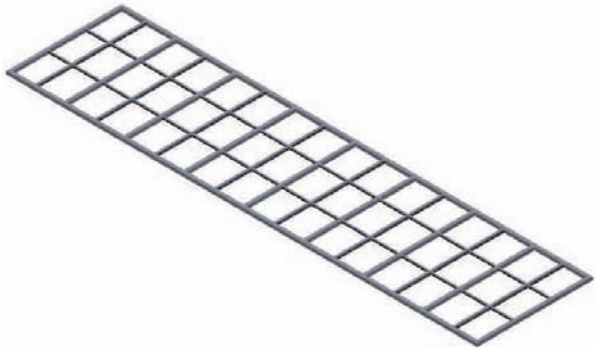

Fig. 6. The digital solid model of the frame unit of the sub-atmospheric pressure press

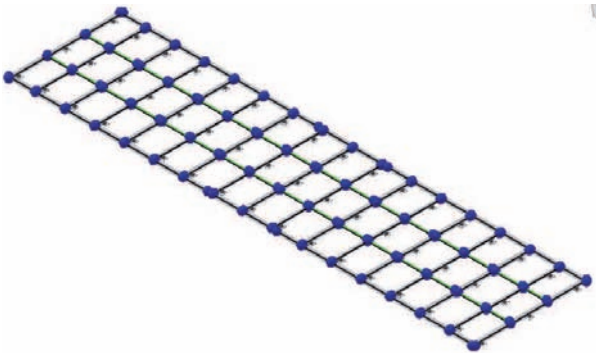

Fig. 7. The digital model of the frame with its nodes

The loading of the construction of the frame unit is originated in the weight-pull force of the particular beams; they come into existences as a result of interaction of the panels-rebate-composite-rubber membrane unit. The other type of interaction considers the bare weight of the particular elements of the work press unit and additional stresses which arise when working sub-atmospheric pressure is implemented. The summary calculations of the beam loading were carried on for the 400 hPa working pressure. It is a presumed working sub-atmospheric pressure which is required in the technological process of adhesion of composite ply materials.

The remaining values of loading for the particular beams (continuous loading and moments of forces) were determined with use of the MES analysis of the press work unit. Values of components of vectors of forces and moments were adjusted to the orientation of the co-ordinate system; the co-ordinates connected with the digital model of the frame unit.

THE STRENGTH CALCULATIONS OF THE SUB-ATMOSPHERIC PRESS FRAME UNIT

The continuous loading of the Q type (components: Qx, Qy, Qz), was implemented to the upper planes of the sections constituting the frame unit; the loading was determined in the MES calculations. The vectors of moments of the M type (components: Mx, My, Mz) were additional outer loading.

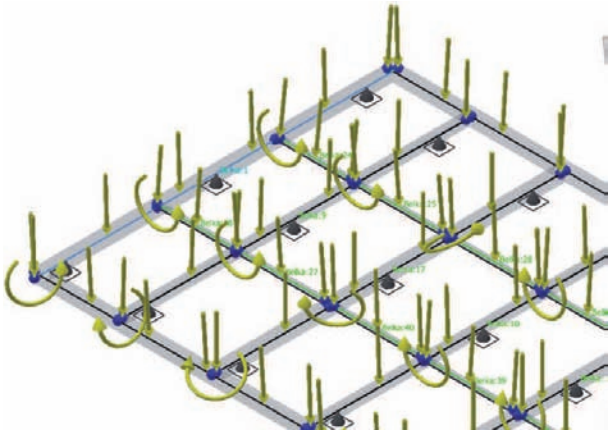

Fig. 8. The visual view of the outer loading implemented to the sections of the frame unit

After the strength calculations of the frame were carried out, the value of reaction, in the points where the frame unit is supported, was determined. Sequencing further, the maximal value of relocation, defined by a computer system, was determined. The determined value met the requirements of permissible limits which are provisioned by technological conditions of adhesive process.

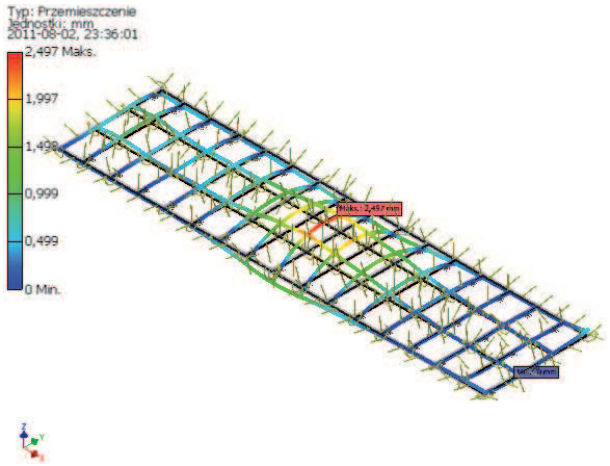

Fig. 9. The layout of the frame unit relocations

The distribution of normative stresses Smax existing in the maximally loaded beam of the frame unit is shown in the picture below. The maximal stress value was 66,65Mpa, which is a value far smaller than the yield point of the material used in this construction.

In progress of the realized MES calculations of the digital model of the test stand of the sub-atmospheric pressure press, the results meeting all the basic strength indicators and the operational criteria were obtained. The maximal relocation of the construction did not exceed the admissible values, specified by the operational requirements for the sub-atmospheric pressure. On the contrary,

the maximal normal stresses in the beams of the carrying frame was far smaller than the yield point (the calculated factor of safety exceeds the 7,0 value). The numerical analysis indicated that the construction operated with the 400 hPa working sub-atmospheric pressure meets both the operational requirements and the conditions of strength.

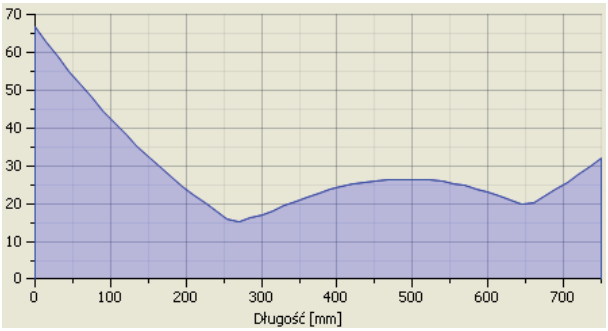

Fig. 10. The layout of reduced stresses in a selected beam of the carrying frame

VERIFICATION OF THE OBTAINED RESULTS OF CALCULATIONS

The test stand was built in the Production of Building Components Firm "Container" - LLC in Płock, Poland based on the digital model of the sub-atmospheric pressure press. Experimental research on realization of the adhesive process of large-size composite panels was completed. The results of the numerical calculations were acknowledged by the empiric research. The construction met both the presumed criteria of strength and stiffness. The press deformations, during realizing the process of technological adhesion of panels, did not exceed the admissible values, do to this fact, the desired geometry of large-size and multi-ply composite objects was performed.

Fig. 11. The composite panel produced with implementation of the vacuum adhesion technology

CONCLUSIONS

The obtained results of calculations have been shown as numerical maps, tabular statements and charts. The analysis of the theoretical calculations proved that they meet the results obtained by means of the empiric research conducted in the Production of Building Components Firm "Container" - LLC in Płock, Poland. Practical implementation of the CAD systems and the MES calculations into the issue presented and discussed in this paper gives useful advantage in the following questions:

– considerable reduction of the time needed to conduct research, due to the numerical analysis of many alternatives of the press,
– relief given to a research unit from routines and uncreative activities,
– undertaking veracious research with application of computer systems -
– just at the stage of the press design,
– ability to perform the numerical analysis of press functioning for cases dealing with adhesion of many types of composite elements differing in both the geometry and the layered structure.

The proposed method of research shall be practically used for fulfilling orders for the needs of agricultural machinery and device industry, building industry, defense industry.

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OBLICZENIA STANOWISKA BADAWCZEGO PRASY PODCIŚNIENIOWEJ Z ZASTOSOWANIEM METODY ELEMENTÓW SKOŃCZONYCH

S t r e s z c z e n i e. W artykule przedstawiono zastosowanie systemów CAD i metody elementów skończonych do obliczeń stanowiska badawczego prasy podciśnieniowej. Uzyskane wyniki obliczeń przedstawiono w postaci map numerycznych, zestawień tabelarycznych oraz wykresów. Zaproponowana metodyka badań zostanie praktycznie wykorzystana do realizacji zleceń dla potrzeb przemysłu maszyn i urządzeń rolniczych, budownictwa oraz przemysłu obronnego.

S ł o w a k l u c z o w e: komputerowo wspomagane projektowanie, metoda elementów skończonych, naprężenia kontaktowe, rozkład naprężeń w glebie, prasa podciśnieniowa.