Lodz University of Technology,
Department of Technical Mechanics and Computer Science

INVESTICE DO ROZVOJE VZDĚLÁVÁNÍ

# IMPACT OF MATERIAL PARAMETERS ON TEMPERATURE FIELD WITHIN CLOTHING LAMINATES

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# CREATING OF CLOTHING LAMINATES. BASIC PROBLEMS

- Protection of clothing against creasing during production and use.
- Clothing laminates improve aesthetic quality by application of different inlayer materials.
- Typical inlayer materials: woven fabrics, knitted fabrics and non-wovens.
- Insert provides the form durability and create textile laminate using the polymer softened by heat transport.

# CREATING OF CLOTHING LAMINATES. PARAMETERS

## TEMPERATURE T

•Measured between insert and external fabrics, heater has the greater temperature.

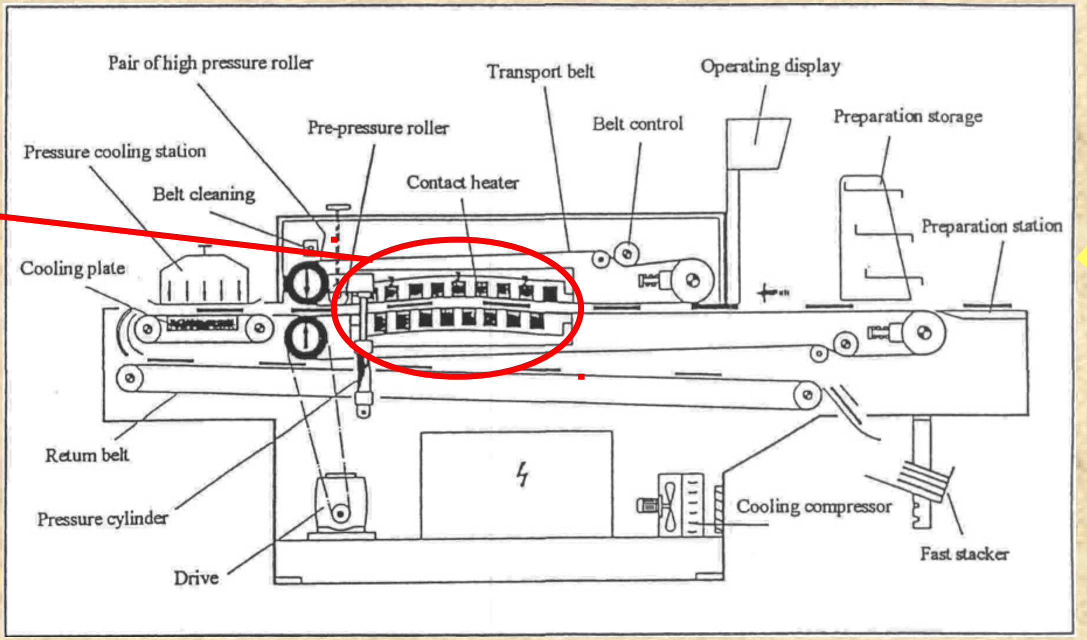
•Temperature distribution depends on heat transfer system.

Two-side heating: distribution of T is symmetrical, adhesion is correct.

•T ↑ = polymer viscosity ↓ . Polymer penetrate the insert and impregnate the external textile material.

•The most applied temperature T=(90-120)ºC

Contact heater

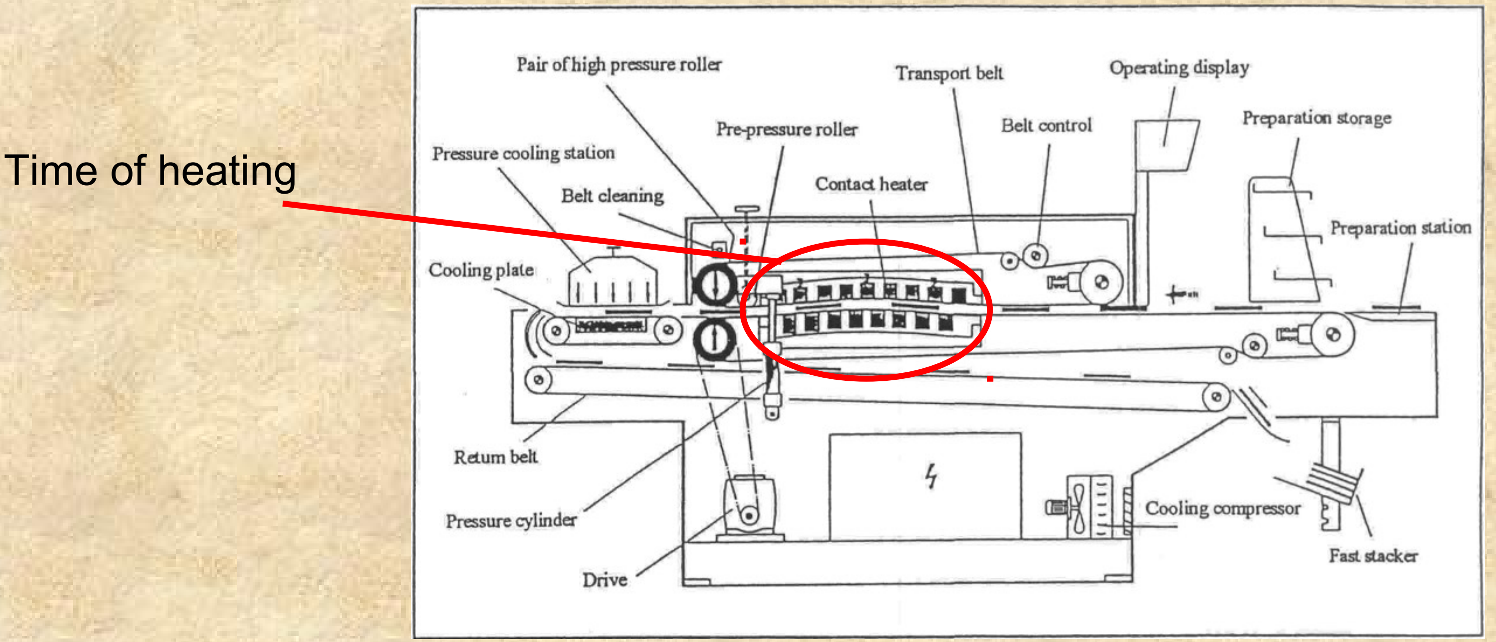



Continuous automatic fusion press KFH 600 for shirt and blouse fusion with pressure cooling station at output (Source Meyer)

## CREATING OF CLOTHING LAMINATES. PARAMETERS

### TIME t

- Necessary to heat transfer into material, help to create the stable laminate.
- Heating time = polymer is softened by the heat.
- The shorter the time the harder the polymer i.e. the adhesion within connection is reduced. The longer the time the more fluid the polymer i.e. the better penetration both external material and inlayer.
- The most applied time t=(12-18)s



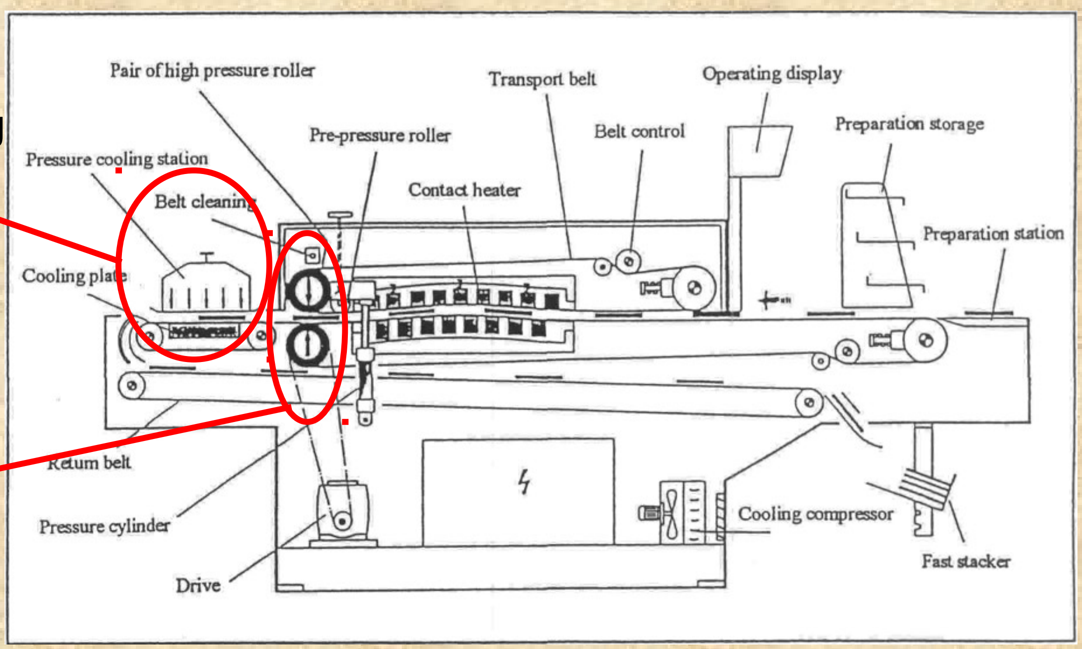
# CREATING OF CLOTHING LAMINATES. PARAMETERS

## PRESSURE Q

- Pressure of upper plate/rollers on unit surface should be optimized.
- Q ↓ = connection between insert and fabric is weak;
Q ↑ = polymer penetrates the insert, glue points are flatten, touch is hard.
- The most applied pressure Q=(3 – 30)·$10^4$ N/$m^2$

Pressure cooling station
(Source Meyer).

Pressure rollers
(Source Meyer).

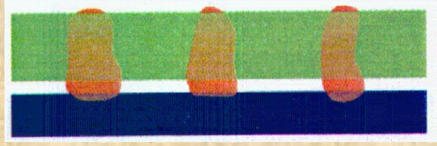


## CREATING OF CLOTHING LAMINATES. PARAMETERS

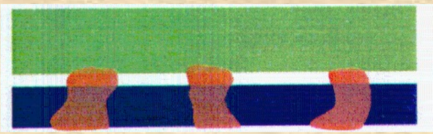
### OTHER PARAMETERS

- Inlayer structure defined by material stiffness, dimensional durability, material parameters characterizing the heat transfer.
- Material composition, i.e. the kind of applied fibers.
- Surface mass and finishing procedure to secure the soft textile feel.
- Purpose and place of application which determine the model description.
- Kind of glue, the most popular are powders made of polymers.
- Adhesive spread procedure, i.e. the point-wise or the continuous method.
- Distance between the glue points, i.e. regular net or irregular glue points.

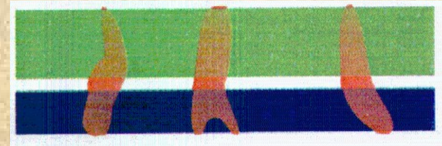
## CORRECT STRUCTURE OF TEXTILE LAMINATE



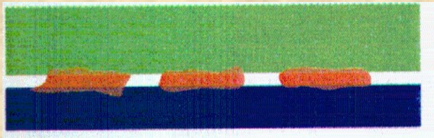
Penetration of glue through the external layer



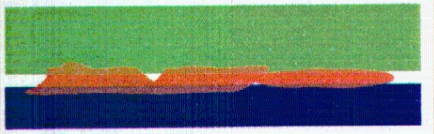
Penetration of glue through the insert



Penetration of glue through both materials

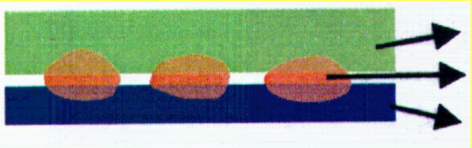


Insufficient penetration of glue

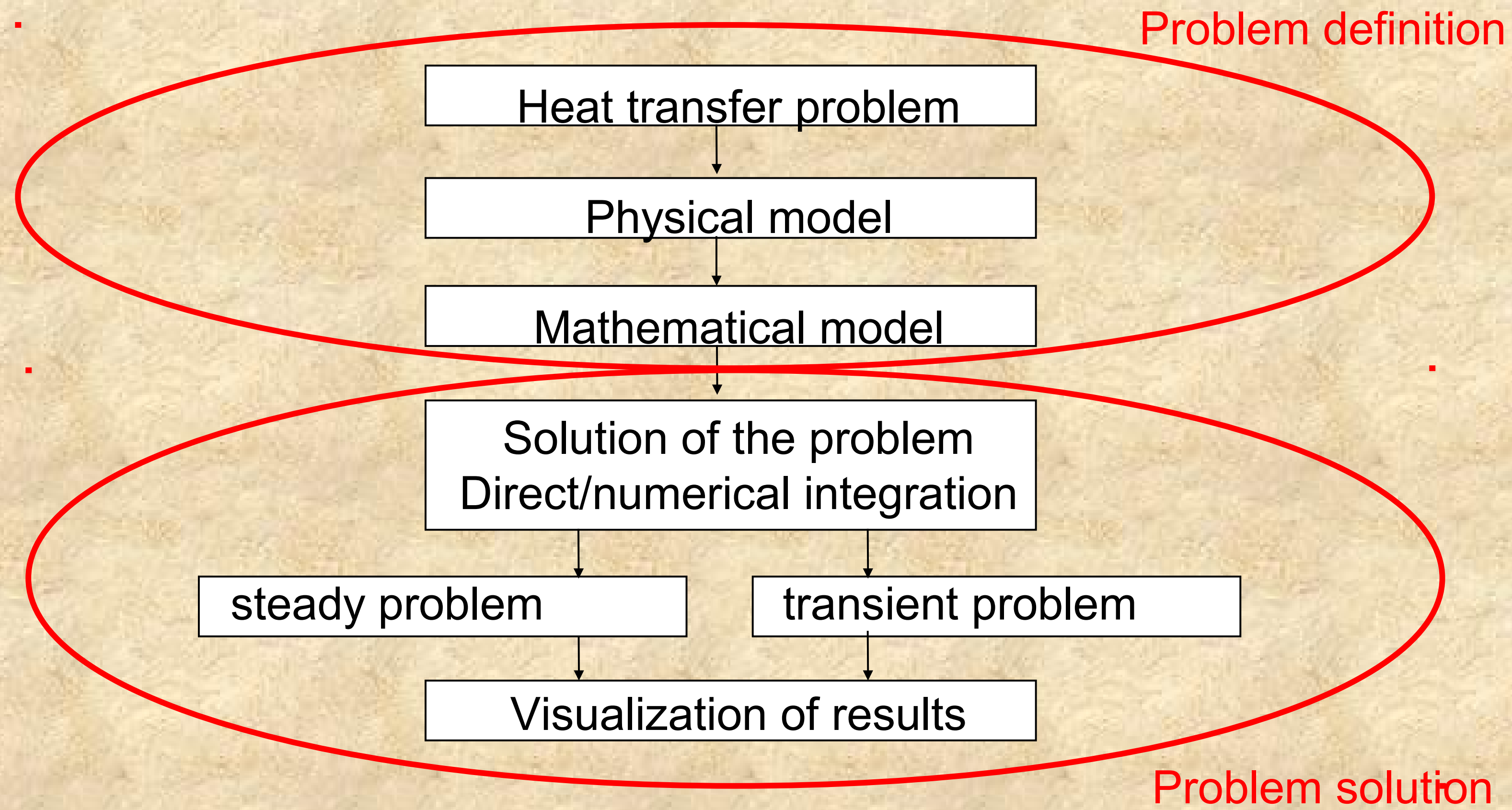


Connected glue points

**Correct structure of seam**

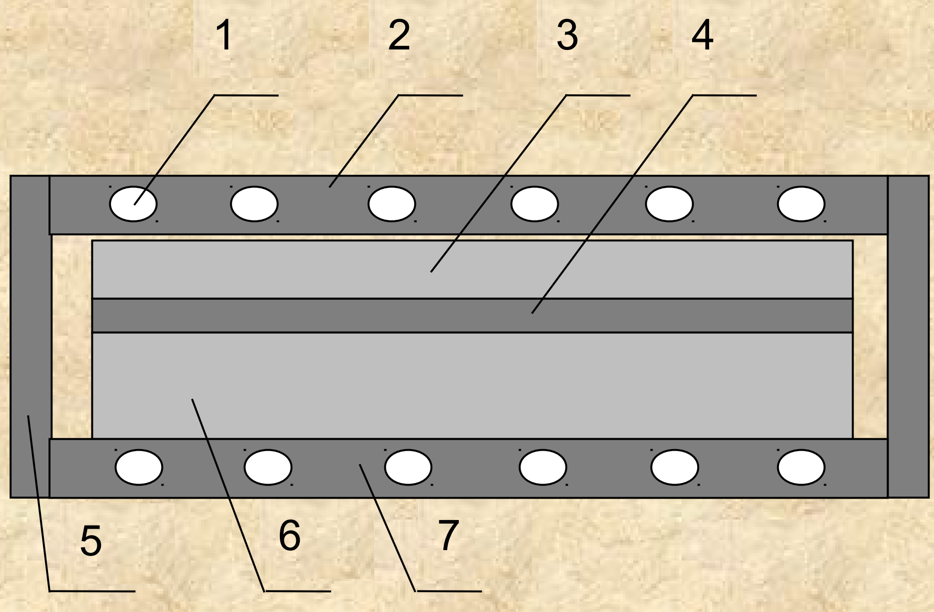


## SOLUTION STRATEGY OF HEAT TRANSFER PROBLEM



## SCHEME OF CROSS-SECTION WITHIN HEATING DEVICE

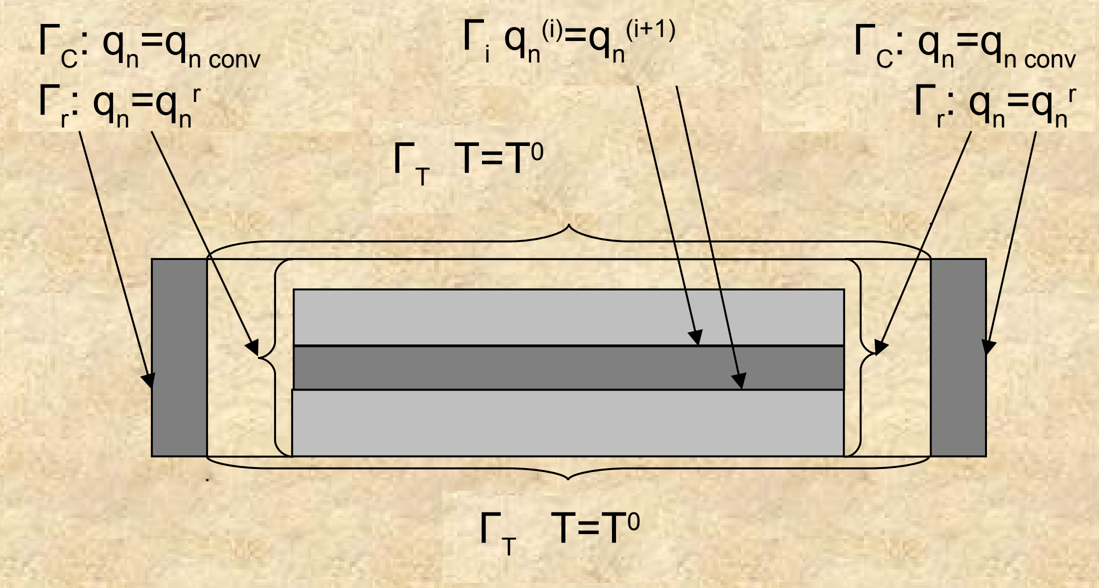
- Description of heat transport depends on heating system. Two-side heating is applied.




1 – heating elements, 2,7 – heating devices, 3 – inlayer, 4 – homogenized polymer layer, 5 – side thermal housing, 6 – outer textile material

# PHYSICAL MODEL OF HEAT TRANSPORT IN HEATING DEVICE

- The only heat sources are heaters within heating press.
- Heat is lost by accumulation in fibers and transport to surrounding through external boundary.
- Introducing heat balance, the heat transport equation is formulated as the second-order differential equation of T with respect to coordinates.
- It is necessary to determine the set of boundary conditions.



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# MATHEMATICAL MODEL OF HEAT TRANSPORT IN HEATING DEVICE

$$\operatorname{div} q^{(i)} = 0$$

$$q^{(i)} = A^{(i)} \cdot \nabla_{x y x ¿ ¿} T^{(i)} + q^{¿(i)}$$

$$x \in \Omega ; \quad = ¿\{¿\}¿\{\} ; \{¿¿¿$$

$$T^{(i)}(x,t) = T^{0}(x,t) \quad x \in \Gamma_T ;$$

$$q_{\mathrm{nC}^{(i)}}(x,\mathrm{t}) = h\left[T(x,t) - \mathrm{T}_{\infty}(x,t)\right] \quad x \in \Gamma_C ;$$

$$q_{n^{r(i)}}(x,t) = \sigma\left[T(x,t)\right]^{4} \quad x \in \Gamma_r ;$$

$$q_{n^{(i)}}(x,t) = q_{n^{(i+1)}}(x,t) \quad x \in \Gamma_i .$$

***q*** vector of heat flux density,

***q****** vector of initial heat flux density,

$q_n$=***n·q*** vector of heat flux density normal to surface defined by unit vector ***n***,

***A*** matrix of heat conduction coefficients,

*T* temperature,

$T^0$ prescribed temperature,

*t* real time,

*h* surface film conductance,

$T_\infty$ surrounding temperature,

*σ* Stefan-Boltzmann constant.

## IMPACT OF MATERIAL POROSITY ON TEMPERATURE FIELD

- Let us assume for simplicity: outer woven fabric and cotton inlayer of isotropic heat transfer properties.
- Material has single-component matrix of heat transfer coefficients.
- Heat transfer coefficient of cotton fibre before homogenization is constant $\lambda=0{,}072 W/(mK)$.
- Heat transfer coefficient of polymer glue is temperature-dependent: $\lambda=0{,}08 W/(mK)$ for $T<115°C$, $\lambda=0{,}10 W/(mK)$ for $116°C<T<125°C$; $\lambda=0{,}11 W/(mK)$ for $126°C<T<135°C$; $\lambda=0{,}12 W/(mK)$ for $136°C<T<145°C$.
- Heat capacity of cotton $c=1320 J/(kgK)$; polymer $c=1200 J/(kgK)$.
- Porosity of cotton inlayer is constant $\varepsilon=0{,}350$.
- Air content within layer of polymer is constant $\varepsilon=0{,}450$.
- Constant parameters of air in free spaces: heat transfer coefficient $\lambda=0{,}028 W/(mK)$ and heat capacity $c=1005 J/(kgK)$.
- Surrounding temperature in the housing is $T_\infty=25°C$.
- Surface film conductance $h=0{,}1\ W/(m^2\ K)$.

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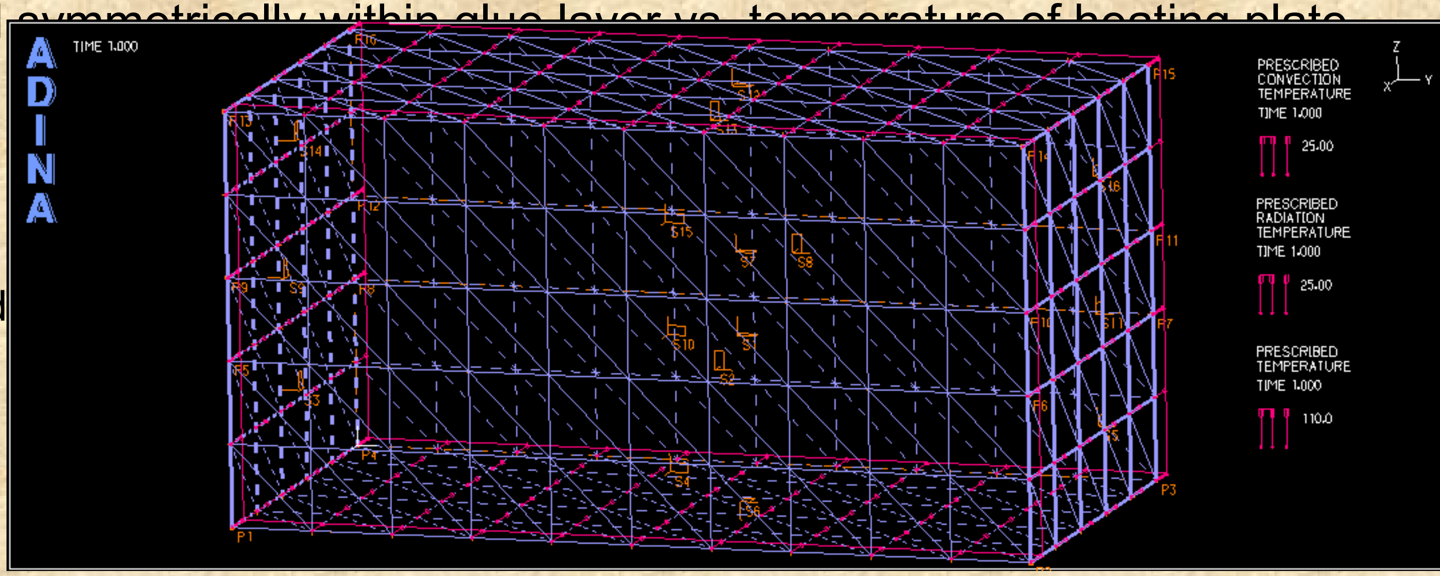
# IMPACT OF MATERIAL POROSITY ON TEMPERATURE FIELD

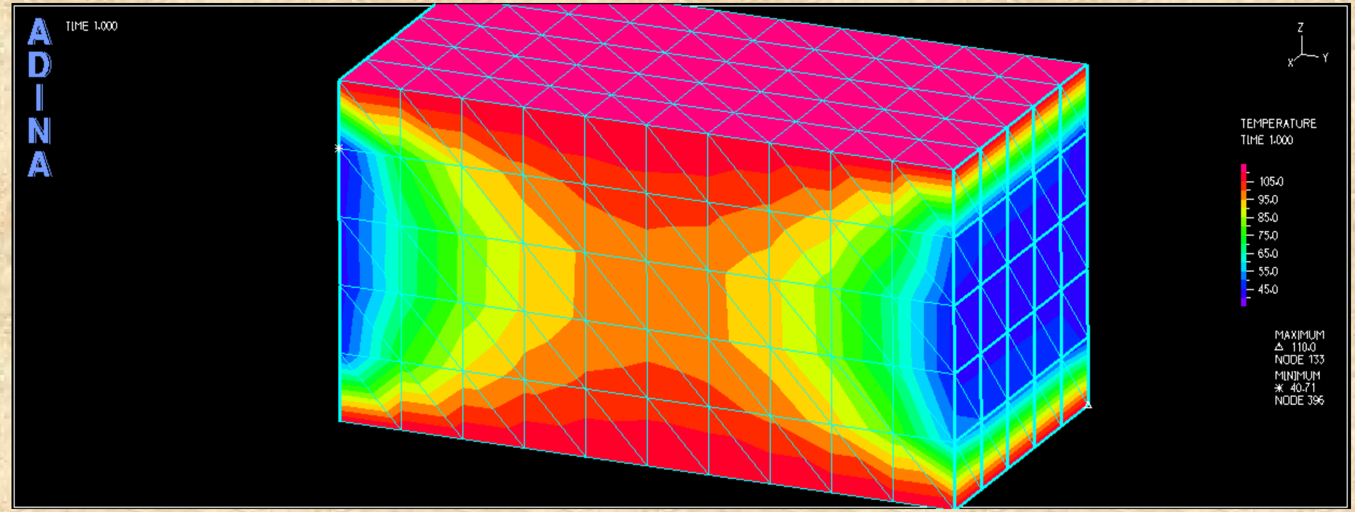
- Integration using the Gauss method, visualization in ADINA-software. Approximation by 3D Finite Element Net, convection+radiation is the spatial function.
- Temperature maps are symmetric in relation to vertical plane of symmetry.
- Temperatures on side surfaces are lower than in centre of inlayer, cf. influence of convection+radiation. It can disturb the stability of laminate.
- Temperature maps enable to create the mean temperature in 27 points located symmetrically within glue layer vs. temperature of heating plate

Finite Element Net for homogenized layer of polymer and air



# IMPACT OF MATERIAL POROSITY ON TEMPERATURE FIELD

homogenized polymer layer, temperature of upper and lower surfaces T=110°C; temperature in housing $T_{\infty}$=25°C




Mean temperature of polymer layer for different cotton porosities

## IMPACT OF SURFACE MASSES ON TEMPERATURE FIELD

- Change in mass determines various heat transfer coefficients.
- Calculations are determined similarly to previous case; porosity of the cotton inlayer $\varepsilon=0,350$.
- Heat transfer coefficient is from range $0,048W/(mK)\leq\varepsilon\leq0,055W/(mK)$.
- The obtained temperature maps have analogical distribution. Differences of mean temperatures are not greater than 2%.
- Mean temperature is not sensitive to change of surface mass of inlayer.

Mean temperature of polymer layer for different heat transfer coefficients

## IMPACT OF TYPE OF FIBERS IN INLAYER ON TEMPERATURE FIELD

- The most applied fibers applied for inlayers are polyester, polyamide, cotton, viscose, Lycra, bamboo ect. Choice of fibers determines heat transfer coefficient.
- Isotropic material has the single-component matrix of heat transfer coefficients; Heat transfer coefficient before homogenization: polyester $\lambda=0{,}200 W/(mK)$; polyamide $\lambda=0{,}210 W/(mK)$; cotton $\lambda=0{,}072 W/(mK)$; viscose $\lambda=0{,}063 W/(mK)$; Lycra $\lambda=0{,}025 W/(mK)$.
- Inlayer porosity $\varepsilon=0{,}350$. All other parameters defined previously.
- Heat transfer equation integrated using the Gauss method. Temperature distribution has the same character as previously but values are different.
- Temperature maps are symmetric relative to vertical plane.

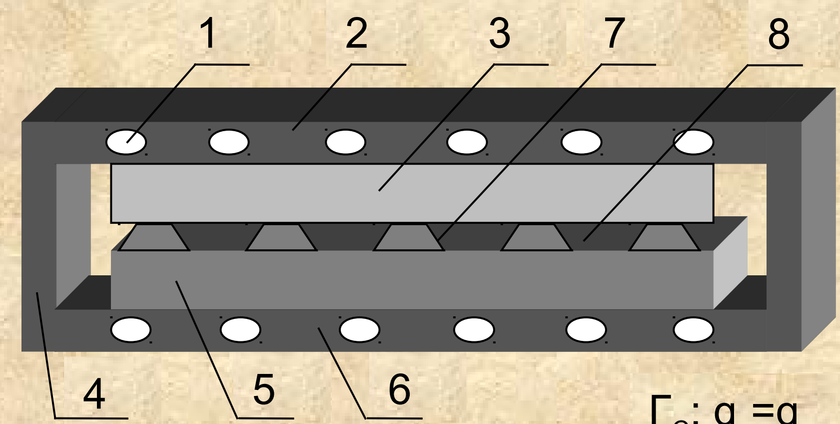
## IMPACT OF TYPE OF FIBERS IN INLAYER ON TEMPERATURE FIELD

- Distributions of mean temperatures can be approximated by straight line.
- The higher the heat transfer coefficient of inlayer material, the better the heat transport through textile inlayer. Mean temperature within polymer layer is higher than the temperature for the more insulating textiles, cf. lower heat transfer coefficients.

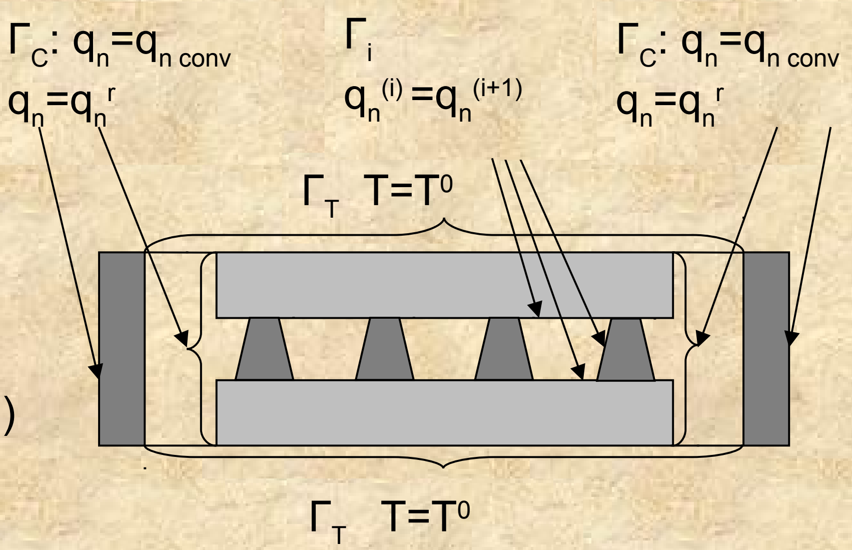
Mean temperature of polymer layer for different inlayer materials

# IMPACT OF POLYMER LAYER MODELING TEMPERATURE FIELD

- Polymer layer defined by glue points and air between these points.

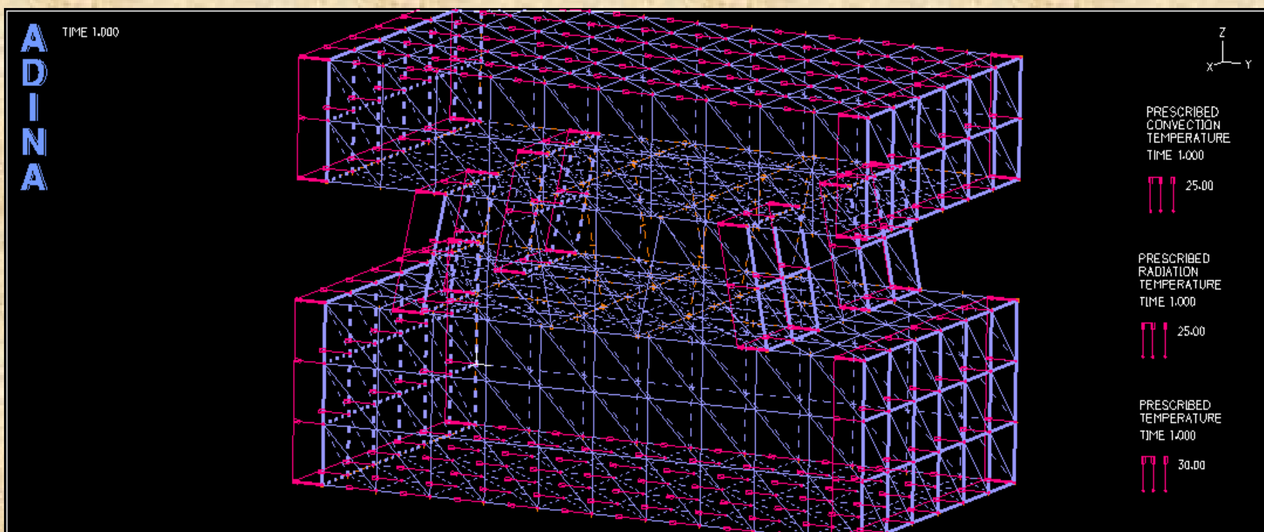



1 – heating elements,
2,6 – heating devices, 3 – inlayer,
4 – side thermal housing,
5 – outer fabric, 7 – polymer point,
8 – air layer between glue points



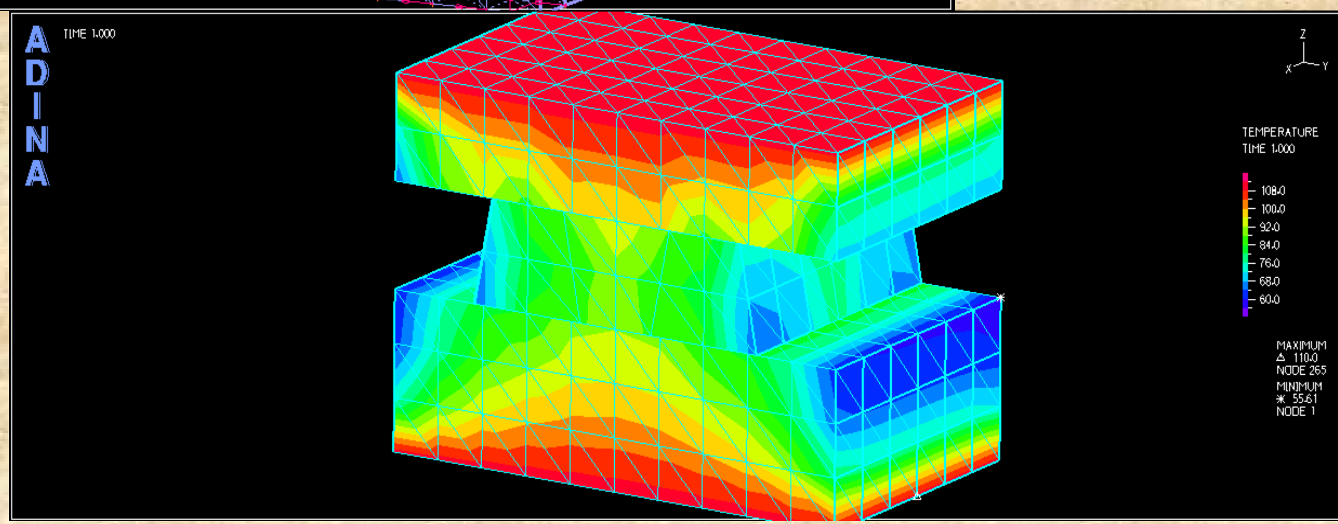

New physical model of structure
(internal surfaces in polymer points)

# IMPACT OF POLYMER LAYER MODELING ON TEMPERATURE FIELD



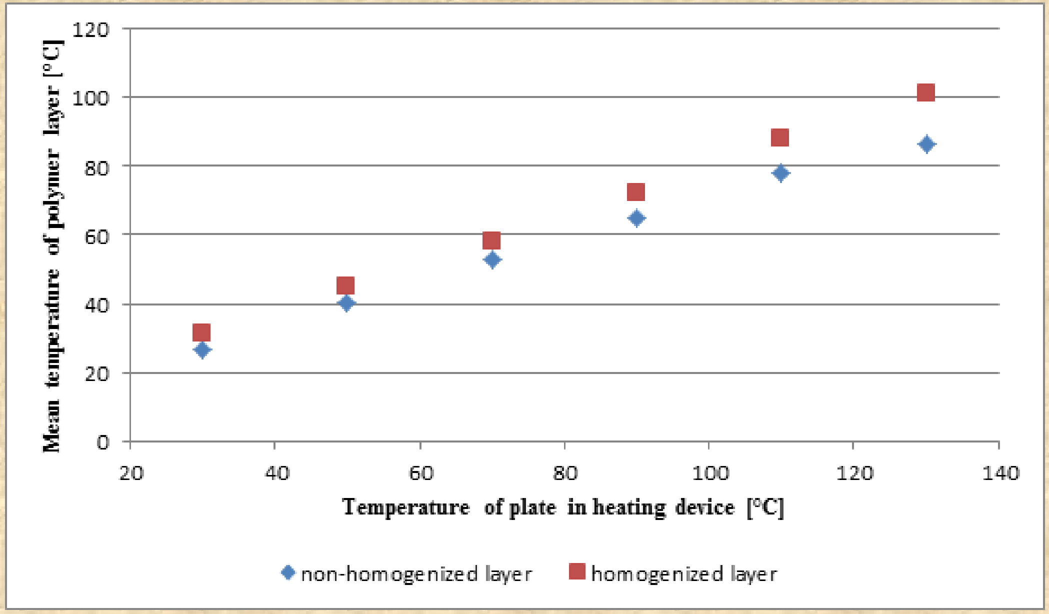

Finite Element Net of 4-nodal elements

separate glue points, temperature of upper and lower surfaces T=110°C; temperature in housing $T_\infty$=25°C



# IMPACT OF POLYMER LAYER MODELING ON TEMPERATURE FIELD

Mean temperature of polymer layer for diifferent models of polymer layer




- Mean temperature of homogenized layer is higher than for separate points.
- The dependence between tempratures within homogenized glue layer and plate of heating device is linear.
  The temperature for separate glue points is non-linear.
- Maximal values within polymer layer are higher than *90°C*, i.e. minimal temperature of the melting point for the low-melting polyamide. Durable laminate is created for disadvantageous boundary conditions.

## CONCLUSIONS

- Temperature maps give information concerning maximal and minimal values of temperature within laminate.
- Mean temperature within polymer layer is determined in 27 points and assumed as the state parameter characterizing polymer layer and consequently textile laminate.
- There are some factors which influence the mean temperature. We can describe sensitivity of mean temperature to these parameters. The mean temperature is sensitive to material porosity and type of fibres within inalyer and insensitive to surface mass.
- Modeling of heat transfer can change the temperature distribution.
  The simplest model is the homogenized polymer layer which can give important conclusions.
  The complicated model introduces the pointwise glue distribution.
- Additional parameters can be analyzed: place and area of application, finishing procedure, lamination technology etc.
- The performed analysis can be applied to shape optimization of laminate.