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A Numerical Study for Rubber Particles Collection Involved in New Thermoforming Composite Process Using Comsol Multiphysics

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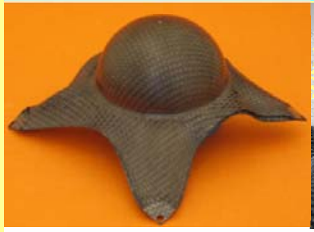
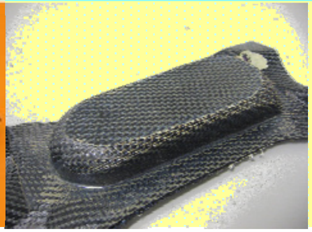
OBJECTIVE

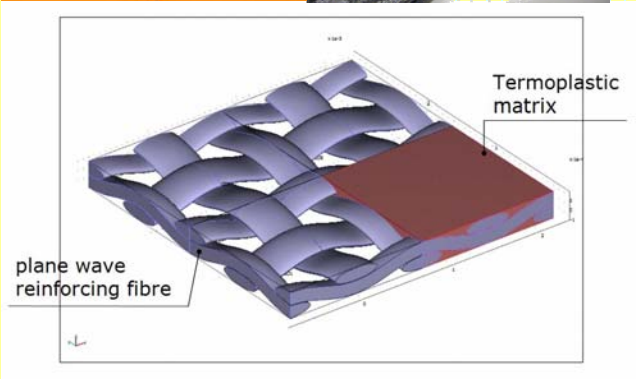
To implement user defined ***hyperelasic constitutive laws*** in a numerical model to simulate a ***new thermoplastic composite*** (TPC) forming process and validate the models by experimental measurements

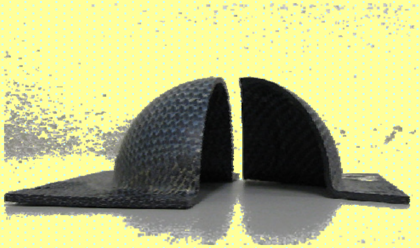
THE THERMOPLASTIC COMPOSITES (TPC)





Are made of reinforced fibres in a thermoplastic resin





ADVANTAGES:

I. the TPC in laminate form can be re-heating and successively formed – speed up the TPC production parts

II. some well known metal forming technologies applicable to the TPC forming process

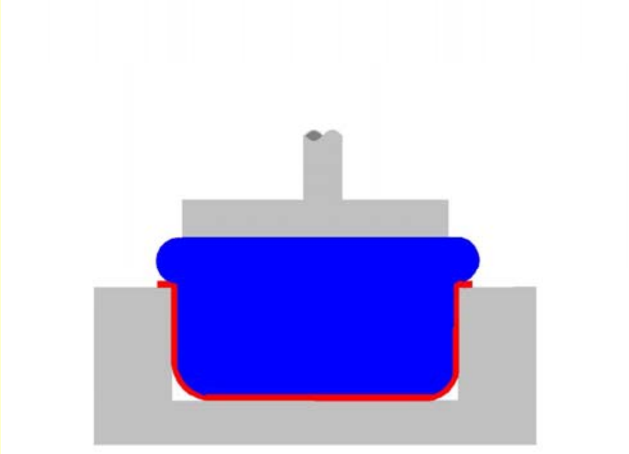
DISADVANTAGES:

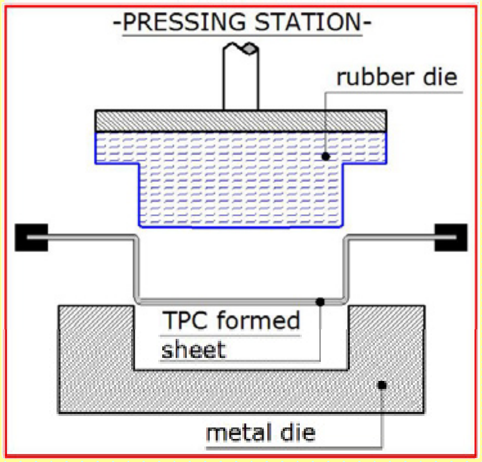
I. relatively low glass transaction temperature for thermoplastic resins

II. the friction in the fibres reduce the layers sliding consequently the TPC formability to any part shapes

TPC - THERMOFORMING PROCESS

The "Classic" forming process use metal and rubber matching dies to form pre-peg TPC laminate previously heated





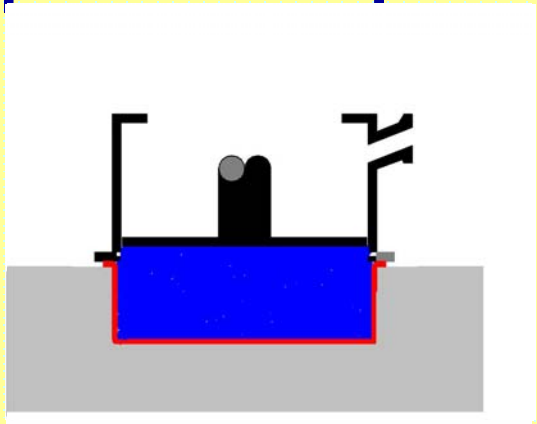
DISADVANTAGES:

I. *low quality of corner detail*

II. *barrelling effect*

NEW TPC THERMOFORMING PROCESS

In the "new" forming process a collection of rubber particles replace the solid "classic" rubber die



ADVANTAGES:

I. *the rubber particles behaviour as a fluid, filling almost all cavity shape*
II. *only the degraded particles must be replaced*
III. *new TPC parts shape require just new metal die replacement*

DISADVANTAGES:

I. *the low surface finishing on the side of rubber particles die*

THE INVESTIGATED PARAMETERS

In this investigation three types of rubber hardness and two rubber particles geometric shape were examined

RUBBER HARDNESS / ***GEOM SHAPE***	20 Shore A	30 Shore A	35 Shore A
ELLIPSOID			
CUBIC			

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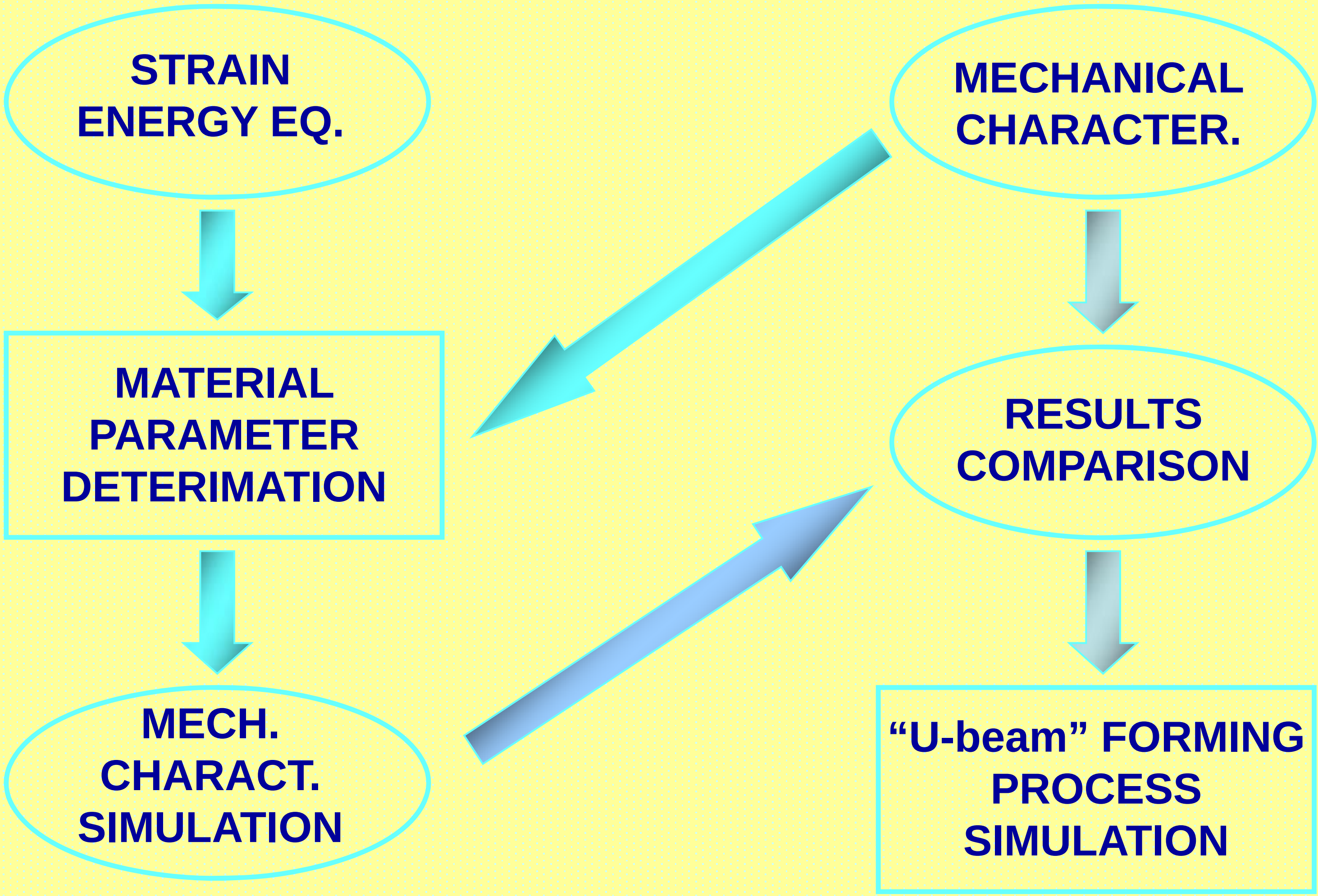
The rubber particles collection were modelled as an

I. *homogeneous continuum material by means their "macroscopic" mechanical properties*

II. *absence of external friction (rubber particles – metal die)*

THERMOFORMING PROCESS: THE INVESTIGATION STEPS



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Assumption of de-coupling principle:

$W(I_1, I_2, I_3) = W_{is}(I_1, I_2, I_3) + W_{vol}(J)$ – I_n PRICIPAL STRAIN INVARIANTS

$W(\lambda_1, \lambda_2, \lambda_3) = W_{is}(\lambda_1, \lambda_2, \lambda_3) + W_{vol}(J)$ – λ_n PRICIPAL STRATCHES

Simplified volumetric term:

$$W(J) = \frac{\kappa}{2}(J-1)$$

J – right Couchy strain tensor determinant

κ – bulk modulus

NEW TPC THERMOFORMING PROCESS: THE HYPERELASTIC LAWS 2/2

Isochoric term:

Three constitutive laws were employed in this investigation

I. Mooney-Rivlin – simplest model

$$W(I_1, I_2) = C_{10}(I_1 - 3) + C_{01}(I_2 - 3)$$

II. Beda – for small and large stretches

$$W(I_1, I_2) = \sum_{1}^{M}{}_i \frac{C_{i0}}{i} \cdot (I_1 - 3)^i + K \cdot \ln \frac{I_2}{3}$$

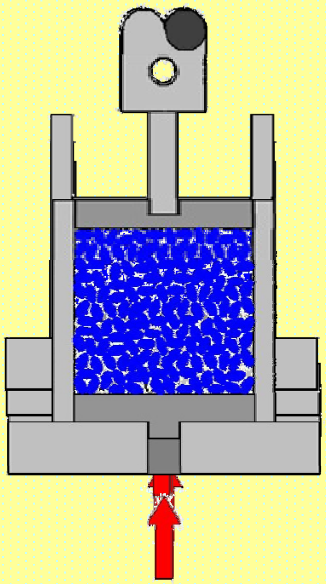
III. Ogden – adequate for large stretches

$$W(\lambda_1, \lambda_2, \lambda_3) = \sum_{1}^{M}{}_i \frac{\mu_i}{\alpha_i} \cdot \left(\lambda_1^{\alpha i} + \lambda_2^{\alpha i} + \lambda_3^{\alpha i} - 3\right)$$

	Mooney-Rivlin	Beda	Ogden
Number of parameter	2 + 1	M = 3, + 1	M = 6, + 1
Isochoric parameters	C_{10}, C_{01}	C_{10}, C_{20}, C_{30}, K	α_1, α_2, α_3, μ_1, μ_2, μ_3
Volume parameters	κ	κ	κ

NEW TPC THERMOFORMING PROCESS: THE CHARACTERIZATION TESTS

Confined compression tests (CC Test) were performed on the rubber particles in a cylindrical container in a quasi-static mode



20 Shore A 30 Shore A 35 Shore A

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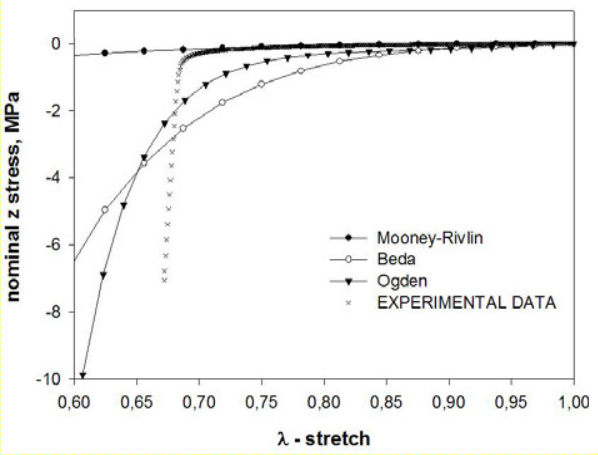
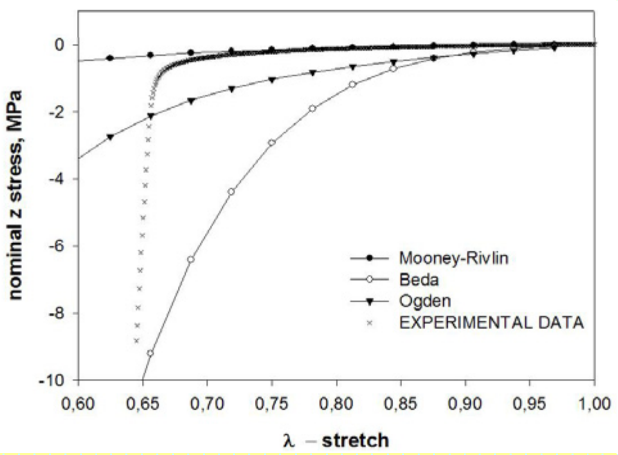
NEW TPC THERMOFORMIN PROCESS:
NUMERICAL vs. EXPERIMENTAL RESULTS

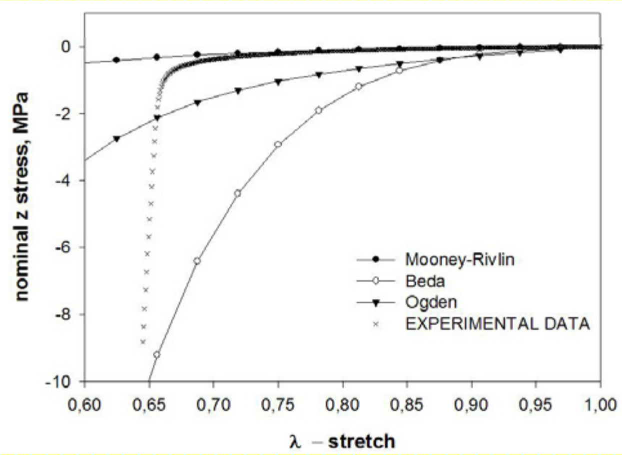
The results of a 2D axial-symmetric FEM model were compared to the experimental CC Tests



20 Shore A



30 Shore A



35 Shore A

OBSERVATIONS:

I. *the model with higher parameter numbers (Beda and Ogden) fit better the experimental data than the Mooney-Rivlin one*

II. *the Beda and Ogden predictions perform differently with the rubber hardness*

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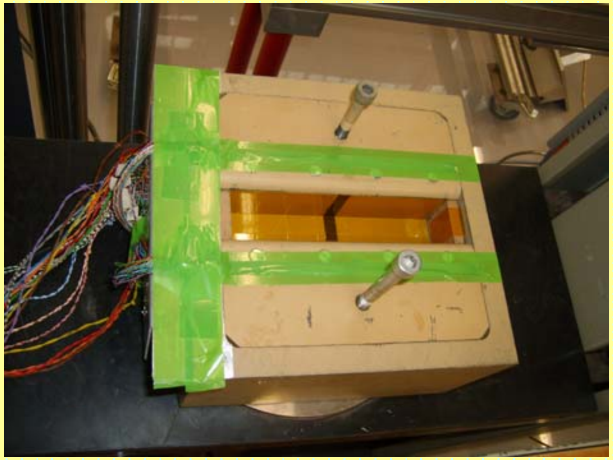
To value the pressure distribution on the metal die surface



TEST CONDITIONS:

I. no TPC laminate between the rubber particles and metal die

II. room temperature test

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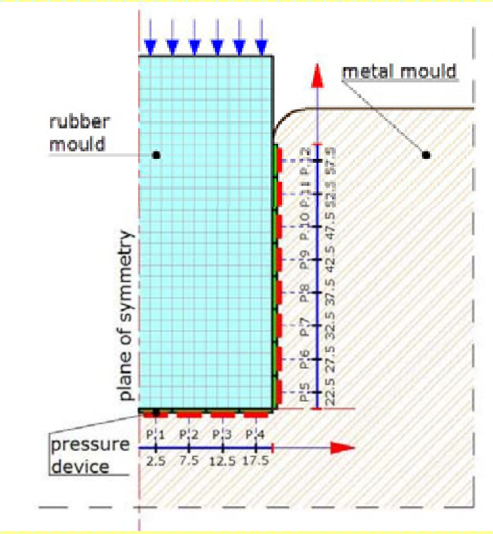
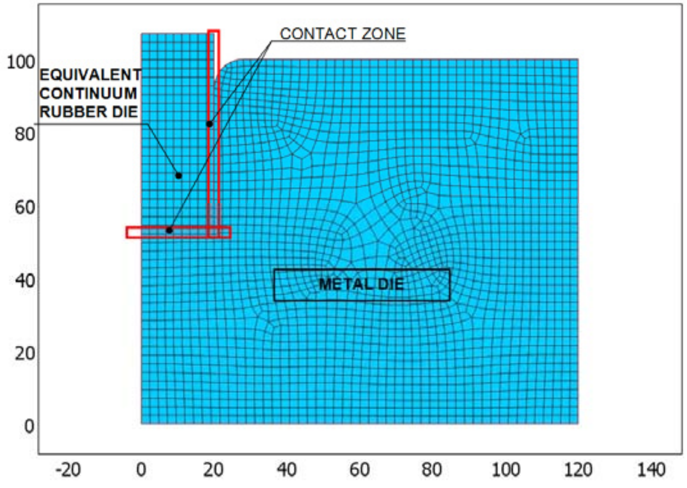
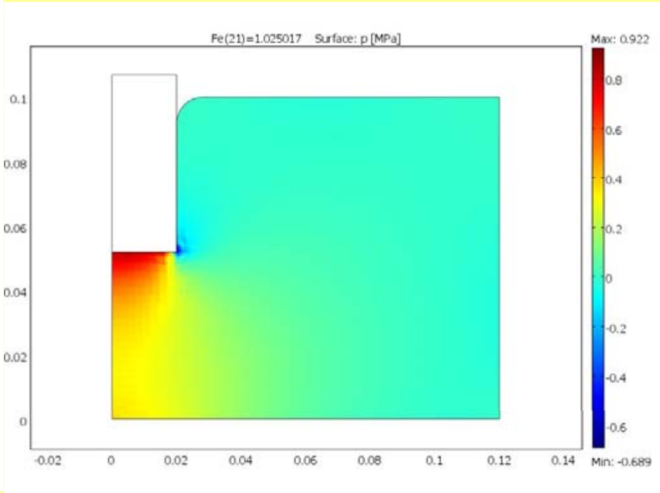
NEW TPC THERMOFORMING PROCESS:
"U-BEAM" PRESSING FORMING SIMULATION







SIMULATION CONDITIONS:

I. half symmetric 2D forming device

II. large displacement in plane strain structural mechanics mode

III. contact boundary condition between rubber and metal die

IV. parameterized boundary applied load

V. no friction contact

VI. Beda and Ogden constitutive laws

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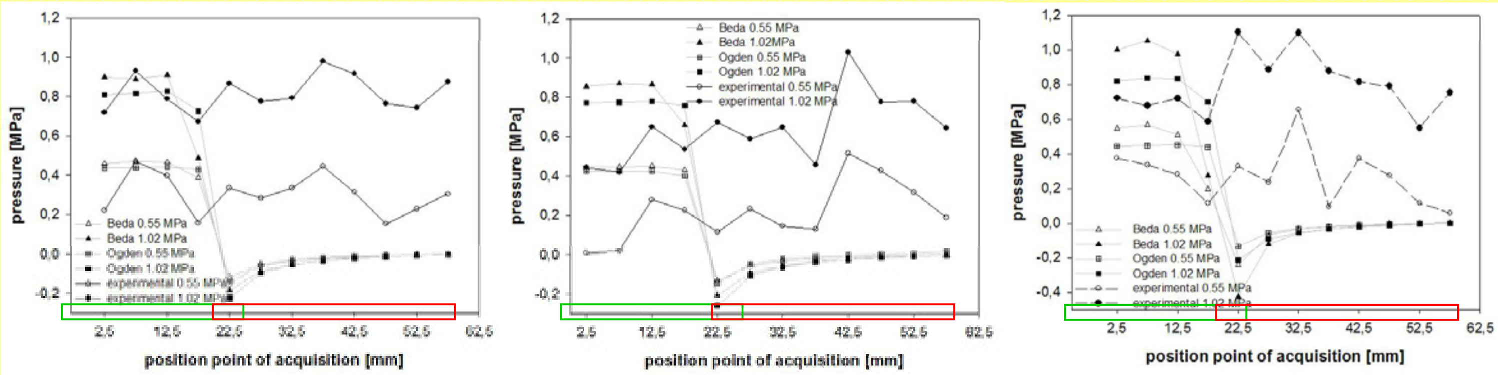
“U-BEAM” PRESSING FORMING TEST
EXPERIMENTAL VS. NUMERICAL RESULTS

The pressure distributions along the contact boundary line were acquired on the pressing device



horizzontal wall

vertical wall

EXPERIMENTAL

- I. *no corner effect*
- II. *pressure distribution independent from contact evaluation zone*

NUMERICAL

- I. *pressure reduction near the corner*
- II. *influence of the contact line on the pressure distribution*

- I. *the frictionless FEM model didn’t catch the experimental pressure distribution on the whole contact surfaces*
- II. *the horizontal contact zone was better fitted by Ogden model*
- III. *the impossibility to predict by FEM simulation the process involving cubic rubber particles shape*

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NEW TPC THERMOFORMIN PROCESS: CONCLUSIONS

The "U-beam" forming model didn't fit well the test data on the whole extension of the contact zone

I. The external friction rubber-metal die contact have to be evaluated

II. More mechanical rubber particles tests types have to be performed in order to improve the hyperelastic material constants valuation

The COMSOL Multiphisycs graphic interface was an extremely flexible tool to implement user defined constitutive material laws

THANK YOU VERY MUCH FOR YOUR ATTENTION