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UNIVERSIDAD DE MÁLAGA

EXPERIMENTAL-NUMERICAL CORRELATION OF A PADEL RACKET SUBJECT TO IMPACT

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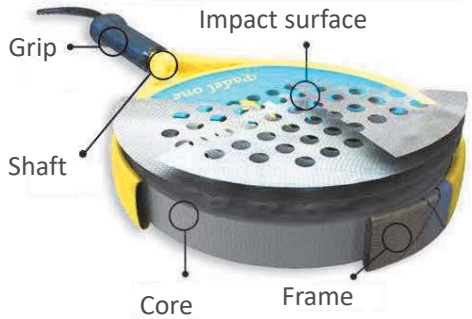
Outline

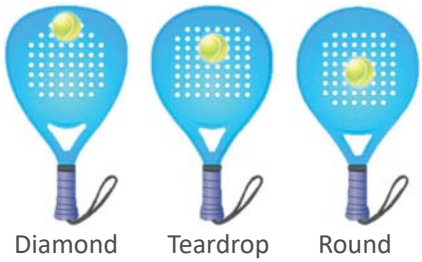
- Motivation
- Padel racket: main features
- Study case: Marvel model
- Material properties' evaluation/estimation
- FEM modelization
- Static & impact tests
- Results
- Conclusions

Motivation

DESIGN PARAMETERS



Fuente: https://www.padelshack.com/how-to-choose-a-padel-racket/



Fuente: https://www.webconsultas.com/ejercicio-y-deporte/material-deportivo/como-elegir-la-pala-de-padel-adecuada- 14616.

SHARK PADEL

Small company from Málaga

PLAYER'S SENSATIONS

Fuente: http://www.hellopadel.org/padel/new/Jeremy-Gala-Belgian-WPT-Padel-player

Motivation

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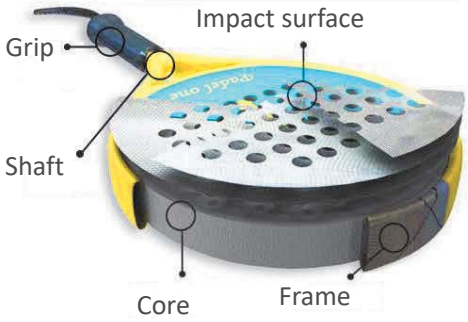

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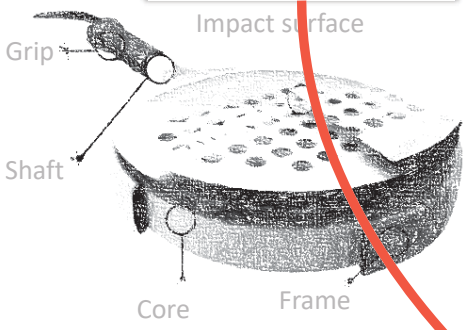

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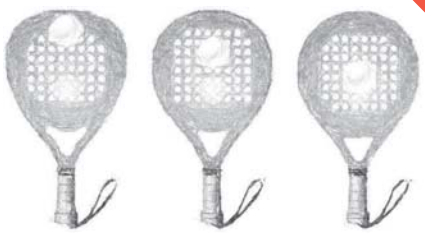

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PLAYER'S SENSATIONS

Fuente: http://www.hellopadel.org/padel/new/Jeremy-Gala-Belgian-WPT-Padel-player

Padel racket: main features

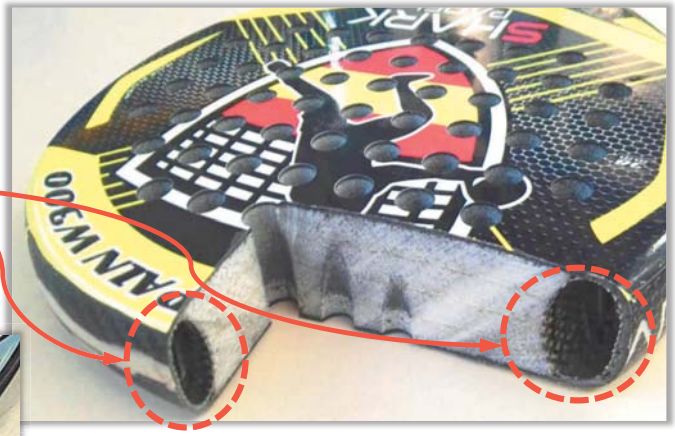
Padel racket: main features

Frame: stiffness

Strike surface
Balanced stiffness
(durability)

Shaft: stiffness
Vibration reduction

Grip



Padel racket: main features

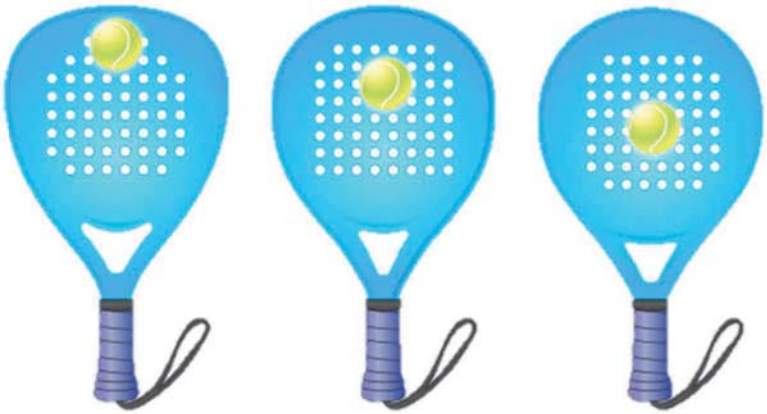
Frame: stiffness

Strike surface
Balanced stiffness
(durability)

Shaft: stiffness
Vibration reduction

Grip

Sweet spot



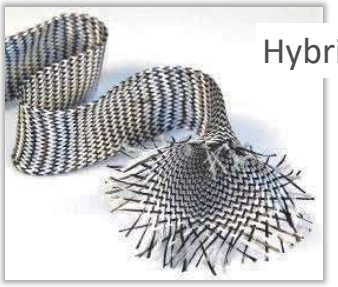
Diamond Teardrop Round

Fuente:
https://www.webconsultas.com/ejercicio-y-deporte/material-deportivo/como-elegir-la-pala-de-padel-adecuada- 14616.

Study case: Marvel racket

Type: ROUND

- Balanced glass fabric:220 gr/m^2.
- Twill 3K carbon fibre 2×2: 200 gr/m^2 .
- Hybrid braiding carbon/glass 40 mm: 39.8 gr/m.
- EVA foam (Ethylene-vinyl acetate).
- Multipurpose epoxy resin for manual lamination.



Hybrid braiding

Fuente: https://www.castrocompositesshop.com

Study case: Marvel racket

Glass fiber $[0/90]_3$

Braiding

Foam EVA

Glass fiber $[0/90]_3$

Foam EVA

(Poly) Ethylene-vinyl acetate

Glass fiber $[0/90]_3$

Foam EVA

Carbon fiber [0/90]

Braiding

Internal wall

Carbon fiber [0/90]

Study case: Marvel racket

Glass fiber $[0/90]_3$

Braiding

Foam EVA

Glass fiber $[0/90]_3$

Foam EVA

(Poly) Ethylene-vinyl acetate

Glass fiber $[0/90]_3$

Foam EVA

Carbon fiber [0/90]

Braiding

Internal wall

Carbon fiber [0/90]

Study case: Marvel racket

Glass fiber $[0/90]_3$

Braiding

Foam EVA

Glass fiber $[0/90]_3$

Foam EVA
(Poly) Ethylene-vinyl acetate

Glass fiber $[0/90]_3$

Foam EVA

Carbon fiber [0/90]

Braiding

Internal wall

Carbon fiber [0/90]

Study case: Marvel racket

Glass fiber $[0/90]_3$

Braiding

Foam EVA

Glass fiber $[0/90]_3$

Foam EVA
(Poly) Ethylene-vinyl acetate

Study case: Marvel racket

Glass fiber $[0/90]_3$

Braiding

Foam EVA

Glass fiber $[0/90]_3$

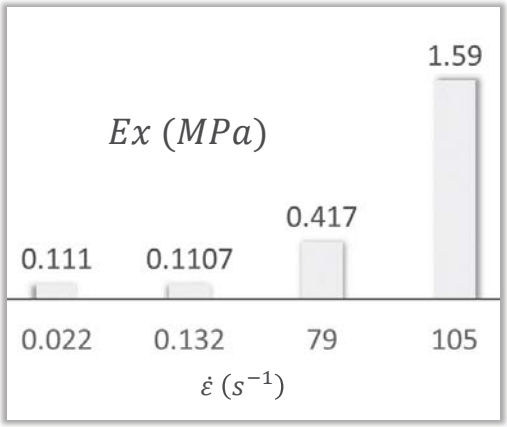
Foam EVA
(Poly) Ethylene-vinyl acetate

Material properties' evaluation

Cylindrical specimens
$\emptyset$ 25 mm

	$\dot{\varepsilon}\ (s^{-1})$	$Ex\ (MPa)$ Average	$Ex\ (MPa)$ Deviation
Quasi-static Tests (1)	22.10^{-3}	0,111	0,003
	132.10^{-3}	0,1107	0,0004
Low velocity impact test (2)	79	0,417	0,008
	105	1,59	0,02

Core: EVA foam
Viscoelastic behavior

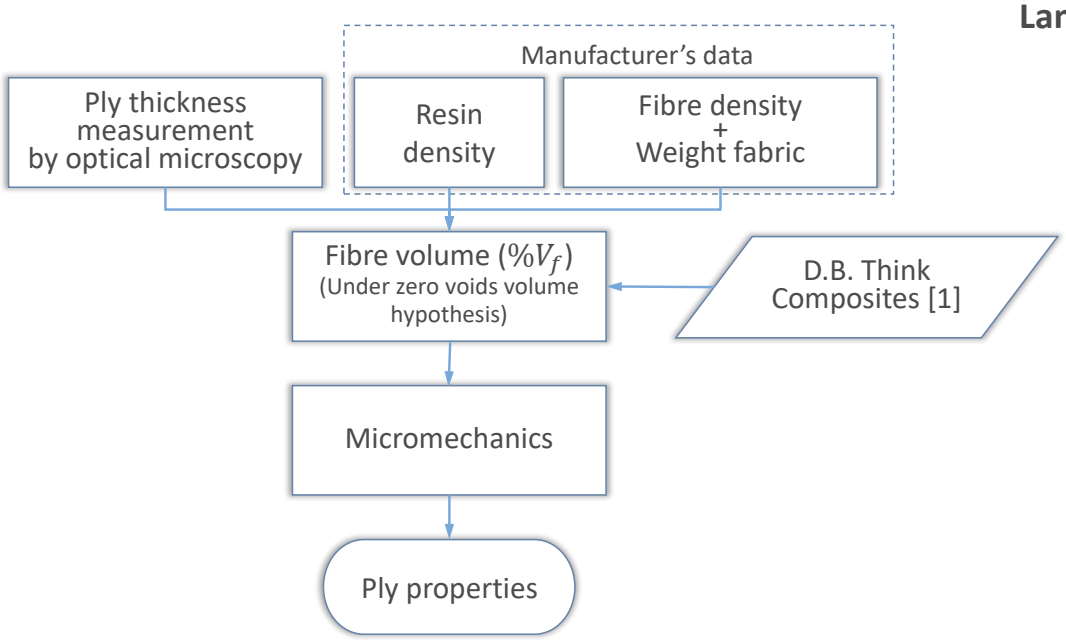


(1) Universal test machine Servosis ME-405/10. Load cell $1\ kN$

(2) Drop test machine Instron CEAST 9350. Load cell $2{,}25\ kN$

Material properties' evaluation

Laminates



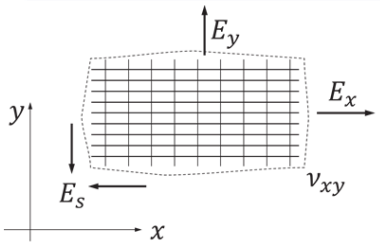
[1] Notice d'utilisation des logiciels (MIC-MAC, GENLAM, LAMRANK, MATFIX). THINK COMPOSITES.

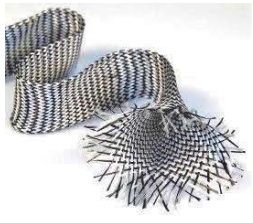
Material properties' evaluation

Laminates

Fabric ply

Property	Carbon	Glass
$E_x = E_y$	32.5 GPa	12.2 GPa
E_s	2.6 GPa	1.9 GPa
ν_{xy}	0.04	0.09
$X = Y$	299 MPa	296 MPa
$X' = Y'$	414 MPa	228 MPa
S	73 MPa	222 MPa
V_f	29 %	25 %
Density	1270 kg/m^3	1430 kg/m^3
Thickness	0.39 mm	0.33 mm



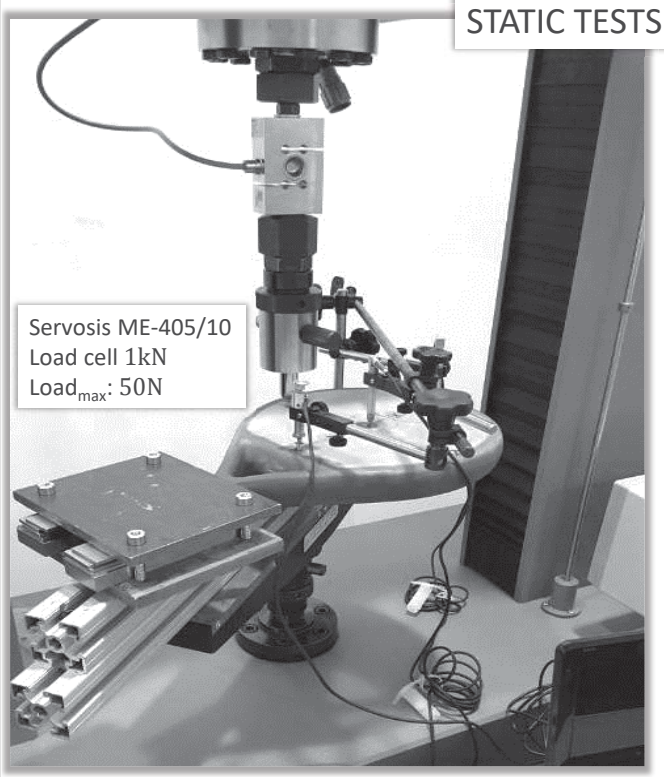


Hybrid braiding

Property	Unidirectional ply	
	Carbon	Glass
E_x	59.5 GPa	20.25 GPa
E_y	5.3 GPa	4.04 GPa
E_s	2.6 GPa	1.9 GPa
ν_{xy}	0.28	0.26
X	621 MPa	590 MPa
X'	562 MPa	328 MPa
Y	40 MPa	93 MPa
Y'	246 MPa	354 MPa
S	68 MPa	216 MPa
Density	1270 kg/m^3	1430 kg/m^3
Thickness	0.099 mm	0.121 mm

Static & Dynamic (impact) tests

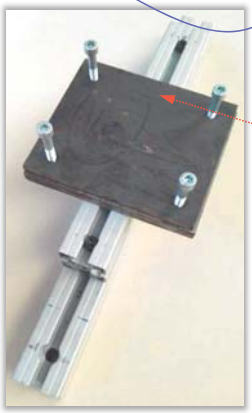
STATIC TESTS

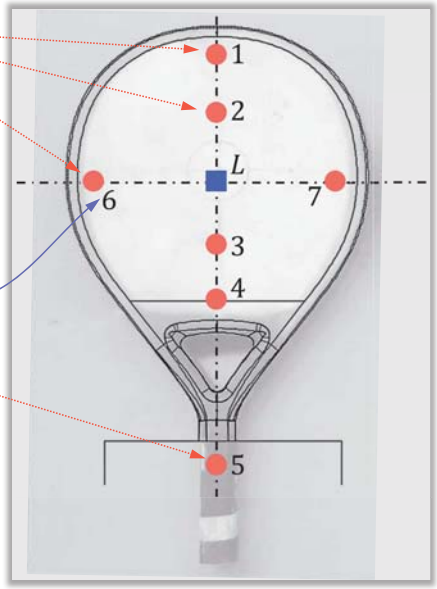


Servosis ME-405/10
Load cell 1kN
$Load_{max}$: 50N

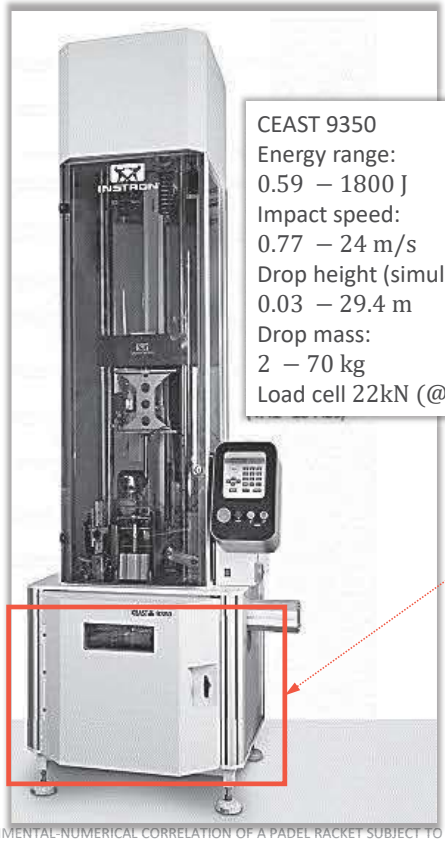
LVDTs
(1) $L_0 = 4mm\ (\pm 1\mu m)$
(2) $L_0 = 5mm\ (\pm 2.5\mu m)$

Load



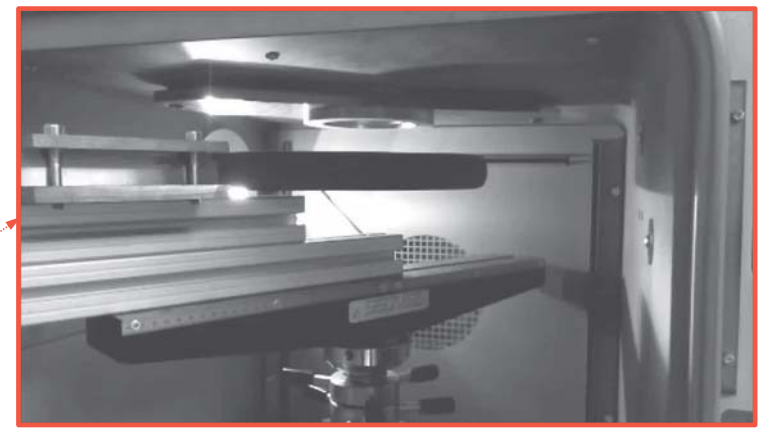


Static & Dynamic (impact) tests



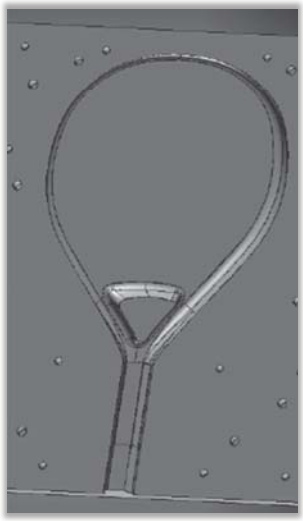
CEAST 9350
Energy range:
$0.59\ -1800$ J
Impact speed:
$0.77\ -24$ m/s
Drop height (simulated):
$0.03\ -29.4$ m
Drop mass:
$2\ -70$ kg
Load cell 22kN (@ 10%)

IMPACT TESTS



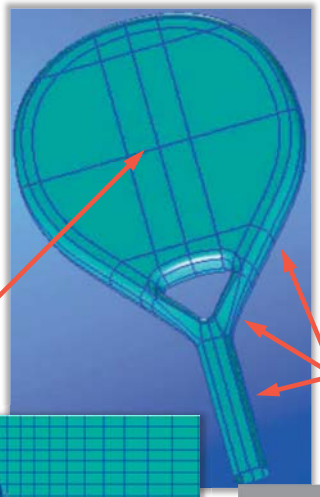
FEM modelization

1. Linear elastic analysis: properties' validation
2. Non-linear explicit dynamic: impact analysis

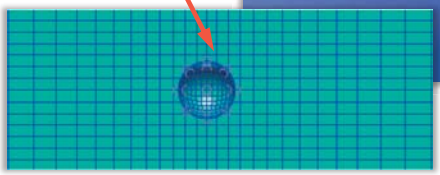


CAD model from mold's manufacturer

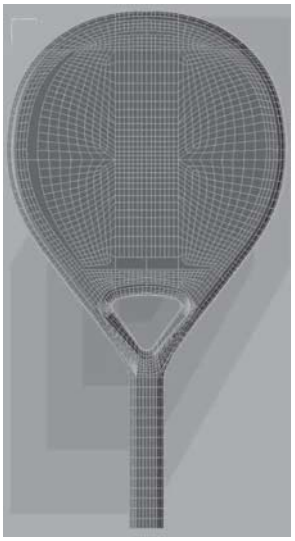
MSC-NASTRAN model



3D linear elements

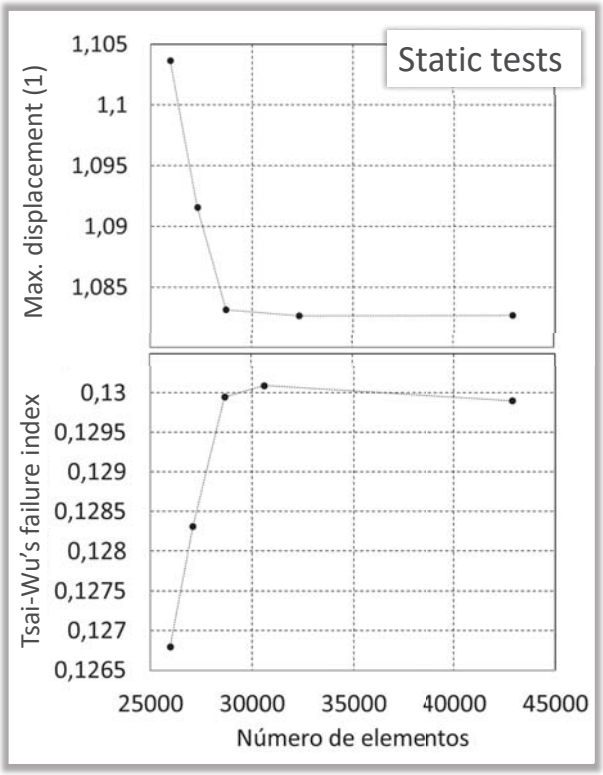


2D linear elements

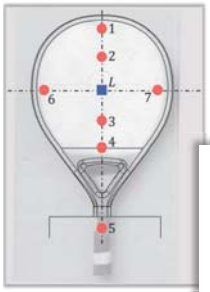


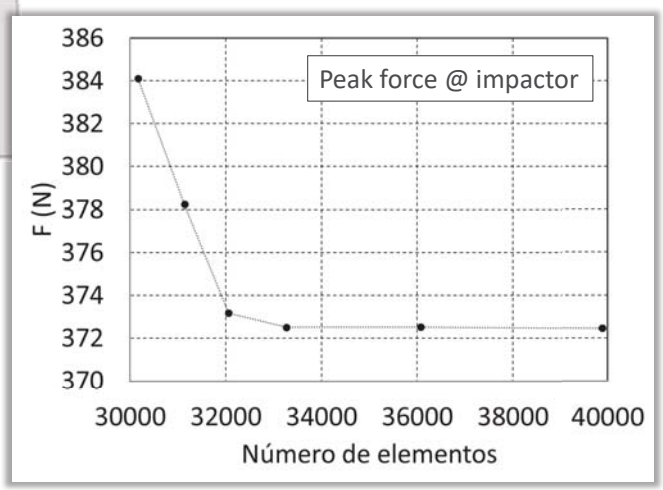
FEM modelization

Static tests



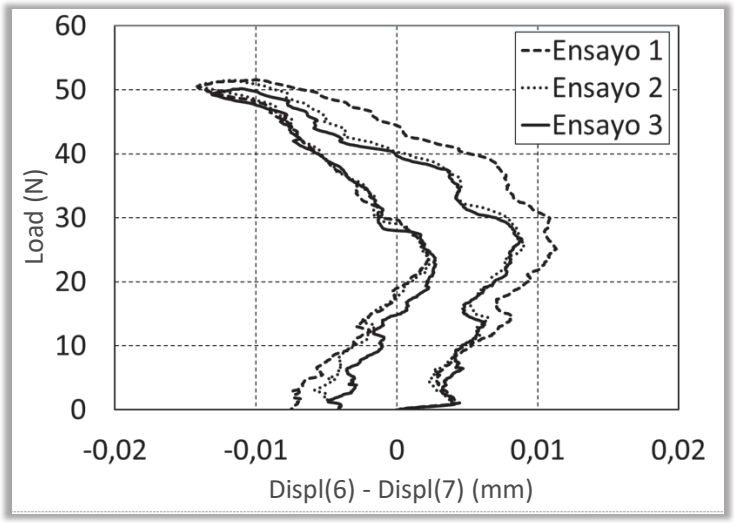
IMPACT TESTS



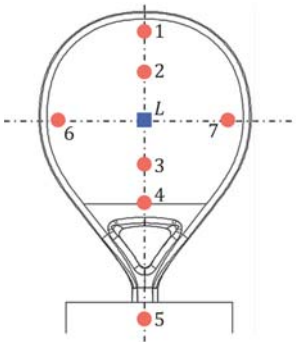


Results

STATIC TESTS

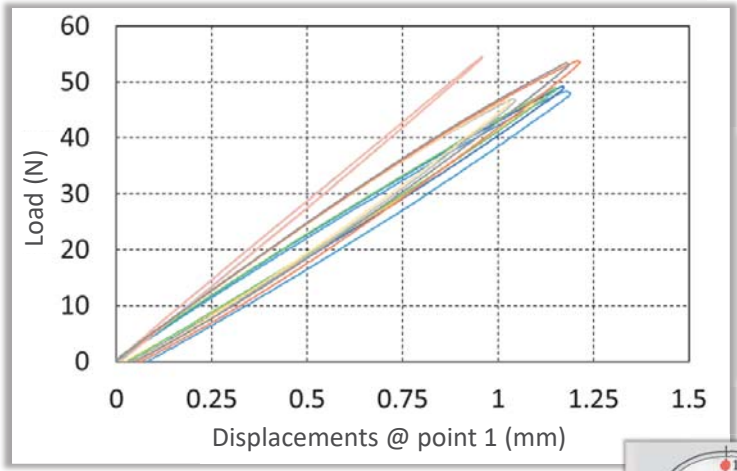


	Measurement points						
	1	2	3	4	5	6	7
1st step of test							
2nd step of test							
3rd step of test							

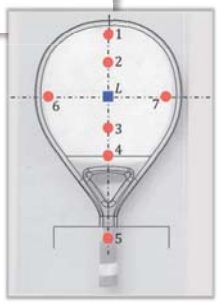


Results

STATIC TESTS



Results for the three specimens



- Quasi-linear behavior.
- Hysteresis caused by the foam and (probably) by a non linear behavior of the racket.
- Some dispersion between specimens.
- Dissimilar behavior between both faces of the specimens.

Compatible with a handicraft manufacturing procedure

IMPACT TESTS

Impact test conditions:

Mass: $2{,}41\ kg$ } ⇒ Impact velocity: $1{,}42\ m/s$

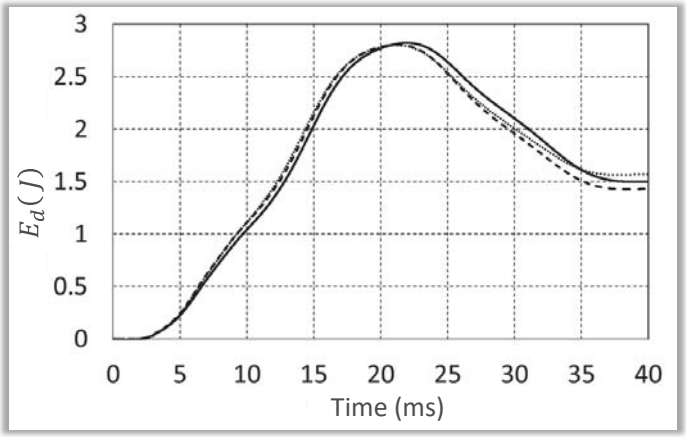
Height: $0{,}1\ m.$ } ⇒ Impact energy: $2{,}36\ J.$

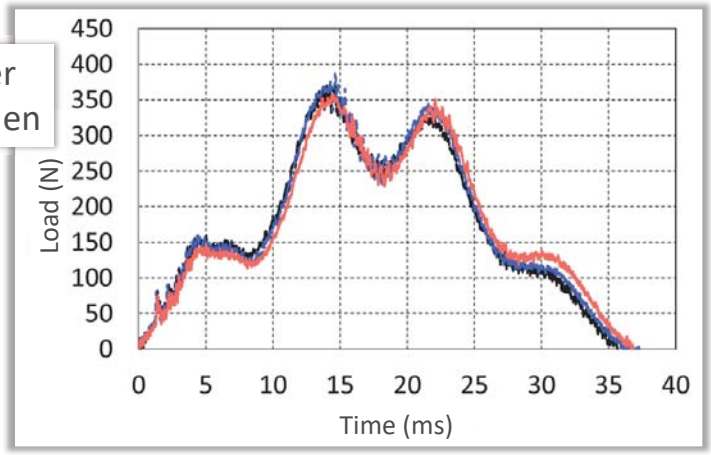
Acquisition frequency: $500\ kHz$

Acquisition time: $40\ ms$

Load cell: $22\ kN$ @ 10%

Three tests over the same specimen





$$E_d(t) = \int_0^t F(t) \cdot \left[v(0) + \frac{1}{m_{imp}} \cdot \int_0^t F(t)dt \right] dt$$

Results

IMPACT TESTS

Impact test conditions:

Mass: $2{,}41\ kg$ } ⇒ Impact velocity: $1{,}42\ m/s$

Height: $0{,}1\ m.$ } ⇒ Impact energy: $2{,}36\ J.$

Acquisition frequency: $500\ kHz$

Acquisition time: $40\ ms$

Load cell: $22\ kN$ @ 10%

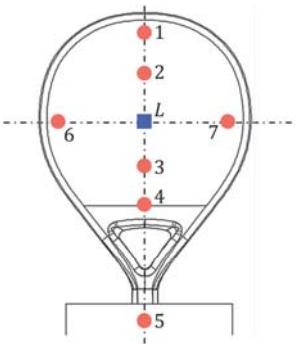
All over the tests:
3 specimens × 2 strike surfaces × 3 test

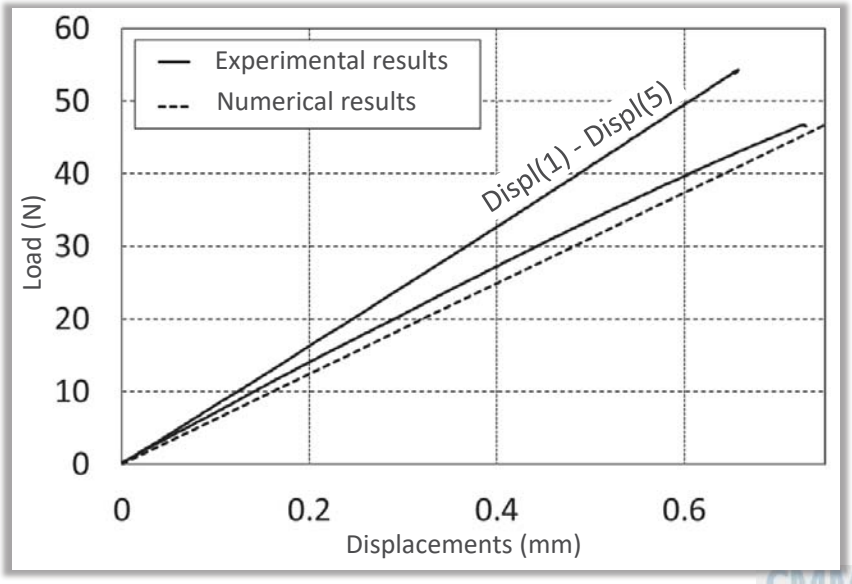
Contact force peak (N)	Contact time (ms)	Dissipated energy (% impact energy)
$366 \pm 3.8\ \%$	$37 \pm 2.3\ \%$	$49 \pm 5\ \%$

Results

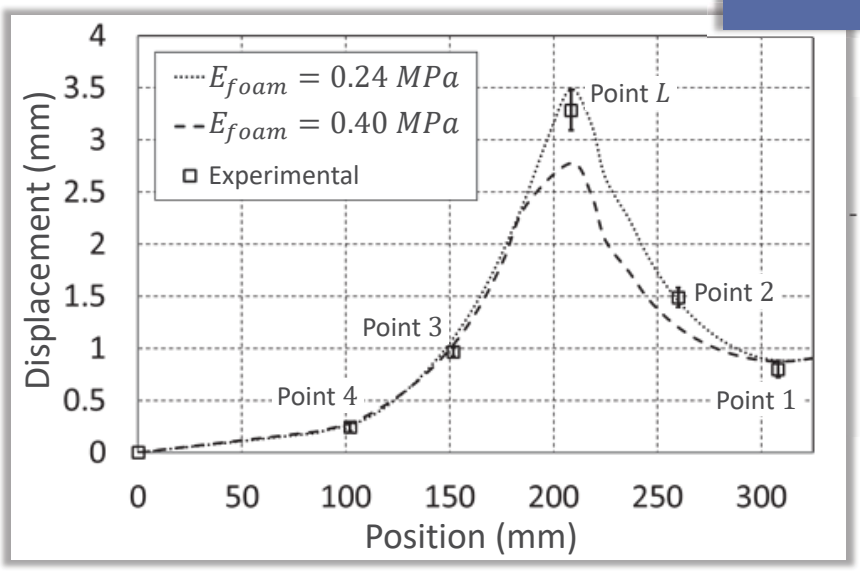
76% Experimental stiffness < Numerical stiffness < 95% Experimental stiffness

CORRELATION
Static results

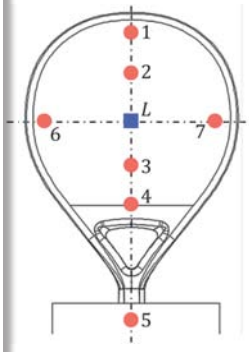




Results



CORRELATION
Static results

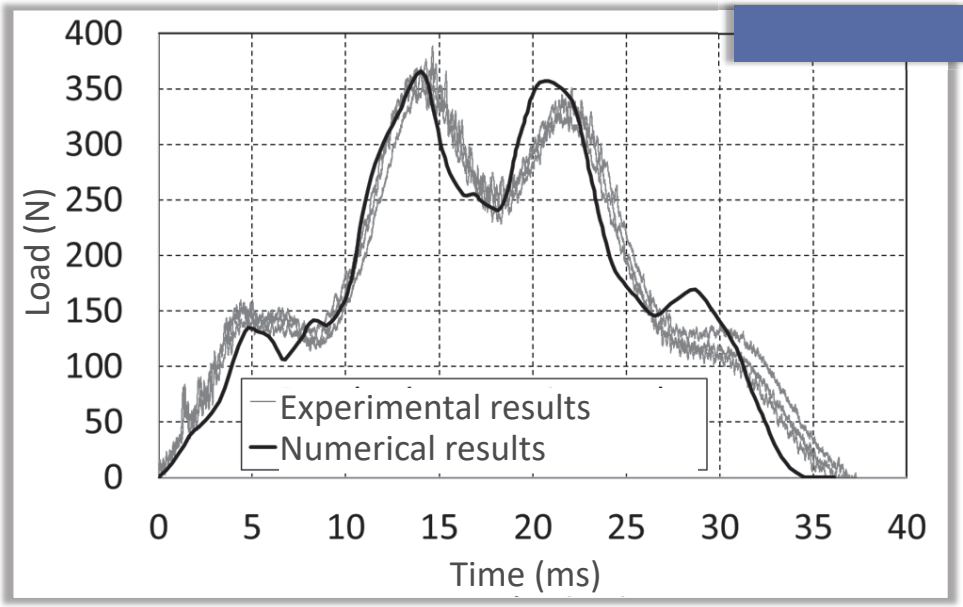


Foam behavior influence

$\dot{\varepsilon}\ (s^{-1})$	$Ex\ (MPa)$	
	Average	Deviation
22.10^{-3}	0,111	0,003
132.10^{-3}	0,1107	0,0004
79	0,417	0,008
105	1,59	0,02

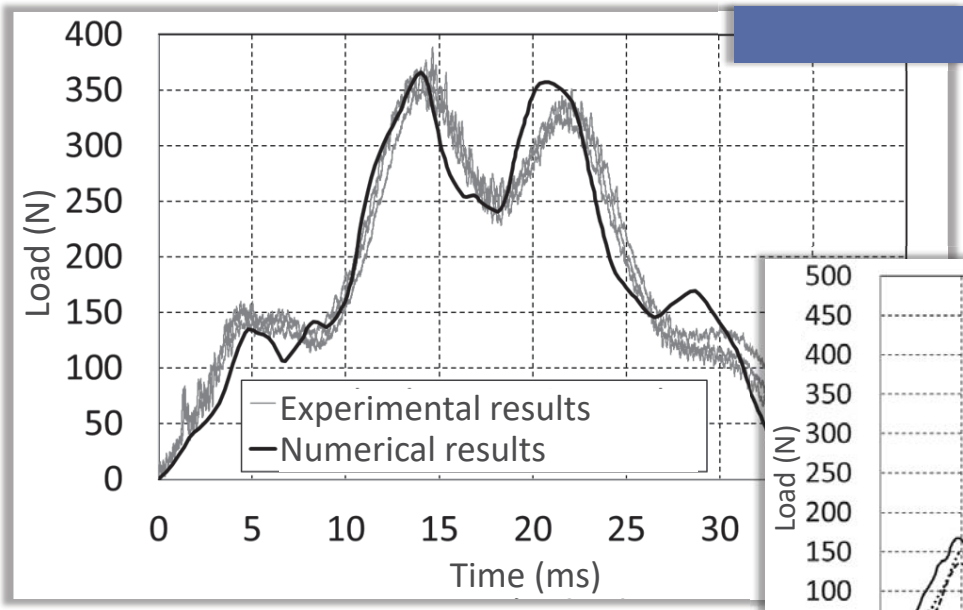
Results

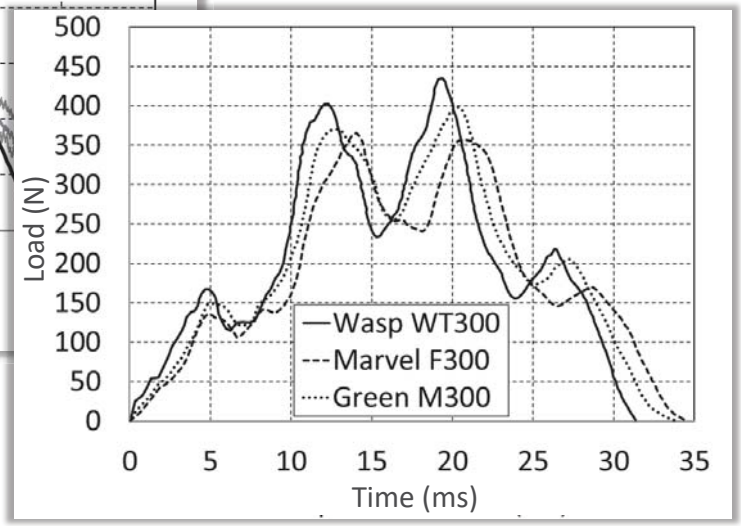
CORRELATION
impact results



Results

CORRELATION
impact results





Conclusions

A PRELIMINARY NUMERICAL MODEL
HAVE BEEN DEVELOPED
IT ALLOWS CORRELATE RACKETS' DESIGN PARAMETERS
WITH ITS FINAL BEHAVIOR

A FEM model have been developed with the aim of predict the racket's behavior before its manufacturing.

This model can be a useful tool to made efficient design decisions (materials and/or geometry).

The model have been validate by mean of static experiments.

Set up a methodology for estimating materials properties overcoming the impossibility to obtain viable samples.

Numerical force peaks and contact time capture significantly well the observed data which translates into a efficient evaluation of consumed energy.

Force vs. time results for Marvel FE model are consistent with the experimental records obtained for all over the tests.

Still working

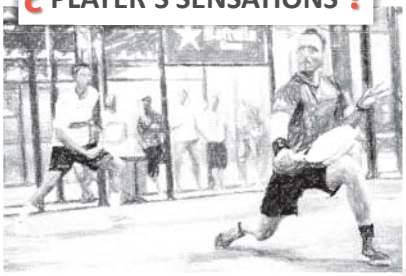
A deep analysis of viscoelastic behavior of foam must be done.

Of course, when holes are introduced in de model, the laminates will lose stiffness and, consequently, the foam behavior will gain leadership in the structural behavior of the racket.

The number, size and distribution of these holes will be parameters to take under consideration especially in the analysis of durability which would be the final step of this work.

SHARK PADEL

¿ PLAYER'S SENSATIONS ?



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We'll see

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Germán Castillo López; **Felipe García Sánchez**

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That's all
THANKS FOR YOUR KIND ATTENTION
Questions?