TriMech Simulation Solutions

Optimised Engineering Design

Multi-Functional Property Optimisation of an Adidas Football Boot using Abaqus and TOSCA Structure

TriMech Simulation Solutions

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Football Boot

- Do football players get a customised football boot?
- Yes…! But…only fit and colour!
- Need a bit more advanced customised football boots!

But…How to Optimise?

Athlete visit

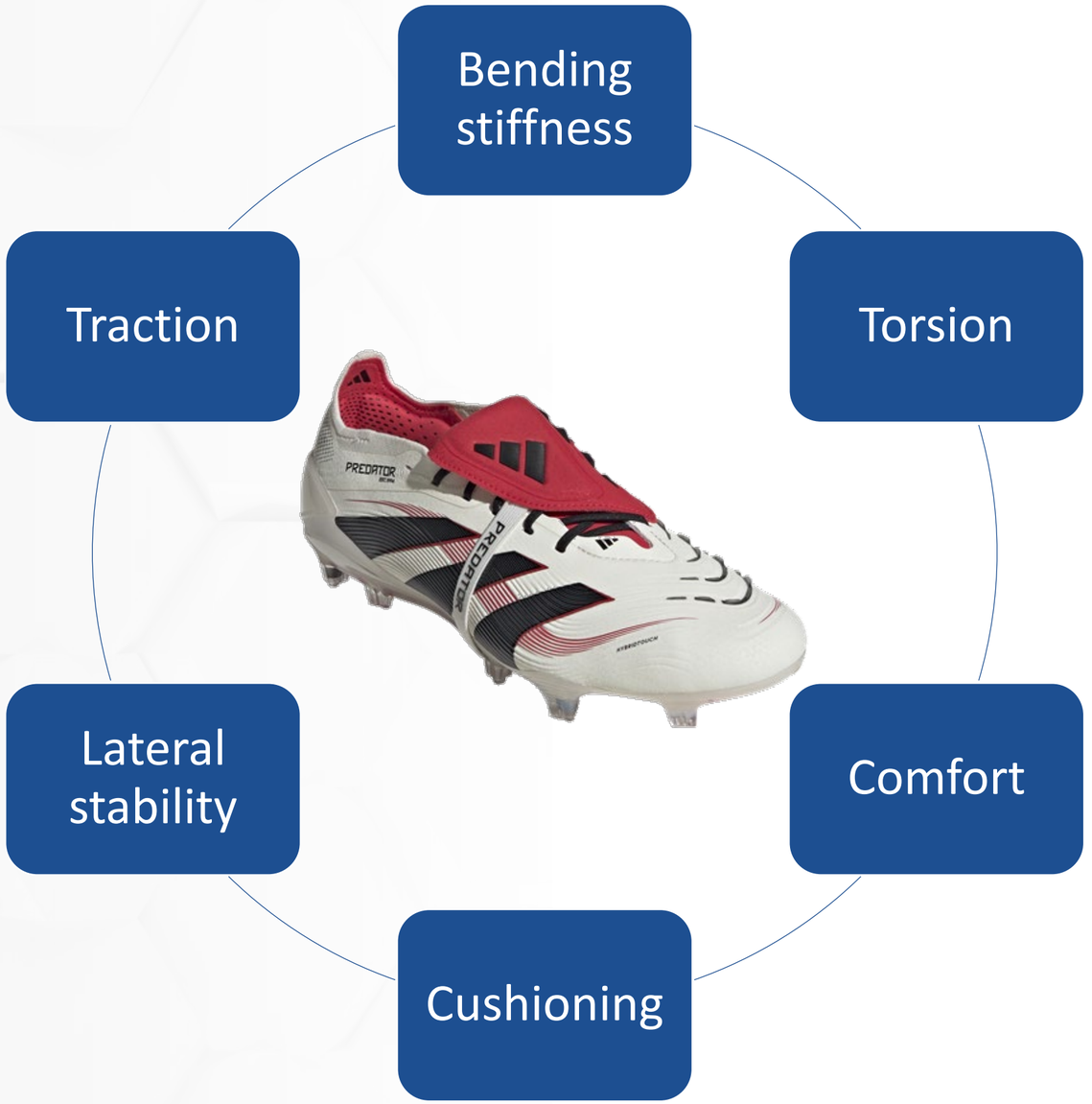
Optimisation loop

Production

- The optimisation process enables the creation of the customised football boot.

What Do You Mean by ‘Functional Property’?

Functional Properties of Football Boot

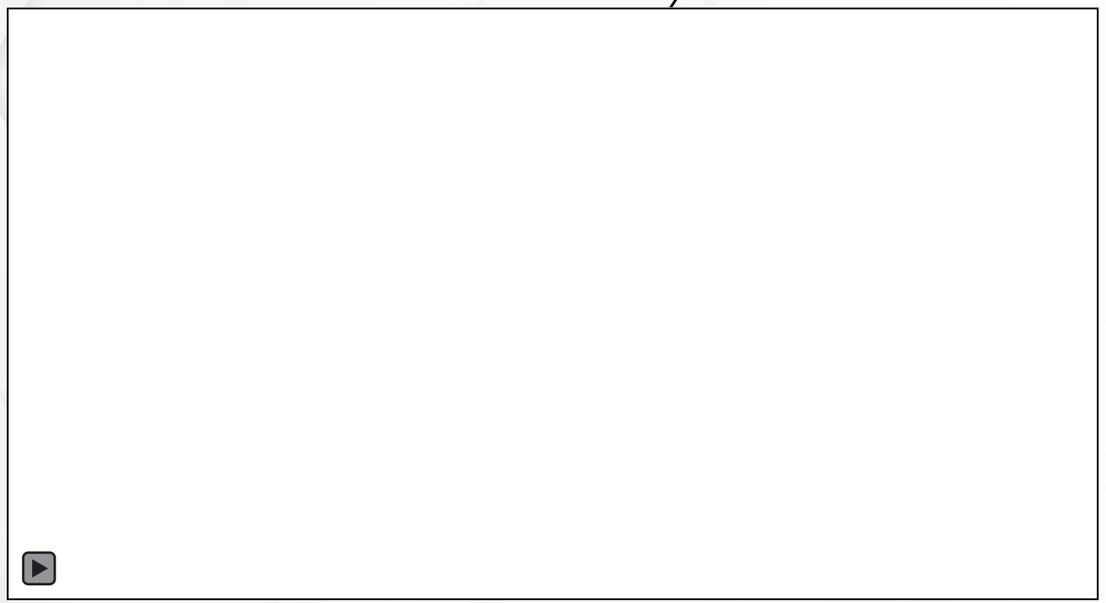


Importance of Functional Properties

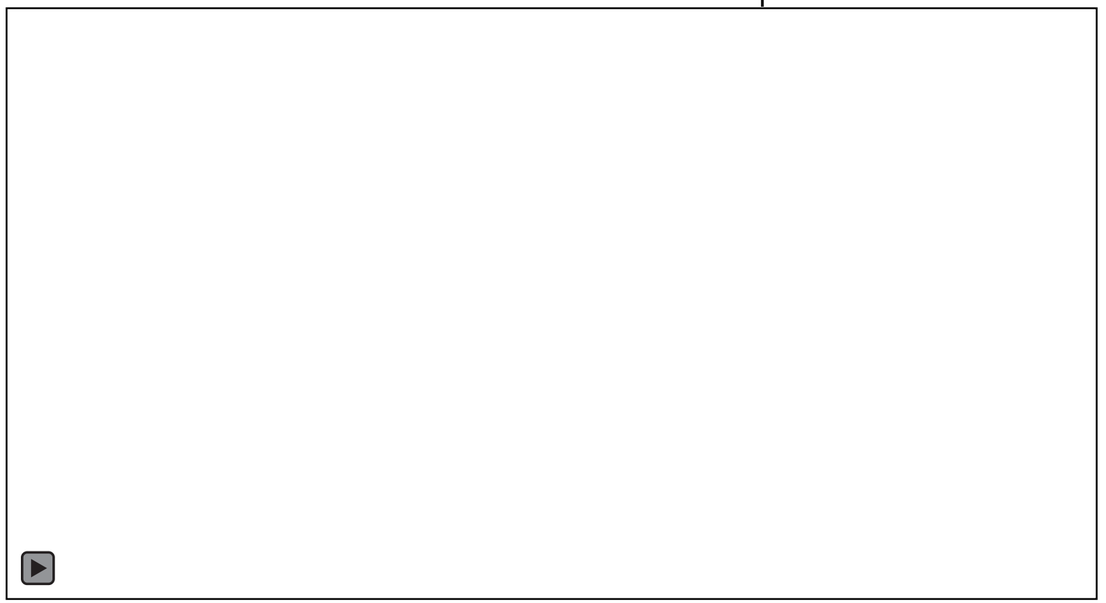
Inappropriate functional properties could influence…

- Athlete's performance
- Injury
- Score

Defender slips!



Watch his right ankle



Research Aim

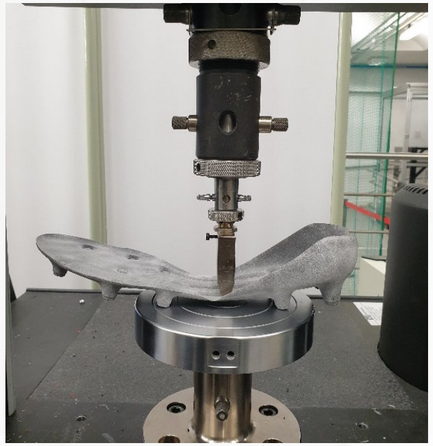
- The aim of the research was to investigate the relationship and interdependence of functional properties of a football boot outsole during a shape optimisation process.

- Three functional properties were investigated.
  - Midfoot bending stiffness (MFBS)
  - Forefoot bending stiffness (FFBS)
  - Torsional stiffness (TS)

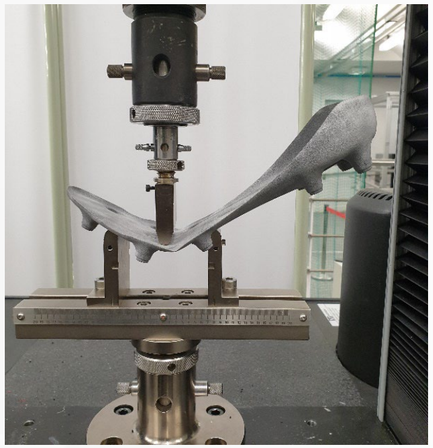
- Structural optimisation was applied based on Finite element analysis
  - Abaqus
  - TOSCA structure

Mechanical Characterisation of Functional Property

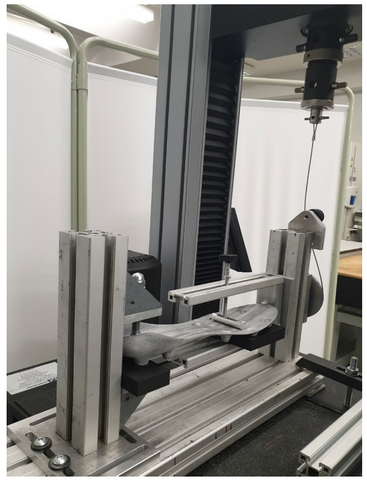
Midfoot bending

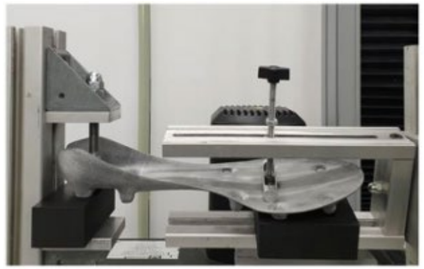


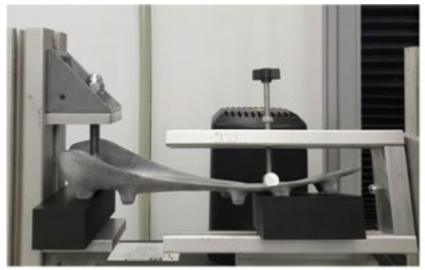
Forefoot bending



Torsion







FEA Simulation

- Finite element models for individual FP measurement and combined FP measurements were developed.

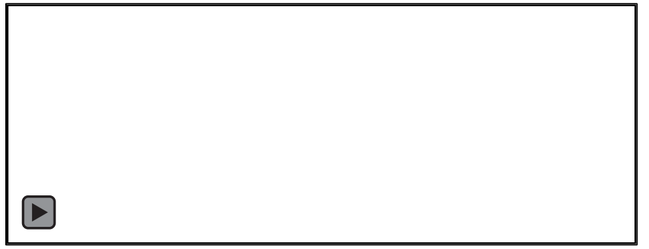
Individual FP simulation

Midfoot bending

Forefoot bending

Torsion

Combined FP simulation



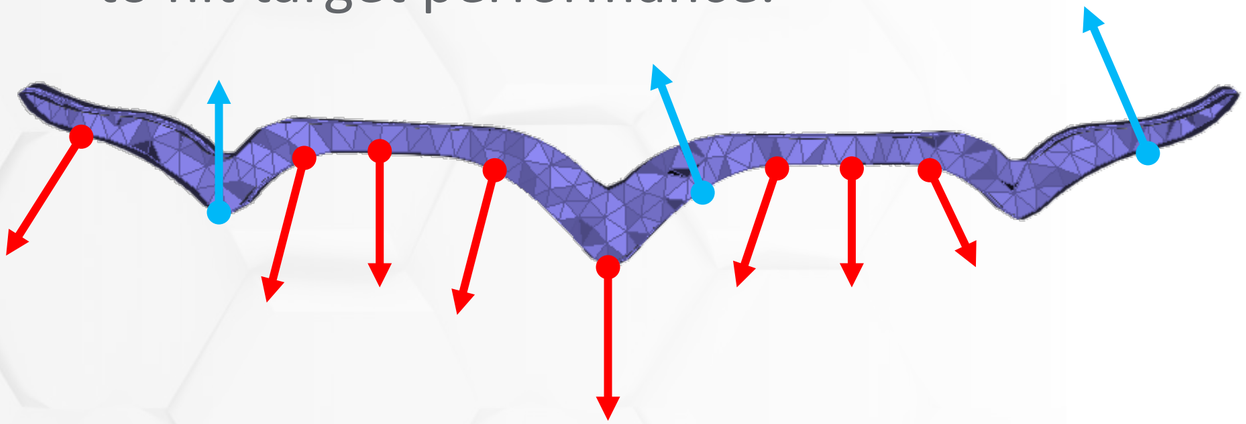
Midfoot bending + Torsion + Forefoot bending

Optimisation Study

Let’s Optimise!

Shape optimisation

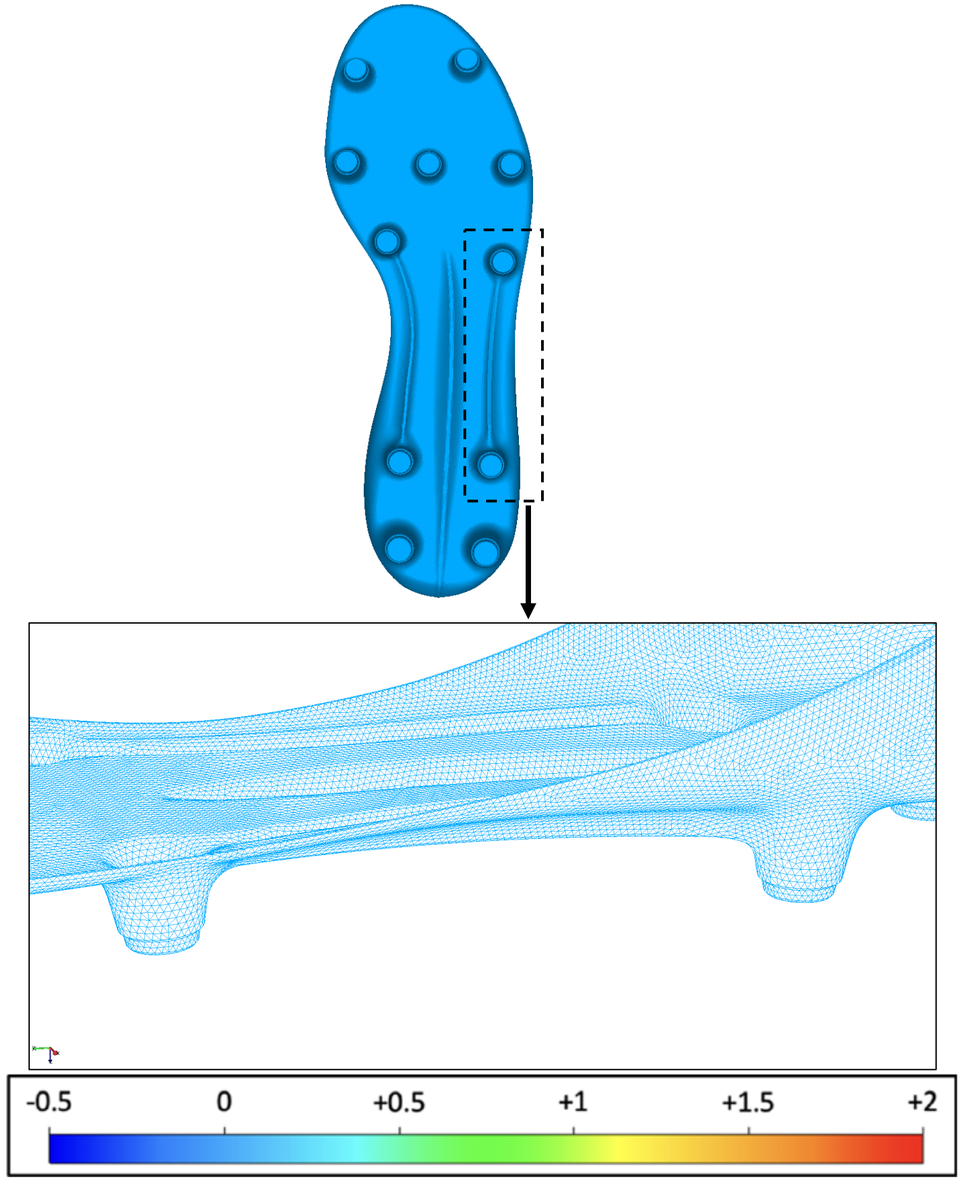
- Change the location of the surface nodes to hit target performance.



- Sensitivity-based algorithms

$$\frac{\mathrm{d}\boldsymbol{K}}{\mathrm{d}s} \approx \frac{\boldsymbol{K}(s+\Delta s)-\boldsymbol{K}(s)}{\Delta s}+\alpha$$

$\mathrm{d}\boldsymbol{K}$: Derivative of stiffness
$\mathrm{d}s$: Changes in the design variable
α : Correction factor



Surface nodes displacement [mm]

Optimisation Process Preparation

Optimisation task 1

- To investigate how much of each functional property could be changed by minimising the weight.

Optimisation task 2

- To investigate how much of each functional property could be changed while minimising the influence on the other functional properties and also minimising the weight.

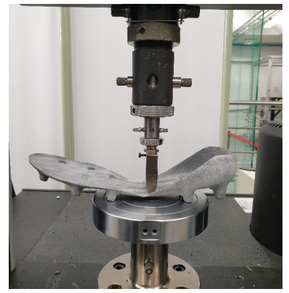
Optimisation Study Results (Midfoot Bending Stiffness)

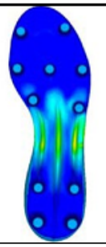
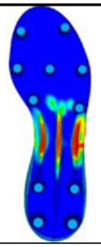
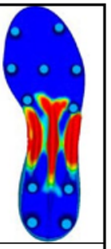
Optimisation task 1

- See how much of $MFBS$ could be changed.

- $-42\% \leq \Delta MFBS \leq +194\%$

- $-21\% \leq \Delta Weight \leq -1\%$



						
Design cycle	5	6	7	12	16	16
MFBS [N/mm]	16.1	22.2	27.7	40.2	55.4	81.4
ΔMFBS [%]	-42	-20	0	+45	+100	+194
Mass [g]	44.2	45.3	45.8	48.6	50.3	55.3
ΔMass [%]	-21	-19	-18	-13	-10	-1

Surface nodes displacement [mm]

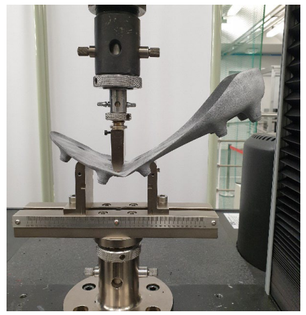
Optimisation Study Results (Forefoot Bending Stiffness)

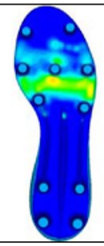
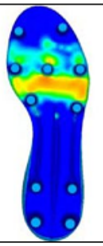
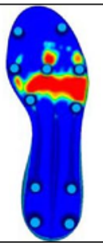
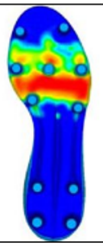
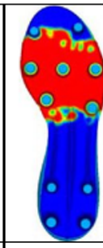
Optimisation task 1

- See how much of $FFBS$ could be changed.

- $-68\% \leq \Delta FFBS \leq +1189\%$

- $-21\% \leq \Delta Weight \leq +21\%$



									
Design cycle	6	9	8	6	17	24	25	25	20
FFBS [N/mm]	1.1	2.1	2.8	3.5	10.5	17.5	24.5	31.5	45.1
ΔFFBS [%]	-68	-40	-20	-1	+200	+400	+600	+800	+1189
Mass [g]	44.2	44.7	45.3	45.8	48.1	49.2	51.4	54.2	67.3
ΔMass [%]	-21	-20	-19	-18	-14	-12	-8	-3	+21

Surface nodes displacement [mm]

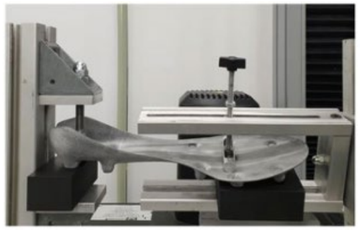
Optimisation Study Results (Torsional Stiffness)

Optimisation task 1

- See how much of TS could be changed.

- $-42\% \leq \Delta TS \leq +325\%$

- $-21\% \leq \Delta Weight \leq +38\%$



Optimisation task 1

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- $-42\% \leq \Delta TS \leq +325\%$
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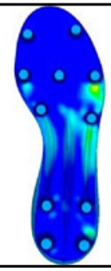
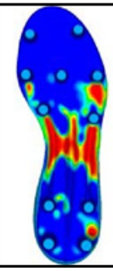
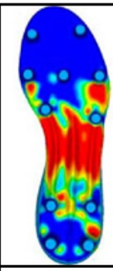
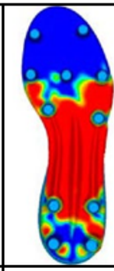
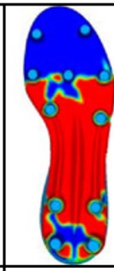
								
Design cycle	6	9	9	12	35	35	29	24
TS [Nm/°]	0.016	0.020	0.024	0.028	0.056	0.084	0.112	0.119
ΔTS [%]	-42	-30	-15	0	+100	+200	+300	+325
Mass [g]	44.2	44.7	46.4	47.0	53.7	62.0	72.7	77.1
ΔMass [%]	-21	-20	-17	-16	-4	+11	+30	+38

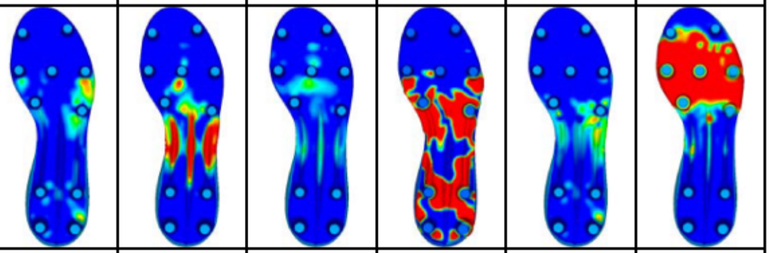
Surface nodes displacement [mm]

Optimisation Study Results (Multi-functional Properties)

Optimisation task 2

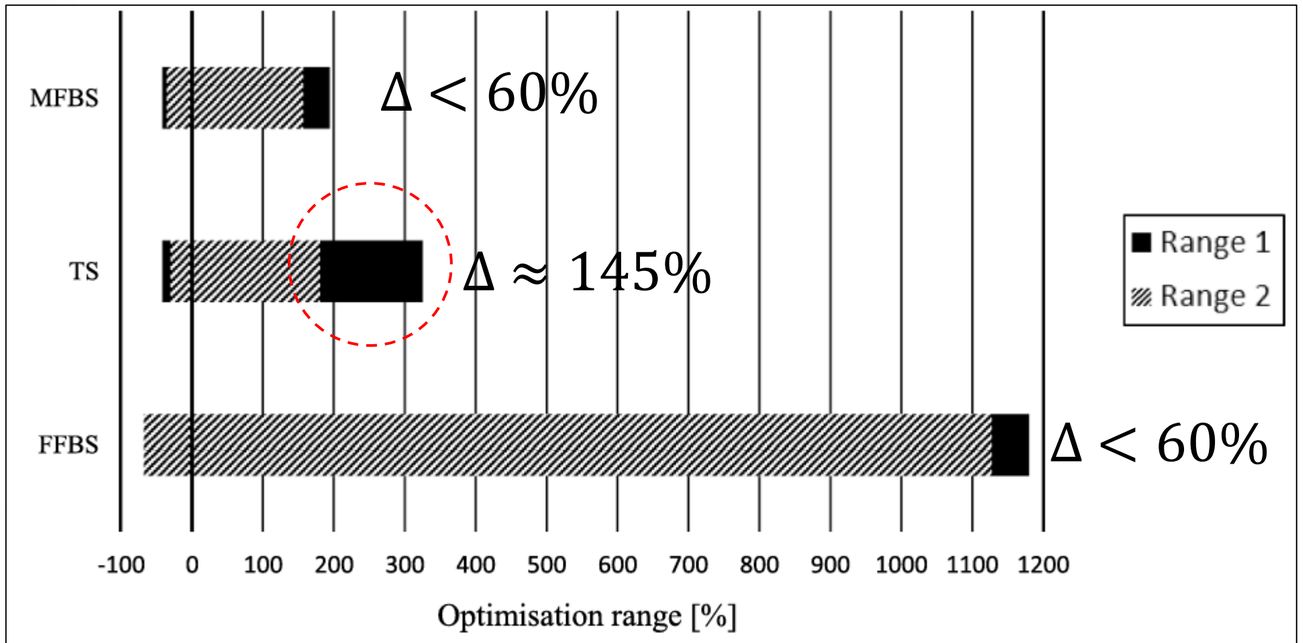
Change one functional property without changing the other functional properties.

- $-35\% \leq \Delta MFBS \leq +157\%$
- $-30\% \leq \Delta TS \leq +180\%$
- $-68\% \leq \Delta FFBS \leq +1127\%$

Optimum outsole	1	2	3	4	5	6
						
Design cycle	14	21	10	37	18	24
MFBS [N/mm]	19.1	75.6	29.4	32.3	32.3	29.4
ΔMFBS [%]	-35	+157	0	+10	+10	0
TS [Nm/°]	0.028	0.031	0.020	0.078	0.028	0.031
ΔTS [%]	0	+9	-30	+180	0	+10
FFBS [N/mm]	3.8	3.5	3.5	3.9	1.1	42.9
ΔFFBS [%]	+9	0	0	+10	-68	+1127
Mass [g]	47.0	52.5	47.0	67.0	48.1	67.0
ΔMass [%]	-16	-6	-16	+18	-14	+18

Optimisation Study Results

- Overlayed two optimisation results.
- The maximum difference of the upper limit was observed in the TS of about 145%.
- The area involved in the TS was highly influential in areas involved in the other two FP measurements.



Range 1: Optimisation range without constraining the other FP values, found from OPT 1

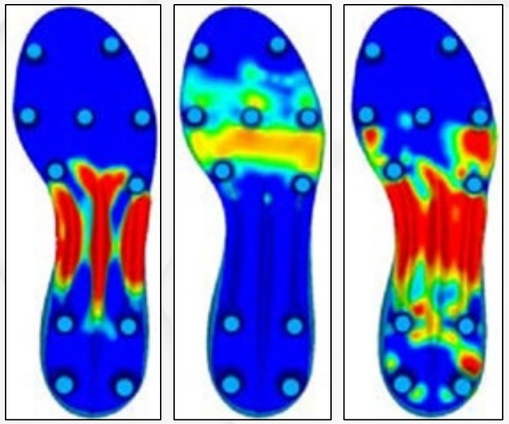
Range 2: Optimisation range which allows the other FP values by a 10% increase or less, found from OPT 2

Sensitivity Study of Optimisation 1 Results

Can we numerically demonstrate the interdependency of each functional property?

Sensitivity Study Preparation

- The sensitivity study was designed to evaluate the changes in the other two FP values while the geometry of the outsoles was optimised to have various individual target FP values.



Individual functional property optimised outsoles

Combined FP simulation

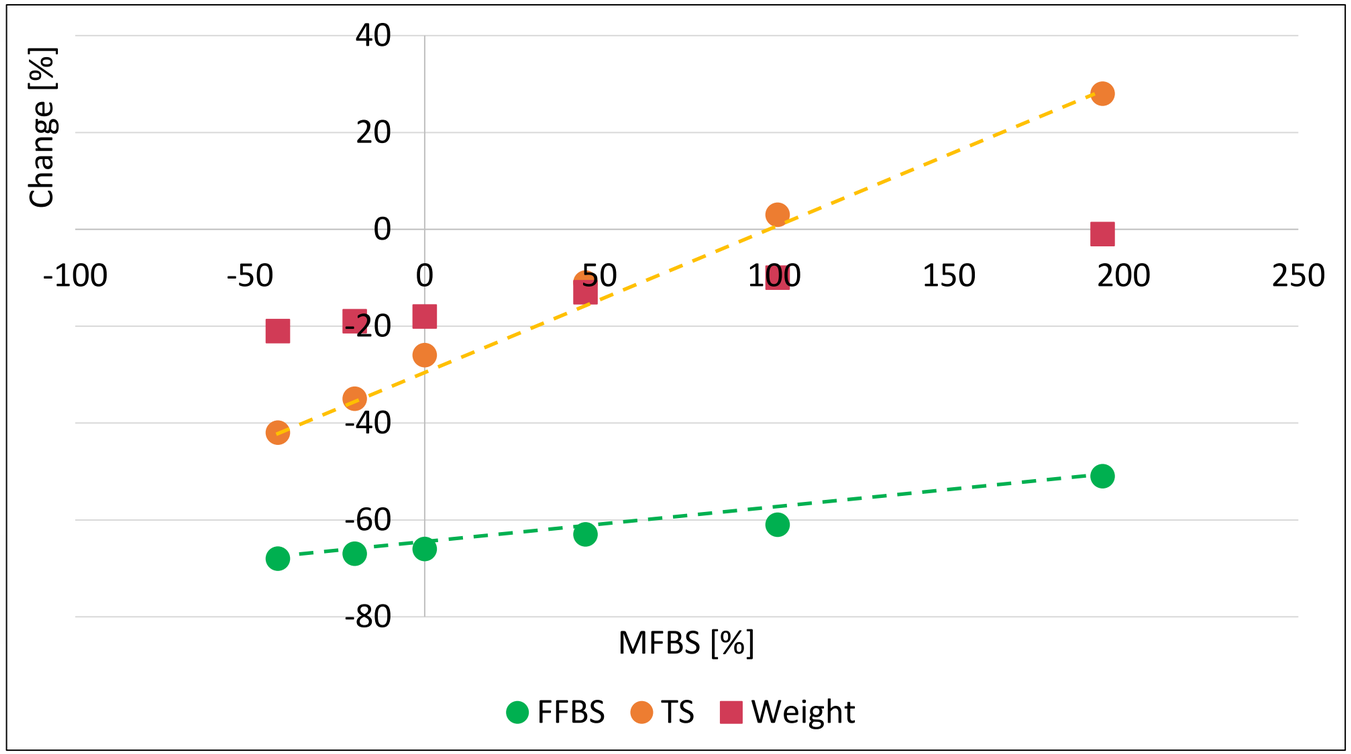
Midfoot bending + Torsion + Forefoot bending

The changes in the other FP values were evaluated

Sensitivity Study Results

- Changed the Midfoot (MFBS) and see how Forefoot (FFBS) and Torsion (TS) were influenced!

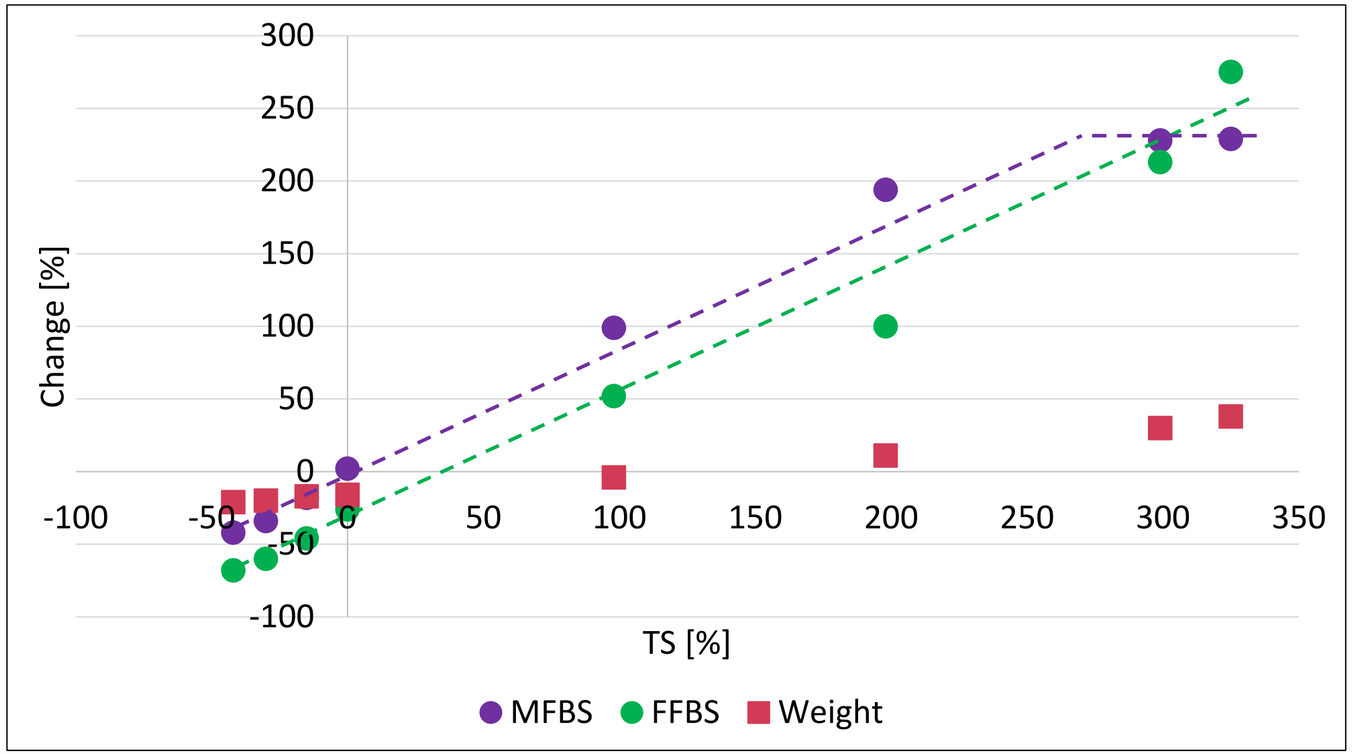
- The overall change in TS was higher than that in the FFBS over the range.



Sensitivity Study Results

- Changed the Torsion (TS) and see how Midfoot (MFBS) and Forefoot (FFBS) were influenced!

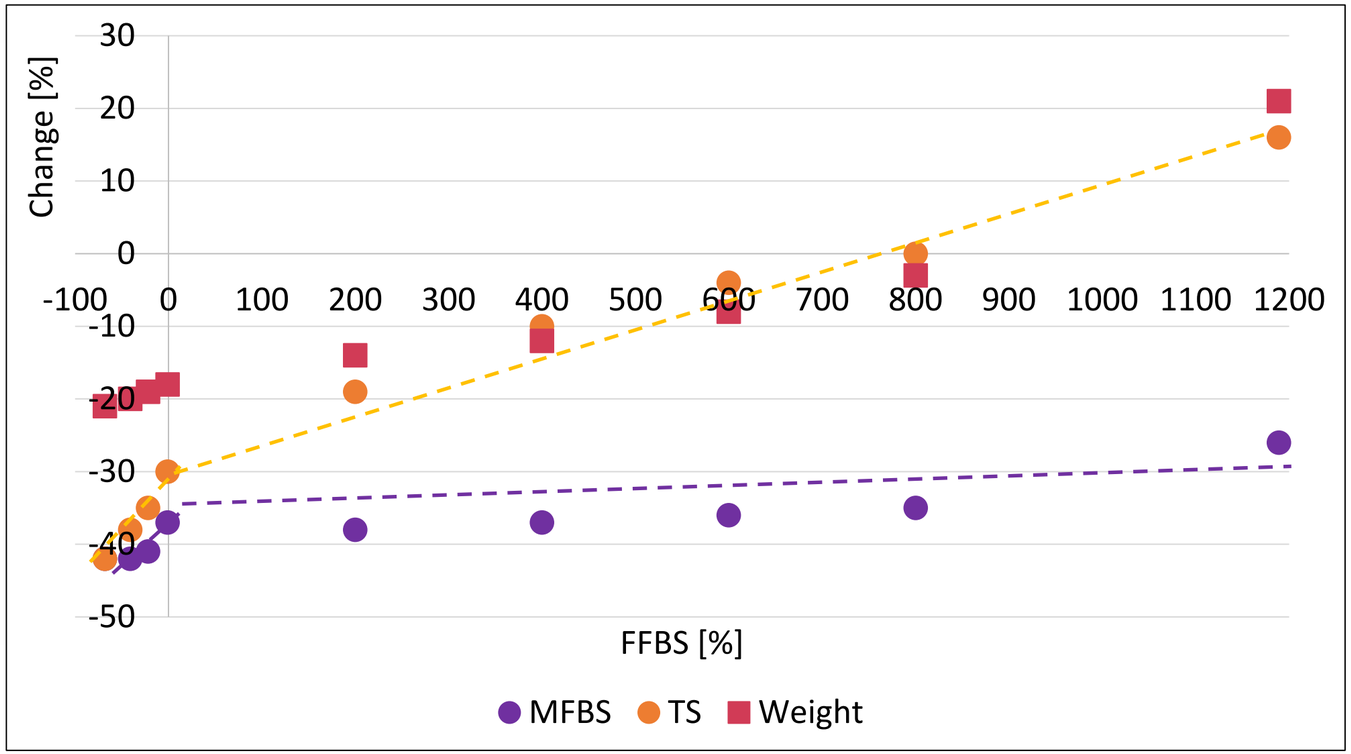
- The MFBS showed a linear response across the range that plateaus when the TS increased more than 300%.



Sensitivity Study Results

- Changed the Forefoot (FFBS) and see how Midfoot (MFBS) and Torsion (TS) were influenced!

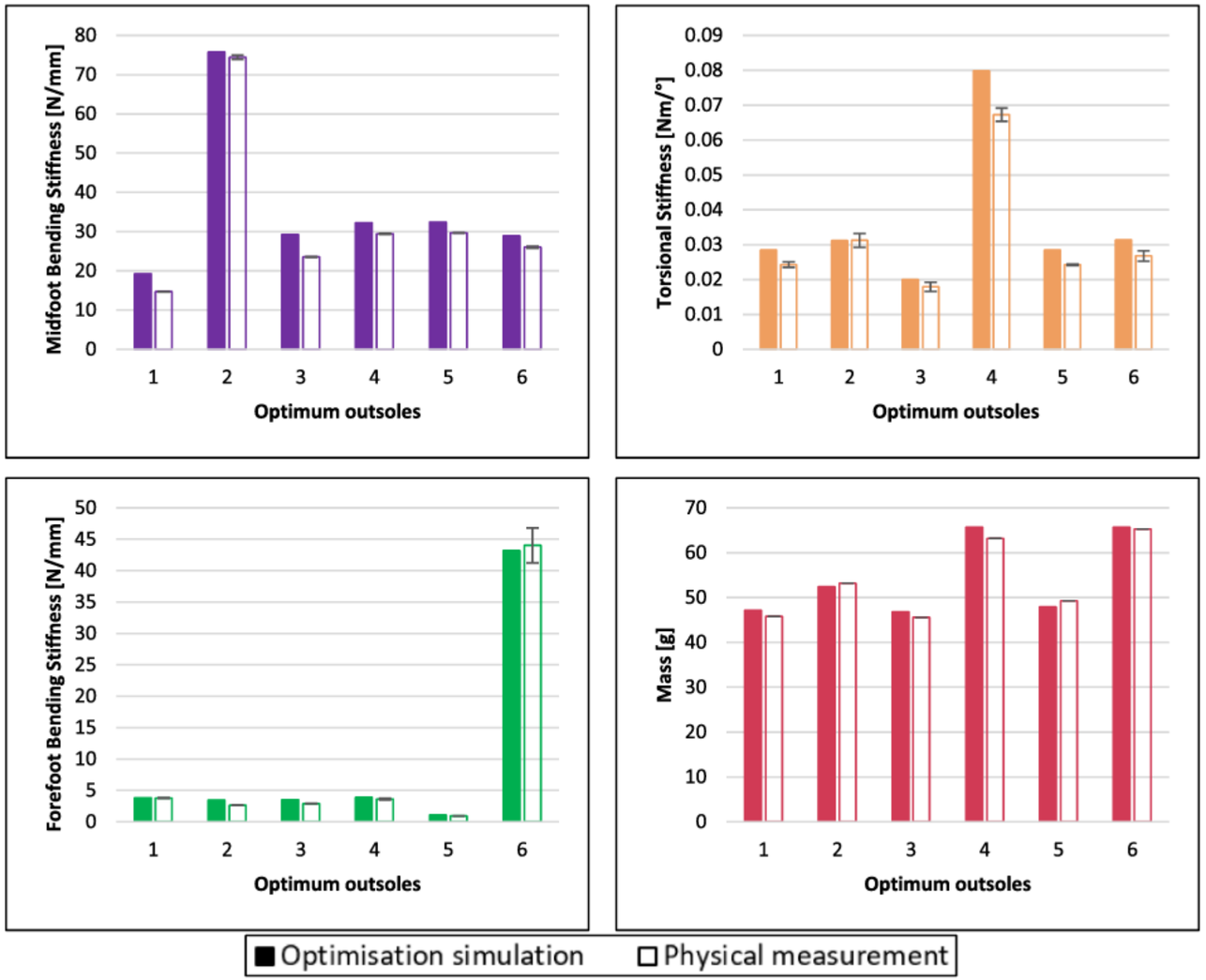
- The MFBS and TS showed an increasing trend over the range but it showed a rapid decrease when the FFBS was targeted at a lower value than the original value.



Validation to Physical Test

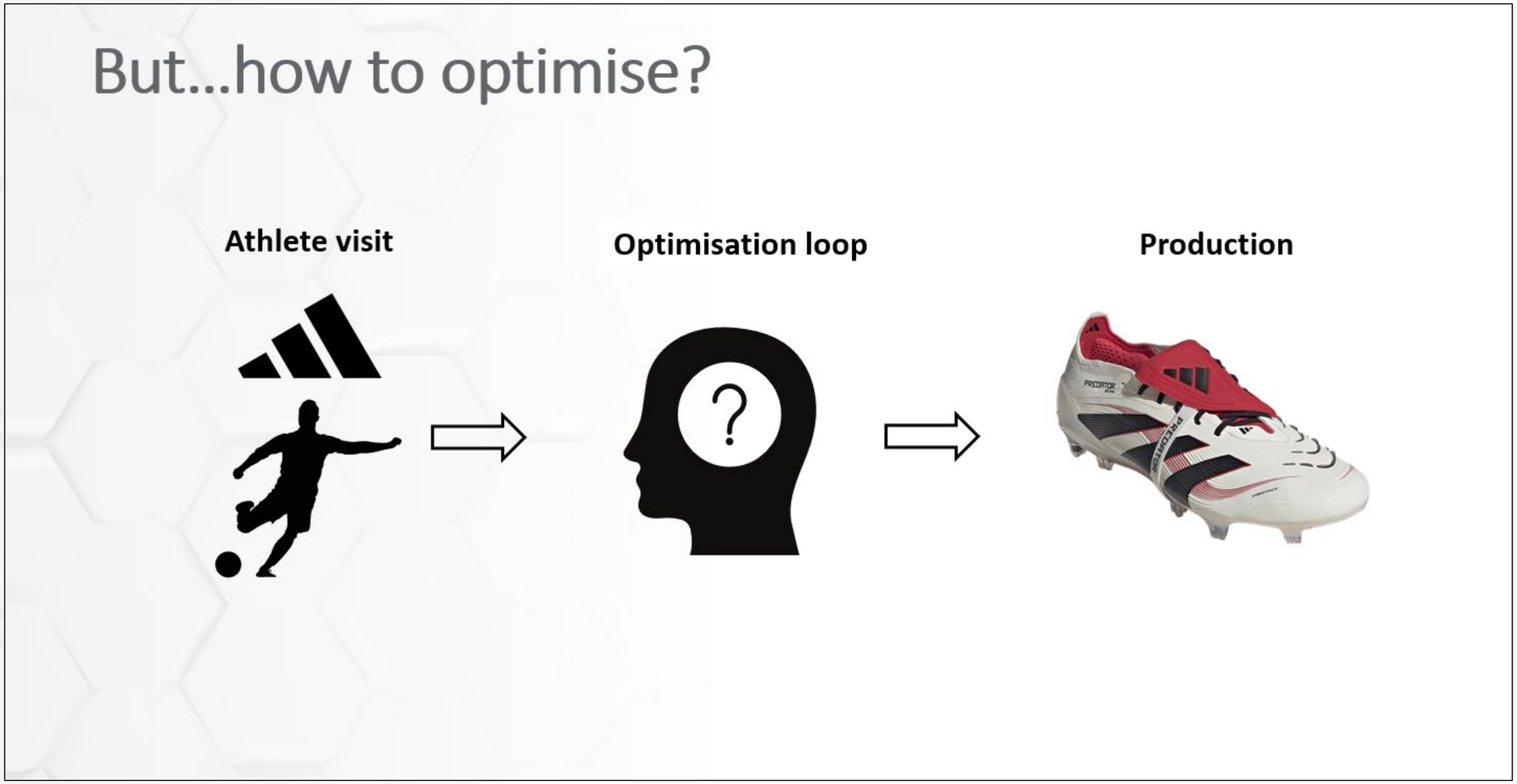
- The optimised outsoles were 3D printed and simulation results were compared with the mechanical test results.

- Mechanical test results followed the same trend with the simulations results and the mean differences was 13% or less from all samples.



What Does This Optimisation Study Mean?

- If we remind ourselves of the earlier question…

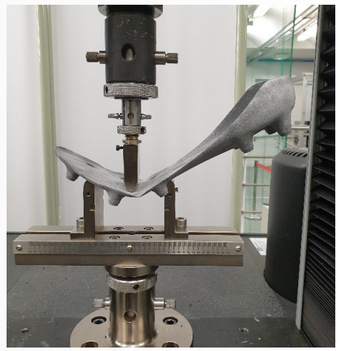


What Does This Optimisation Study Mean?

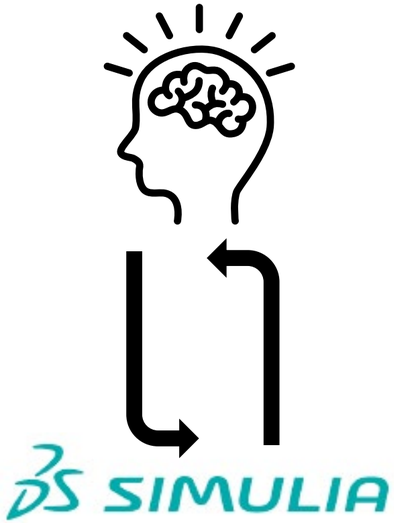
- The results are hugely helpful to a footwear designer to define the design space when creating a customised football boot outsole.

Athlete visit

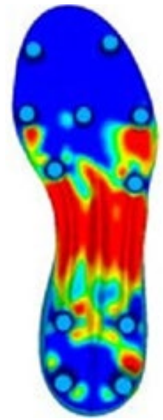
Biomechanical & mechanical parameters



Optimisation loop



Production



Thank you!

If you are more interested in, please scan this QR code!

THANK YOU