

FLANDERS
MAKE

DRIVING INNOVATION IN MANUFACTURING

KU LEUVEN



Adhesive selection via an interactive, user-friendly system based on Symbolic AI

Simon Vandavelde, Jeroen Jordens, Bart Van Doninck, Maarten Witters,
Joost Vennekens

AI VLAANDEREN

BOUWEN AAN JE DIGITALE TOEKOMST



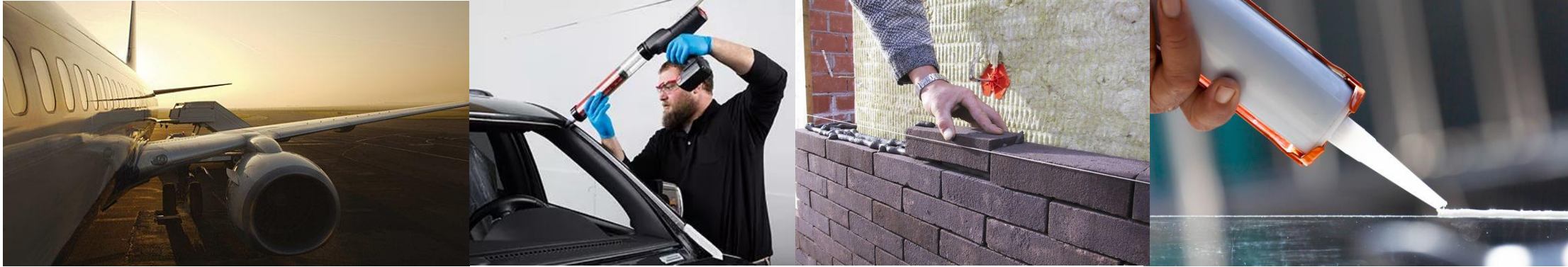
AI FLANDERS

BUILDING OUR DIGITAL FUTURE



Adhesives

widely used in industry



<https://www.dupont.co.uk/products/betaseal.html>

<https://www.livios.be/nl/bouwinformatie/ruwbouw/muren/verlijmen-versus-dun-metselen/>

Not 1 adhesive suitable for all applications



Adhesive selection = crucial step in design process



Traditionally done by adhesive expert
= time consuming + labor intensive process



Support tools

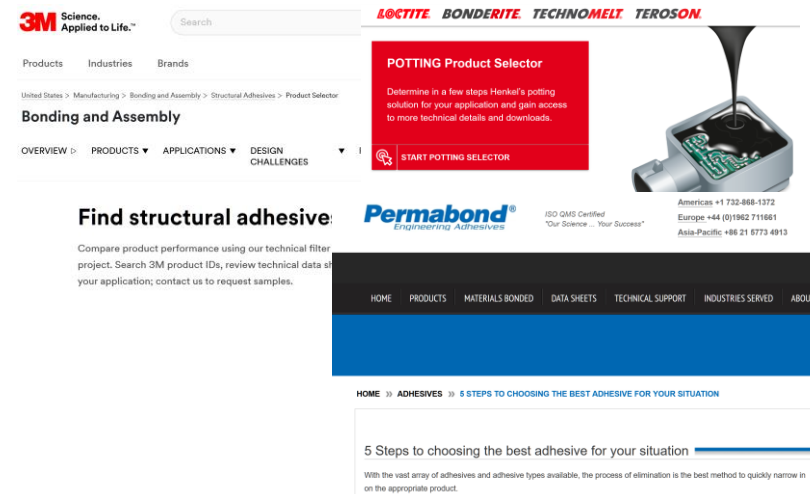
Websites



- Requires much manual work
- Limited functionality

Time consuming

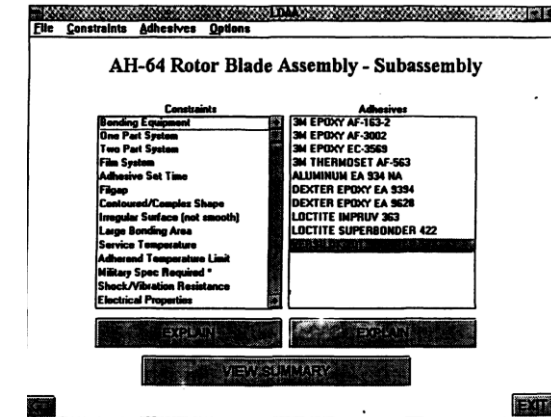
Personal assistance adhesive suppliers



- Contact suppliers via contact form/phone
- Receive personal response

Only brand specific adhesives
Takes couple of days

Expert systems

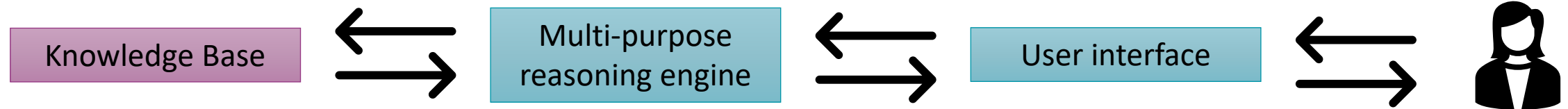


Meyler KL, Brescia JA. Design of a Computer Expert System for Adhesive Selection Using Artificial Intelligence Techniques. Army armament research development and engineering center Picatinny Arsenal...; 1993.

- Decision trees
- Selection tables
- Rule based expert systems

- Low maintainability + user unfriendly
- Limited expressiveness: complex relations not considered
- Limited number of adhesives / substrates

Our approach: Knowledge-Base System



FO(·)

- Extension of First-Order logic
- Very expressive, can capture everything
- Readable for people with engineering background
- Contains the knowledge of the domain experts
- **Formal** description of the knowledge: if expert leaves, knowledge is kept!

IDP-Z3

- Reasoning on knowledge
- Powerful and efficient
- Knowledge can be **re-used** for multiple purposes

$$\text{MaxAllowedStress} = \text{Load} / \text{BondingArea} \quad (1)$$

$$\text{MinBondStrength} \leq \text{BondStrength} \quad (2)$$

$$\begin{aligned} \text{AdhesiveFamily} &\in \{\text{RadiationCuringAcrylates}\} \\ \Rightarrow \text{SAUVTransparent} \vee \text{SBUVTransparent} \end{aligned} \quad (3)$$

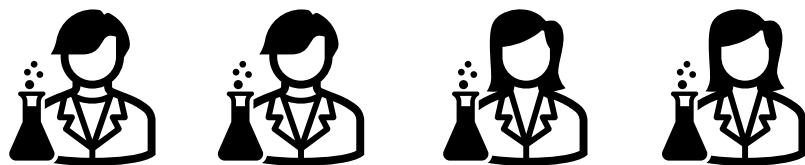
IDP web interface
(Interactive Consultant)

- Generic view of FO(·)
- User-friendly interaction with IDP-Z3
- Explainable!
- Stress = Load / Area
- Bonding strength of the adhesive should be higher than the min required strength for the design
- For radiation curing acrylates: at least one of the two substrates should be UV transparent, to ensure proper curing.

Knowledge Base

1. Creation of knowledge Base:

- Via 3 knowledge articulation workshops with 4-6 domain experts



- 21 adhesive + 11 substrate parameters

2. Integration in interactive consultant tool

Adhesive parameters available in the system		
Bond Strength	Elongation at Break	Lowest/Highest Performance Temp.
Lowest/Highest Application Temp.	Humidity Resistance	Lowest/Highest Humidity
Color	Potlife	Time Until Handling Strength
Adhesion	Viscosity	Water Resistance
UV Resistance	Chemical Resistance	Polymer Type
Min/Max Gap Filling Capability	Adhesive Family	

Substrate parameters available in the system	
Substrate Family	Max Temperature
Water Absorption	Water Vapor Absorption
Max Elongation	Base Material
Strong Acid Resistance	Organic Solvent Resistance
Magnetic Type	Transparency
Electrical Conductivity	

Adhesive selector

Interactive adhesive selector tool with

- 21 adhesive families
- 55 specific adhesives
- 31 substrate families

KU LEUVEN **FLANDERS MAKE** **AI FLANDERS** **Adhesive Selector** File Edit View Reset Modelexpand Application Help

Adhesive = (55)

Performance

Bond Strength Cat

☒ ☒ high strength
☒ ☒ moderate strength
☒ ☒ low strength
☒ ☒ unknown strength

Min Bond Strength = MPa
Flexibility =
Max Operation T = C
Min Viscosity = mPa s
Shock Resistant

Water Resistance

☒ ☒ good
☒ ☒ moderate
☒ ☒ bad
☒ ☒ unknown

Min Elongation At Break = %
Temperature Resistance =
Min Operation T = C
Max Elongation At Break = %
Max Operation T = C
Max Viscosity = mPa s

Humidity Resistance

☒ ☒ good
☒ ☒ moderate
☒ ☒ bad
☒ ☒ unknown

Chemical Resistance

☒ ☒ good
☒ ☒ moderate
☒ ☒ bad
☒ ☒ unknown

UV Resistance

☒ ☒ good
☒ ☒ moderate
☒ ☒ bad
☒ ☒ unknown

Bond Sealing

☒ ☒ good
☒ ☒ moderate
☒ ☒ bad
☒ ☒ unknown

Creep Resistant

☒ ☒ good
☒ ☒ moderate
☒ ☒ bad
☒ ☒ unknown

Production

Min Application T = C
Max Application T = C
Min Application Humidity = %
Max Application Humidity = %
Min Potlife = min
Time Till Handling Strength = min
Max Time Till Handling Strength = min
Max Time Till Full Strength = min
Max Curing T = C

☒ ☒ Apply Pressure After Joining
☒ ☒ Extraction Or Open Air
☒ ☒ Activator
☒ ☒ UV Source Available

Min Curing T = C
Safety Factor = 1
delta Length = mm

Adhesive = (55)

DP760
DP8407NS
DP609
Adekit A 280 400 BK
Adekit A 140 BK
Betaseal 8000 1F

Min Bond Strength = MPa

Flexibility = very_flexible

Max Operation T = 80 C

☒ Shock Resistant

Water Resistance

☒ ☒ good
☒ ☒ moderate
☒ ☒ bad
☒ ☒ unknown

Adhesive selector

- In the interface, **any of the parameters** can be set
- The **consequences** are automatically derived and shown!
- The system can **explain** these consequences, increasing user-friendliness
- Tool is multi-purpose:
 - Find list of suitable adhesives
 - Find cheapest/strongest/most flexible adhesive
 - Verify suitability of pre-owned adhesive
 - Find a second substrate
 - Explain *why* an adhesive is not suitable
 - ...

The screenshot shows a user interface for an adhesive selector. It features a list of requirements, each with a status icon (checkmark or X) and a label:

- Bond Sealing**: Status is mixed (green checkmark and red X).
- Max Operation T**: A text input field with a green border, followed by a unit 'C' and up/down arrow icons.
- Vibration Dampening**: Status is 'checked' (yellow checkmark).
- Shock Resistant**: Status is 'checked' (grey checkmark).

A tooltip is displayed over the 'Shock Resistant' requirement, explaining the consequences of this choice:

Above choice is implied by the following choice(s):

- Vibration Dampening** (checked)

Laws

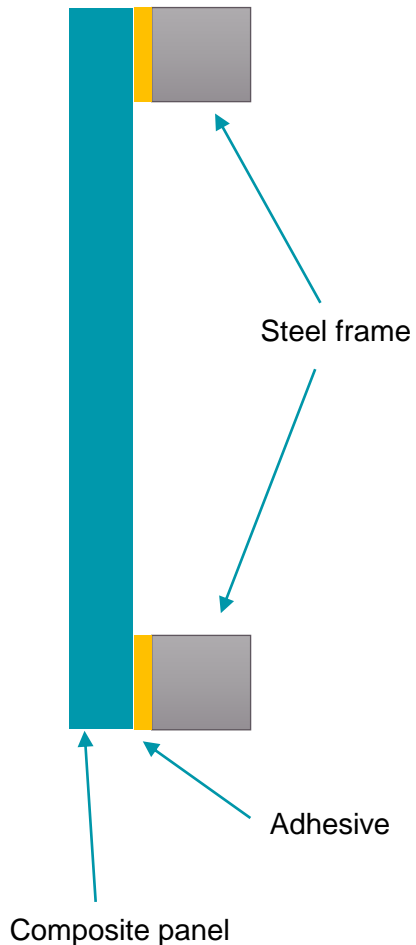
- Vibration_Dampening() \Leftrightarrow Flexibility() = very_flexible
- Shock_Resistant() \Leftrightarrow Flexibility() = very_flexible

At the bottom of the interface, there are navigation icons (back, forward, search) and a 'good' status indicator.

Benchmarking

- Test industrial tool on industrial relevant case
- Compare resources + output adhesive expert with + without tool

Automotive application



Requirements

- Min. shear strength: 11 MPa at room temperature
- Dimensions bondline: 4842 mm x 202 mm
- Good shock + impact resistance
- Desired bondline thickness: 5 mm
- Temperature resistance in operation: -40°C till +80°C
- Range of allowable application temperatures: 18°C to 30°C
- Min. potlife of 60 min
- Max. time till handling strength 12h
- No oven curing possible

Results



Adhesive expert

1. Reasons on possible adhesive families
2. Suppliers of industrial adhesives are contacted
3. Technical datasheets compared
4. Make final selection

MMA: Plexus MA 560-1



3 h



Selection tool

1. Fill requirements in selection tool
2. IDPs propagation inference performed after each value
3. Make final selection

MMA: Plexus MA 560-1



5 min

- Significant reduction in time to find adhesive
- Assumes significant large database of adhesives for selection tool
- Full market study not performed by adhesive expert

Future work

- Extend KB with more adhesives + substrates → automatic datasheet parsing
- Validation of selector tool on more industrial relevant use cases
- Convert KB to cDMN, a novel representation method which aims at being user-friendly

MinElongation		
U	Support	MinElongation
1	free	$0.5 \times \text{deltaLength} / \text{BondThickness}$
2	fixed	$\text{deltaLength} / \text{BondThickness}$

Conclusions

- Adhesive Selection knowledge was captured in FO(\cdot) KB
- IDP-Z3 as reasoning engine & Interactive Consultant as interface
- Adhesive selector is multi-purpose: knowledge can be re-used
- Tool is sufficiently performant
- Tests on industrial use case showed potential

Thank you!

More information:

- s.vandavelde@kuleuven.be
- jeroen.jordens@flandersmake.be
- www.IDP-Z3.be