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Exploring the potential of magnetorheology in robotic grippers

by

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Outline

- Introduction: hard versus soft grippers
- Types of MR materials
- General applications of MR materials
- Gripper applications of MR materials
- Discussion
- Conclusion

Robotic grippers in diverse environments

(De)manufacturing

Logistics, e-Commerce

Agriculture, Food

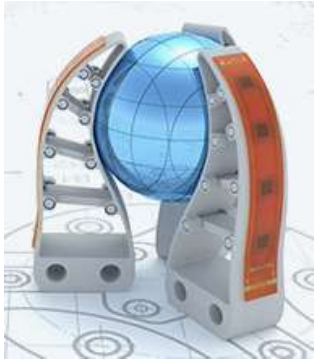
Healthcare, Medical

Trends in robotic grippers

- Customised products (high mix, low volume),
- Handling undefined, non-rigid products,
- Increasing cost of human labour,
- Decreasing cost of robotic systems.

⇨ Change in expected gripper functionalities

Advancements in robotic grippers



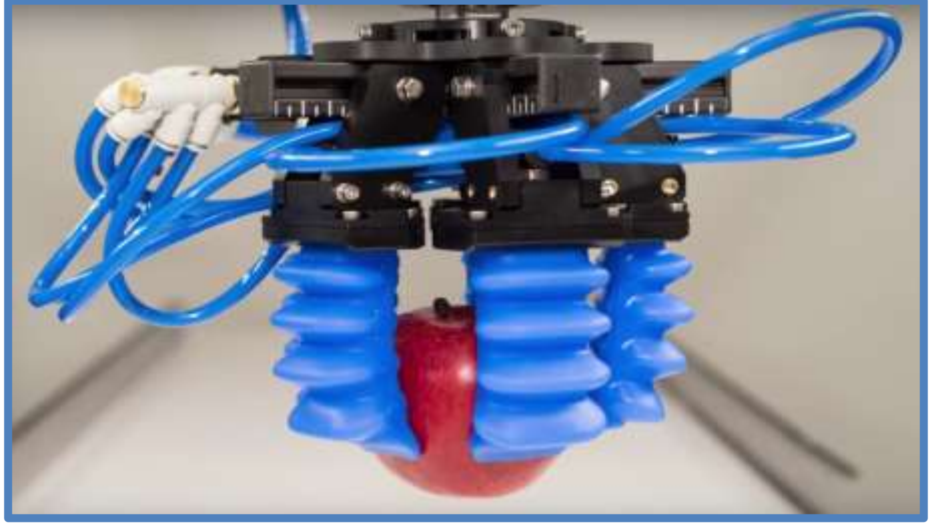
Source: EPFL, Festo, Robotiq, Schunk, Soft Robotics Inc.

Hard versus Soft grippers

Hard grippers

Source: Schunk

Soft grippers

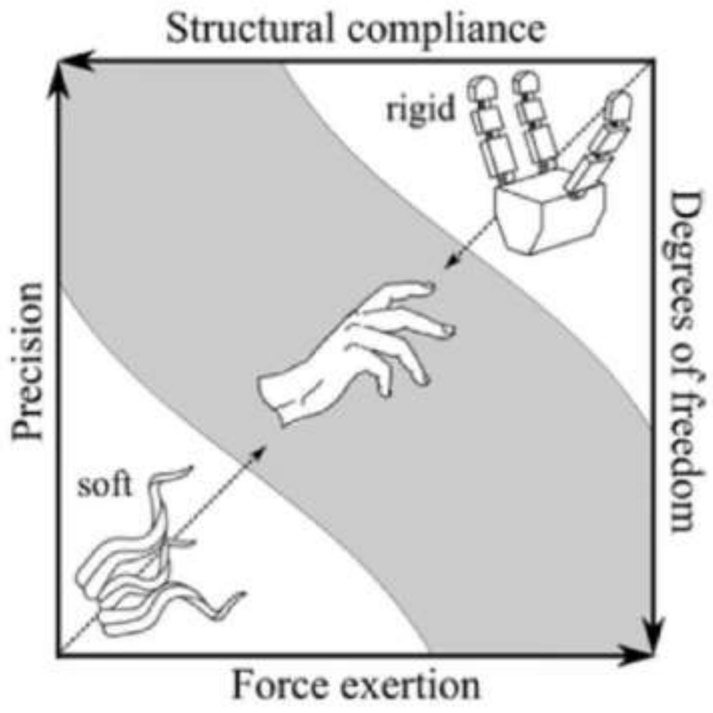


Source: Soft Robotics Inc.

- High grasping force,
- High precision,
- Low DoF,
- Low compliance.

- Low grasping force,
- Low precision,
- High DoF,
- High compliance.

Combining the advantages in hybrid grippers



- Dynamic environments:
  - Unknown, non-rigid objects
  - Human-robot collaboration
- Product versatility

Source: Hughes et al. 2016

Magnetorheological (MR) materials

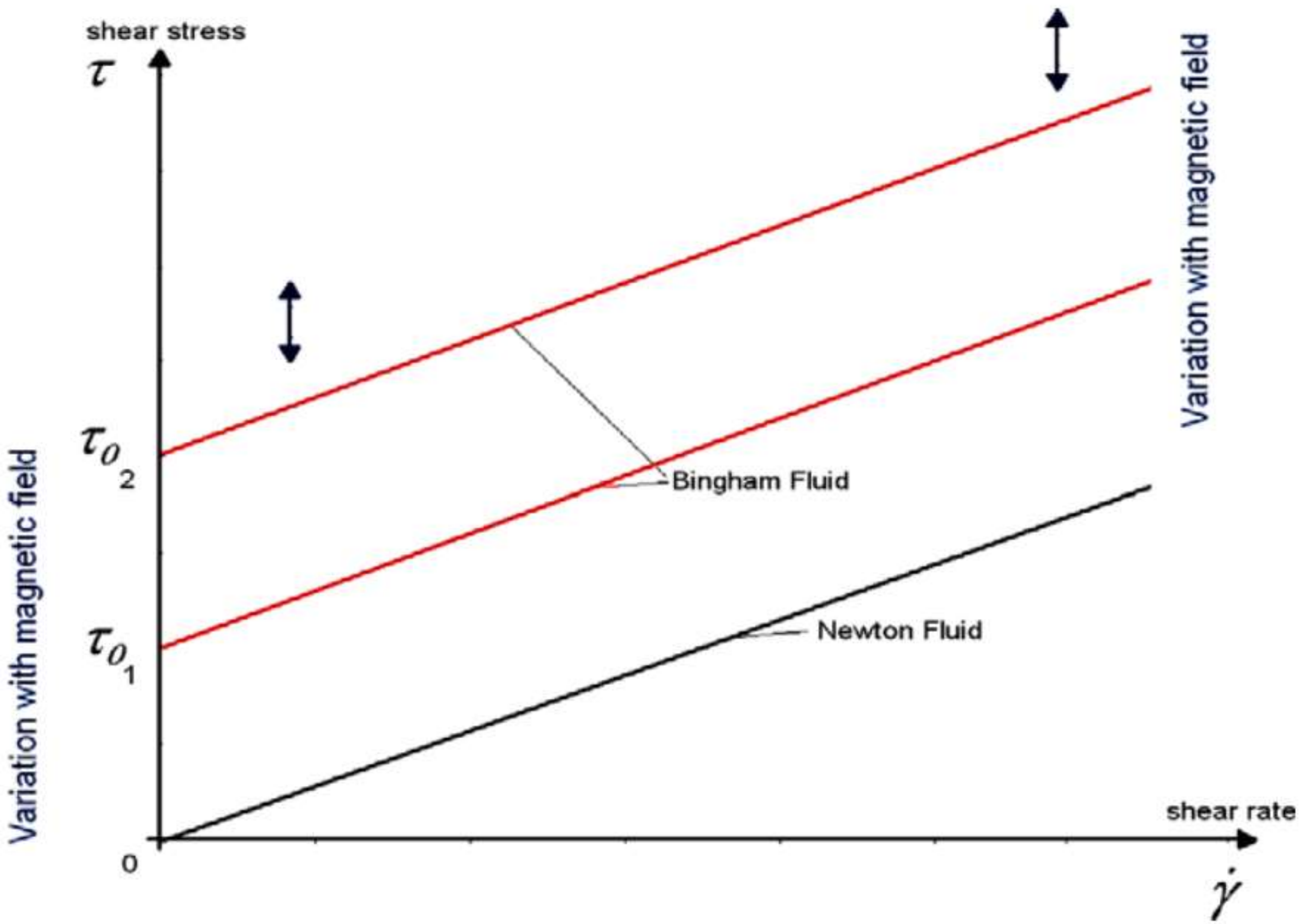
MR fluid

- Micron-sized magnetically permeable particles (carbonyl iron particles)
- Non-magnetic carrier medium (mineral or silicone oil)
- Additives (settling stabilisers, anti-wear components, etc.)
- In the presence of magnetism:
  - From liquid to viscoelastic solid (particle alignment),
  - Stiffness dynamically controllable by varying the field's magnitude.

Source: Tibor Medvegy

Magnetorheological (MR) materials

MR fluid



Source: Olabi et al. 2007

Magnetorheological (MR) materials

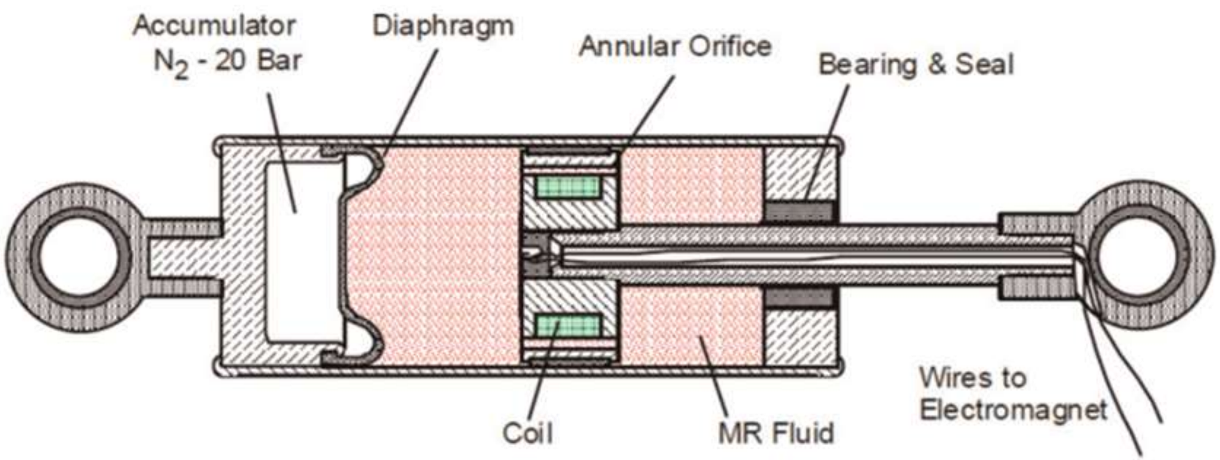
MR elastomer

- Micron-sized magnetically permeable particles (carbonyl iron particles)
- Non-magnetic carrier medium (mineral or silicone oil)
- Elastomer/rubber matrix
- In the presence of magnetism:
  - From soft elastomer to semi-solid (particle alignment)
  - Stiffness and deformation dynamically controllable by varying the field's magnitude.

General applications of MR materials

Vehicle suspensions

- 1990: first MR shock absorbers in primary car suspensions (Delphi MagneRide^{TM}),



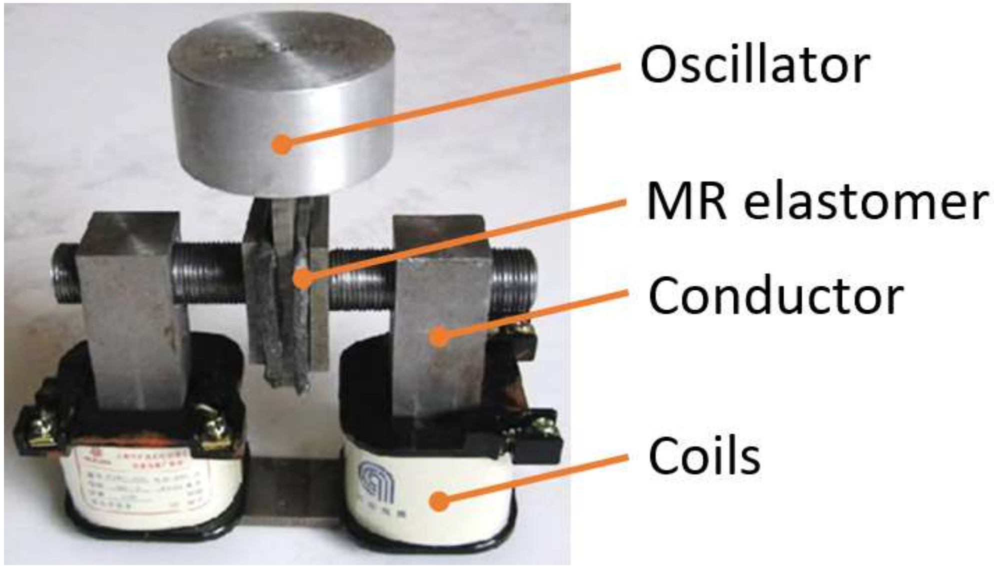
- Damping force is activated and controlled by the magnetic field strength.

Source: Zhu et al. 2012, Wereley et al. 2013

General applications of MR materials

Seismological construction protection

- Prevent the transmission of seismic-induced damage energy through structures: MR fluids in MR dampers, MR elastomers in tunable vibration absorbers (TVA).



Source: Li et al. 2014, Shrestha et al. 2017

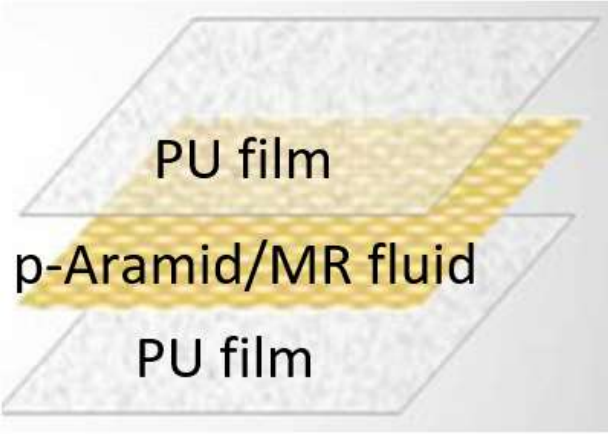
General applications of MR materials

Sensing devices

- Use of MR elastomers' interesting properties:
  - magnetoelasticity,
  - magnetoresistance,
  - magnetostriction,
  - thermoresistance.
- Examples:
  - Force sensor based on the material's electric resistance caused by spacing between the particles through external loading,
  - Magnetic field detector based on the material's electric resistance caused by magnetic field.

Source: Martin et al. 2003, Li et al. 2009, Bica et al. 2011, Li et al. 2014

General applications of MR materials



Liquid body armour

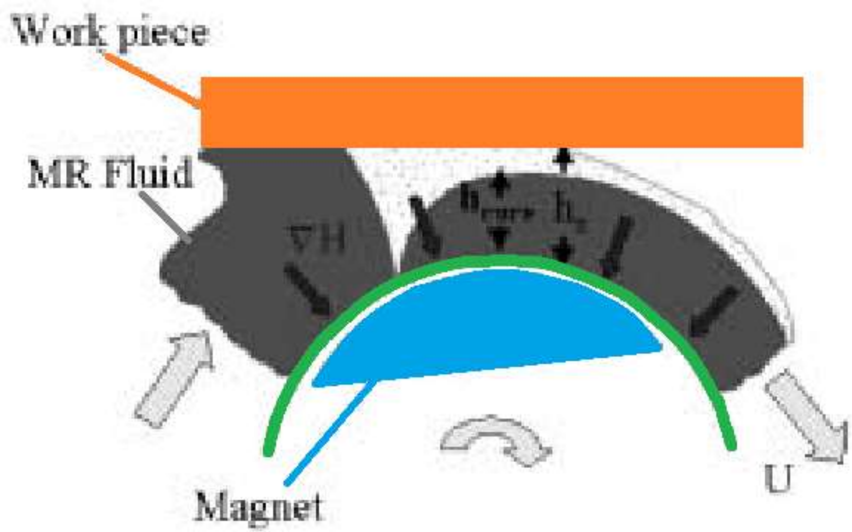
- Conventional body armour:
  - Multiple densely weaved textile layers,
  - Heavier, less mobile and comfortable.
- Liquid body armour:
  - p-Aramid fabric immersed in MR fluid and laminated between two polyurethane films,
  - Lighter, more flexible due to the fluid's adjustable stiffness,
  - Absorbs more impact energy.

Source: Kang et al. 2015

General applications of MR materials

High precision surface finishing

- MR fluid deposited on a rotating wheel, exposed to a magnetic field
- Flow of stiffened MR fluid towards the surface to be polished
- Peak-to-peak surface roughness of 10 nm
- Material removal can be enhanced by non-magnetic abrasive particles in the MR fluid.

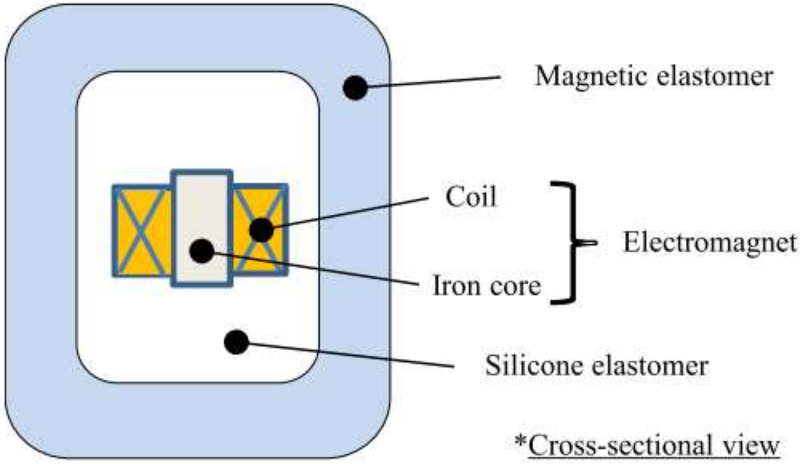


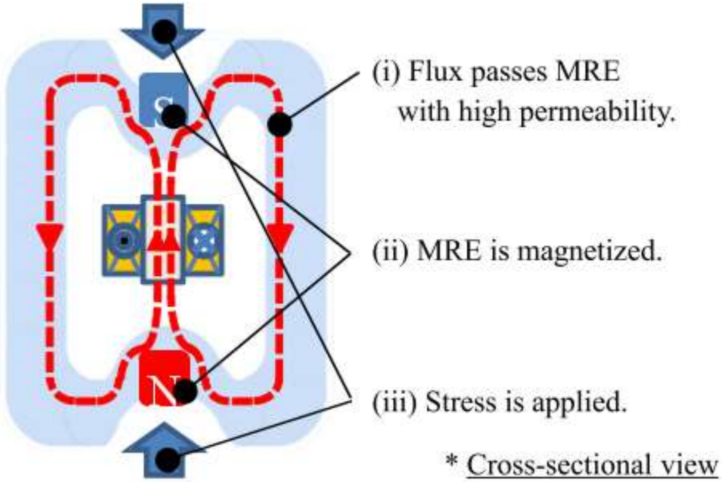
Source: Kordonski et al. 2002

Robotic gripper applications of MR materials

MR elastomeric actuator (1/2)

- Magnetic flux passes through the MR elastomer due to a lower magnetic reluctance compared with the silicone elastomer
- MR elastomer in front of the coil contracts
- Deformation: ~ 2 mm.



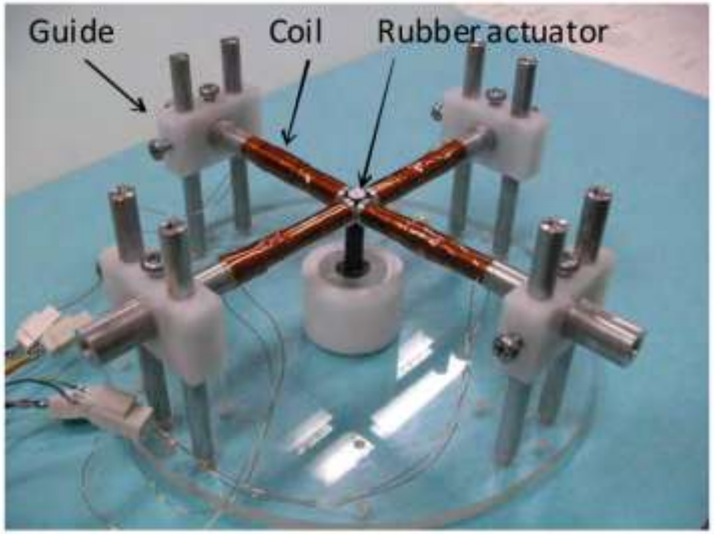


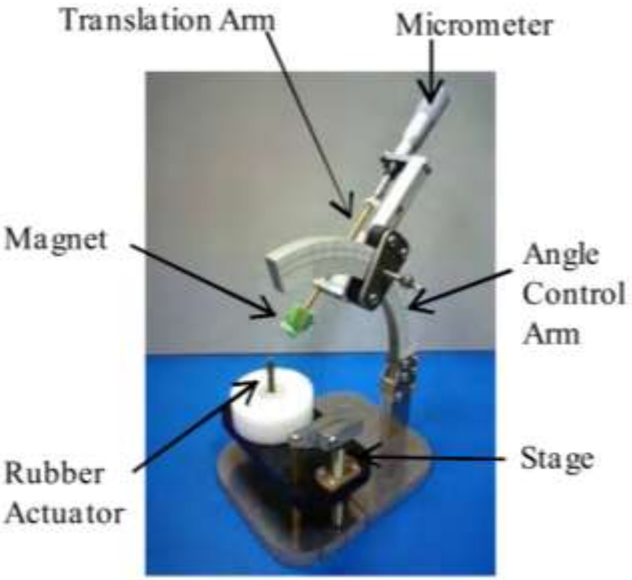
Source: Kashima et al. 2012

Robotic gripper applications of MR materials

MR elastomeric actuator (2/2)

- Compares various mixtures of MR fluid and silicone elastomer at different mass ratios
- Controls the motion of the actuator end according to a circular track (step towards locomotion robots and grippers)
- Deformation: ~ 0,20 - 0,38 mm.





Source: Taniguchi et al. 2010

Robotic gripper applications of MR materials

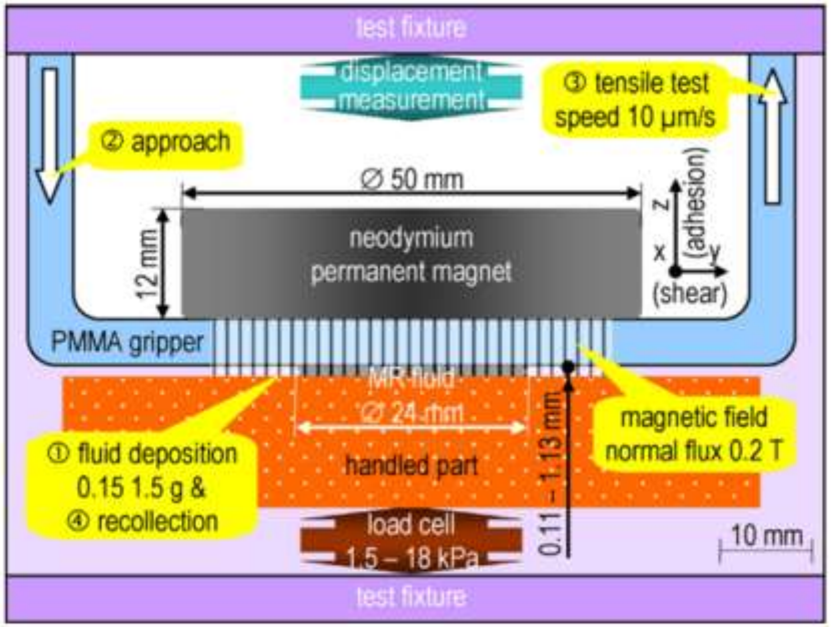
MR elastomeric actuator (discussion)

- Small deformations: submillimetres - millimetres
- Disadvantageous in robotics and grippers
- Advantageous in small devices: fluid flow control valve
- Increasing particle density:
  - Increased magnetic saturation
  - Decreased flexibility

  } Searching for optimum
- Future optimisation regarding large deformations and high stiffness in the magnetised, deformed state.

Robotic gripper applications of MR materials

Controllable wet adhesion gripper (1/2)

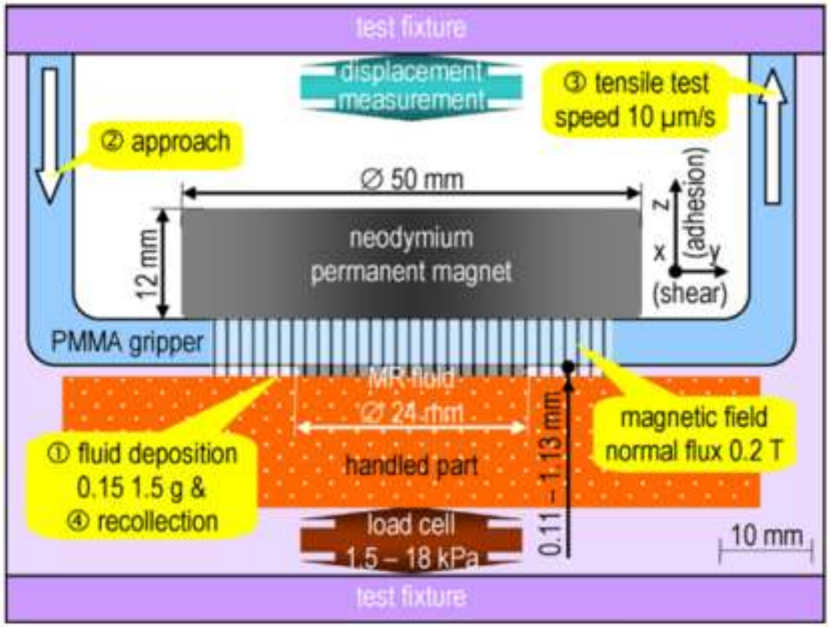


Source: Lanzetta et al. 2013

- Dry adhesion is realised by sub-microscopic surface textures
- Wet adhesion is realised by a glue-like substance (MR fluid)
- Changing the magnetic field strength controls:
  - Adhesion strength
  - Attachment and detachment
- Applicable to a broad range of substrate types and roughness

Robotic gripper applications of MR materials

Controllable wet adhesion gripper (2/2)



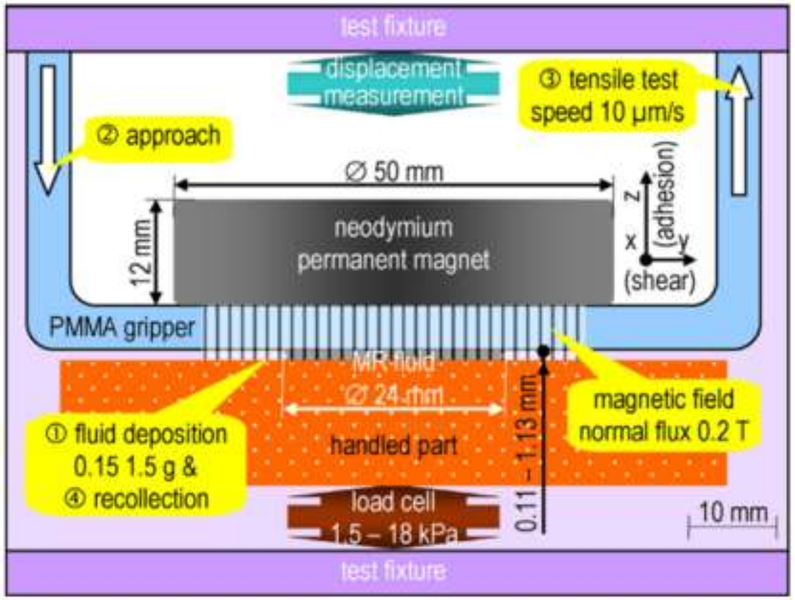
Source: Lanzetta et al. 2013

- Consists of a polymeric grasping surface and a permanent magnet,
- Thin layer of MR fluid is spread over the grasping surface,
- Grasping time: 1 min.
- Grasping force: 5 kPa,
- Fluid deposit: 0,8 g.

Robotic gripper applications of MR materials

Controllable wet adhesion gripper (discussion)

- To low grasping capacity
  (at least 1 kg required)
- After removing the magnetic field:
  40% of the grasping force remains
  (disengaging mechanism required)
- 10% of the expensive MR fluid oil remains behind and contaminates the product.
- Some oils corrode polymer surfaces during wet adhesion.



Source: Lanzetta et al. 2013

Robotic gripper applications of MR materials

Compliant jaw gripper

Source: Pettersson et al. 2010

- Developed to handle food products,
- Each jaw of the gripper consists of an electromagnet and a polyurethane pouch partially filled with MR fluid,
- Compliant pouches deform and shape to the product's contours, preventing bruising and denting.

Robotic gripper applications of MR materials

Compliant jaw gripper (discussion)

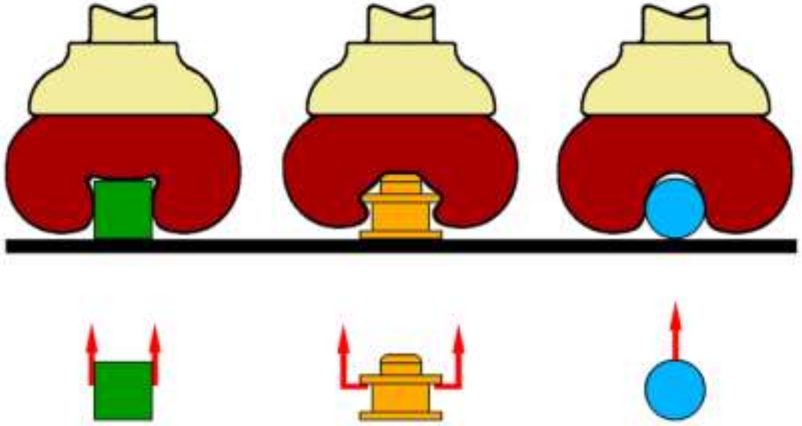
- **Low grasping force** due to the gripper design: product weight is carried by a small pouches' area underneath the object
- **Low closing speed**: MR fluid's inertia slows down flowing when a product is pressed inside the pouches,
- Disadvantageous electromagnets:
  - Large size and weight,
  - Large delay times (L/R).

Source: Pettersson et al. 2010

Robotic gripper applications of MR materials

MRα universal gripper (1/2)

- Based on Amend et al. earlier gripper design:
  - Elastomeric balloon-shaped membrane filled with ground coffee which solidifies under a negative pressure (jamming)
  - Granular material adopts to the object shape
  - Grasping force dependent of the ambient pressure that counteracts the internal pressure



Source: Amend et al. 2012

Robotic gripper applications of MR materials

MRα universal gripper (2/2)

Source: Okatani et al. 2014

- Okatani et al. enhanced gripper design:
  - Elastomeric balloon-shaped membrane filled with MR fluid which solidifies under a magnetic field
  - MR fluid adopts to the object shape
  - Grasping force independent of the ambient pressure
  - Fluid's yield strength enhanced by non-magnetic thermoplastic particles which reinforce the particle chains
  - Carrying capacity: 50,7 N

Robotic gripper applications of MRα materials

MRα universal gripper (discussion)

- High grasping forces by enhanced MR fluid composition
- Jamming principle does not allow simple and accurate positioning without external tools:
  - End stops that pre-define the pose of the object
  - Measurement systems (computer vision)

Source: Harada et al. 2016, Tsarouchi et al. 2016

Conclusion

- Trend towards undefined environments
  customised products, non-rigid/unknown objects, human-robot collaboration

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- Changing expected functionalities of grippers

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- Development of hybrid gripping principles
  potential for MR-based grippers

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- Further development and improvements of the MR-material and gripper architectures are necessary

Thanks for your attention!

Questions?

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