Effect of Microstructure Control on Reaction Characteristics in Al/Ni Reactive Powder

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Outline

- Background and Objectives

  (what is reactive materials (RM) and reactive material structures (RMS))

- Experimental Procedure

  (how to make RM and RMS)

- Microstructure Characteristics
- Reaction Characteristics
- Summary

Reactive Material (RM)

- Reactive materials (RM) are mixtures such as metal-metal, metal-oxide, and metal-polymer that cannot be detonated, but are capable of releasing large amounts of thermodynamic energy very rapidly.
- Examples of RM

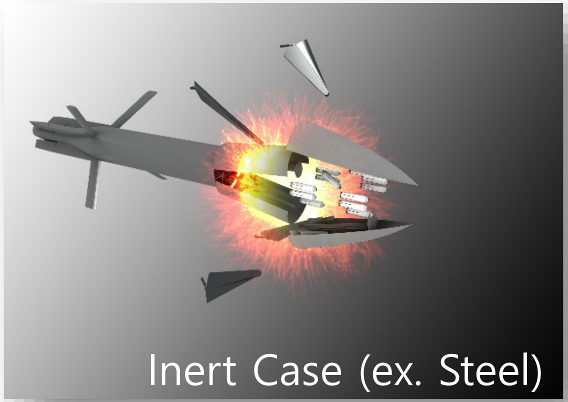
※ TNT : 1,900 cal/cc

Category	System	Heat of Reaction (cal/cc)
Metal-metal (Intermetallic)	Al+Ni=AlNi	1,710
	Al+Ni=AlNi + O_2 = $NiAlO_2$	8,000
	2Al+Zr=Al_2Zr	1,130
	2Al+Ti=Al_2Ti	1,100
Metal-oxide (Thermite)	2Al+3CuO=3Cu+Al_2O_3	4,976
	2Al+Fe_2O_3=2Fe+Al2O_3	3,947
Metal-polymer	Al-PTFE	6,000
Metal-non metal	3Ti-5Si=Ti_3Si_5	428

- RMS, which are made of RM powder, are energetic structures designed to have structural strength and store energy to be released at a desired time.

Reactive Case

- Inert structural materials based on steel are normally used as missile's cases
- If we replace the inert steel case currently used with reactive material structures?

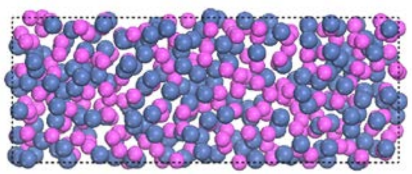


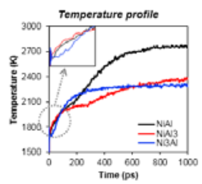
- The delivered energy to target would be increased, because the RMS case is capable to react in the exploding environment of explosives, unlike steel case
- ADD has been working on a project to develop reactive cases since 2014

Objectives

- Secure the core technologies to develop reactive cases

Design technology



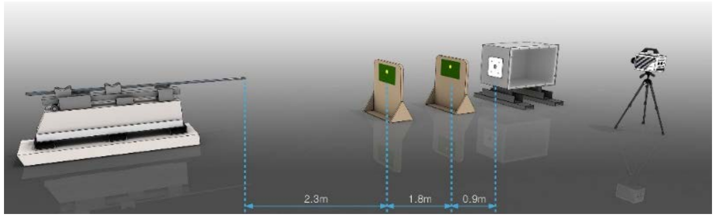


➢ Design technology to design RMS that release a large amount of energy

Fabrication technology

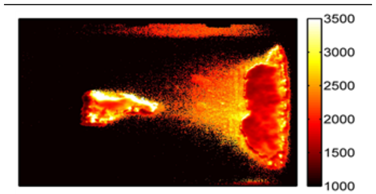
➢ Fabrication technology to fabricate RM powder and RMS as designed states

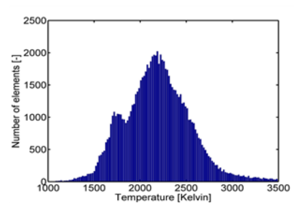
Test technology



➢ Test technology to simulate the RMS operating environment

Analysis technology

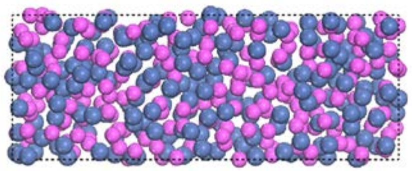


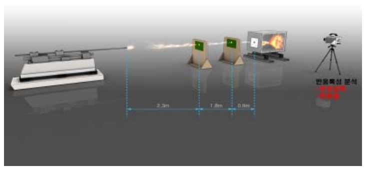


➢ Analysis technology to analyze acquired data from RMS tests

Schematic Procedure for developing RMS

*TM: Turbula Mixing // AM: Attrition Milling // PM: Planetary Milling





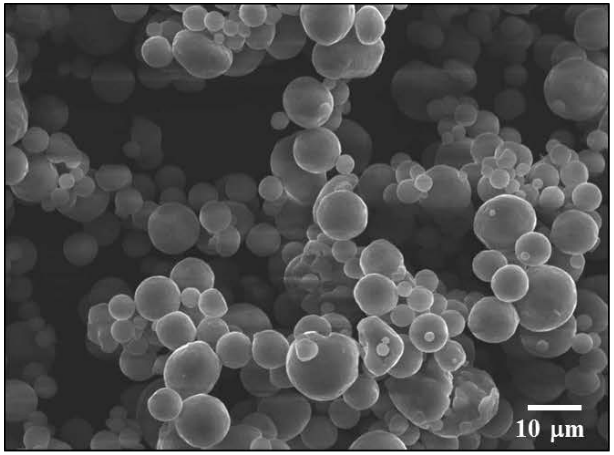
Designed composition acquired from MD Simulation (stoichiometric-composition) → RM powder Manufacturing → RMS Manufacturing → **RMS Characterization**

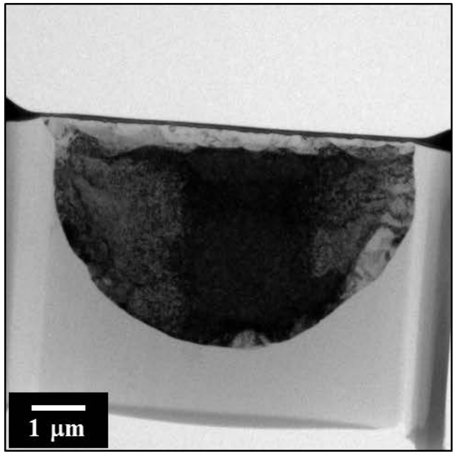
- RM powder Manufacturing:
  - Using various particle sizes
  - Using various Mixing methods (TM / AM / PM)*
- RMS Manufacturing:
  - Using various consolidating methods (into various shapes)
- RMS Characterization:
  - Microstructure, density, compressive strength, Initiation temperature, reaction rate, heat formation, blast effects

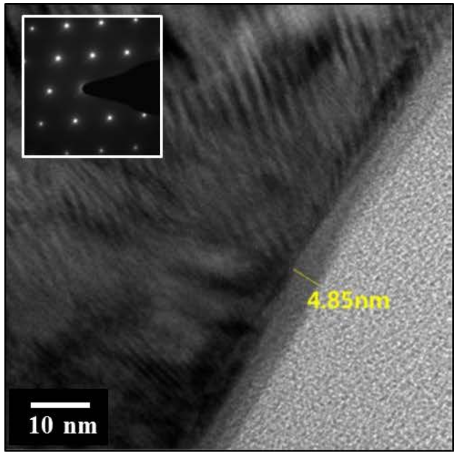
- How to make RM powder
- Microstructural development according to mixing methods
- A Correlation between the microstructure and their reaction characteristics

Microstructure of raw powder (Al, Ni)

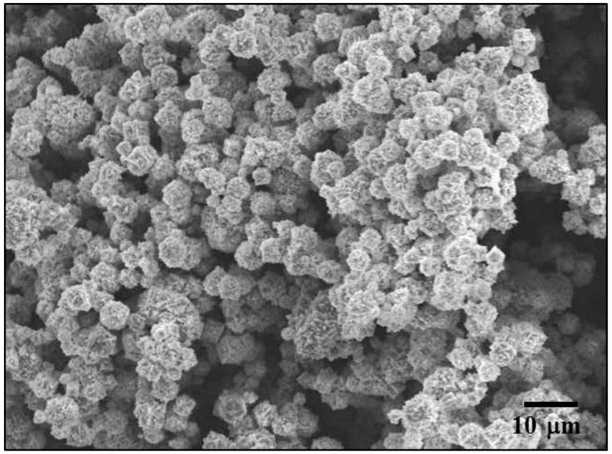
- Spherical shape of Al (AVG = 10 μm)

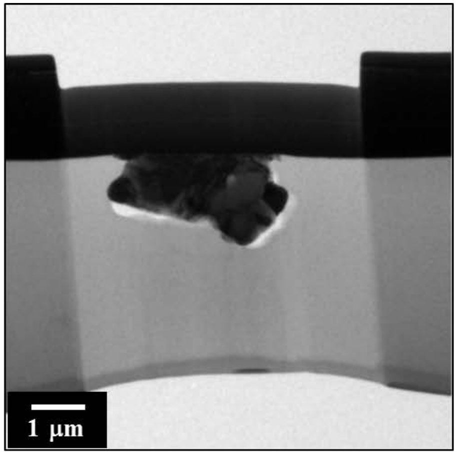


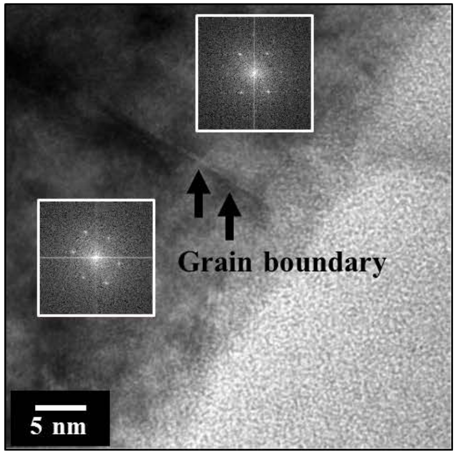




- Needle (spiky) shape of Ni (AVG = 4 μm)



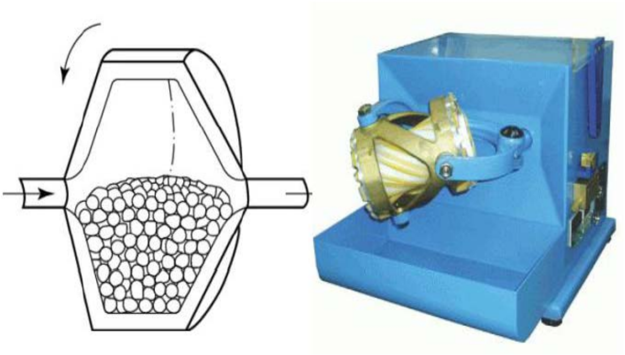


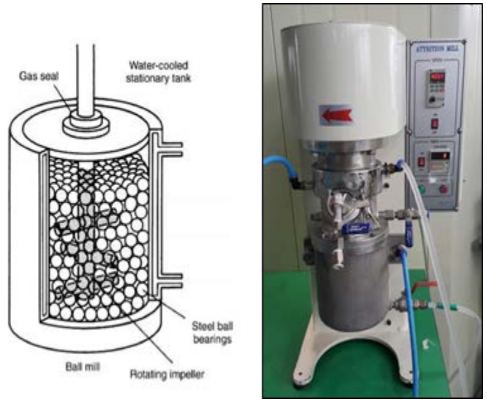


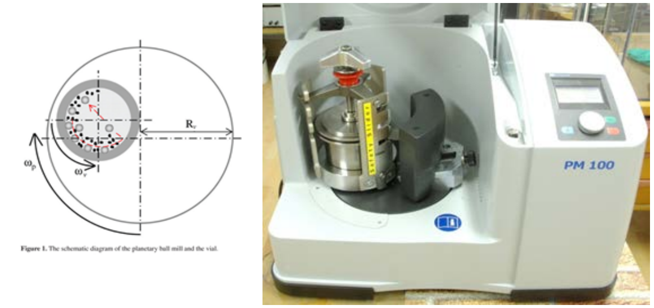
Manufacturing of Al/Ni reactive powder

■ **Use 3 types of mixing methods to modulate microstructure of Al/Ni reactive pow**

- Turbula Mixing (TM)
- Attrition Milling (AM)
- Planetary Milling (PM)







➡ 3D movement of container

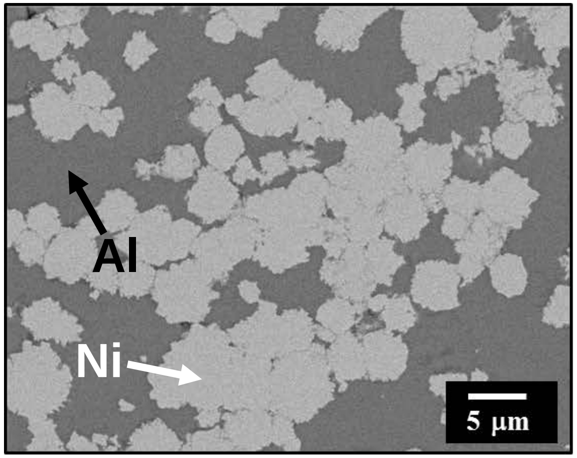
➡ Rotation of impeller in container

➡ Planetary (rotation and revolution) movement of container

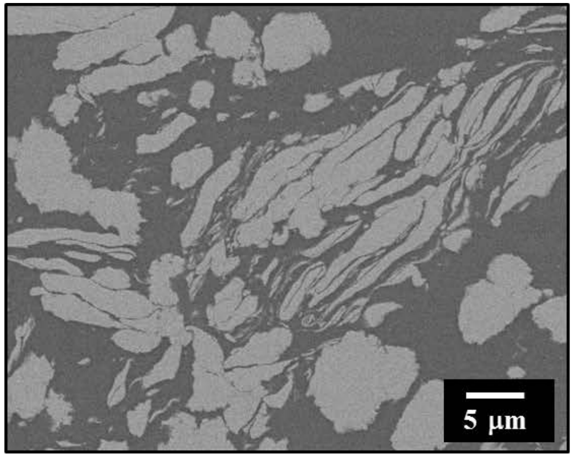
➢ **The amount of energy applied to the powder gradually increases in order of TM, AM, and PM.**

Microstructure of the Al/Ni reactive powder

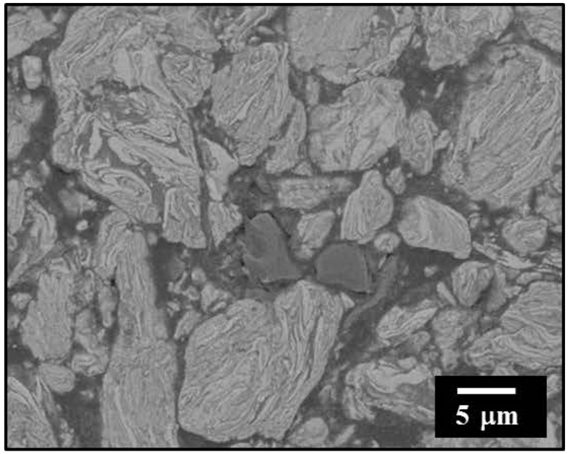
▮ Turbula Mixing (TM)



▮ Attrition Milling (AM)



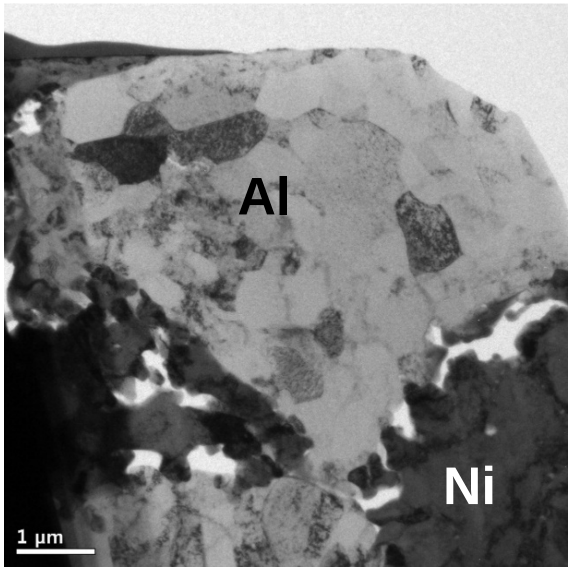
▮ Planetary Milling (PM)



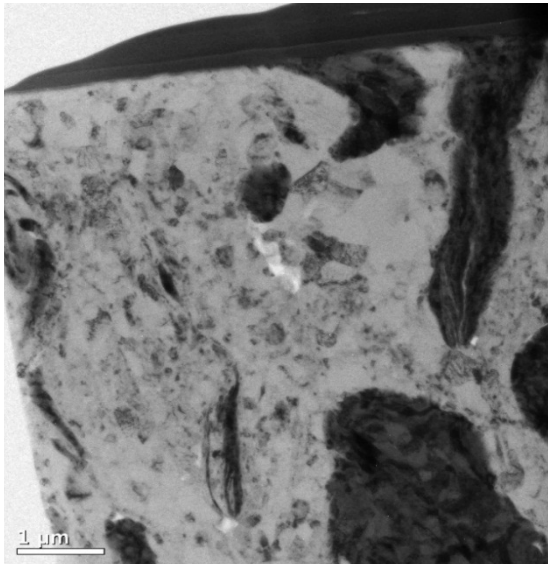
- **In TM-powder, the original shape of Al and Ni raw powder is maintained**
- **In AM-powder, the needle shape of Ni gradually disappear and shows elongated microstructure**
- **In PM-powder, the original shape of raw powder is completely collapsed and mixed at nano-level**

Microstructure of the Al/Ni reactive powder

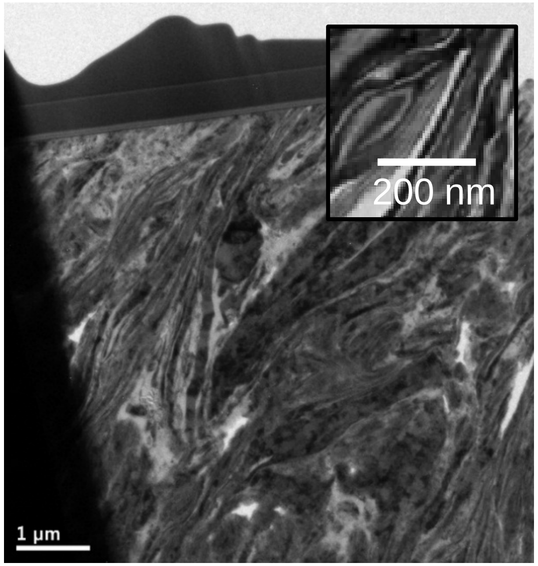
- Turbula Mixing (TM)



- Attrition Milling (AM)



- Planetary Milling (PM)



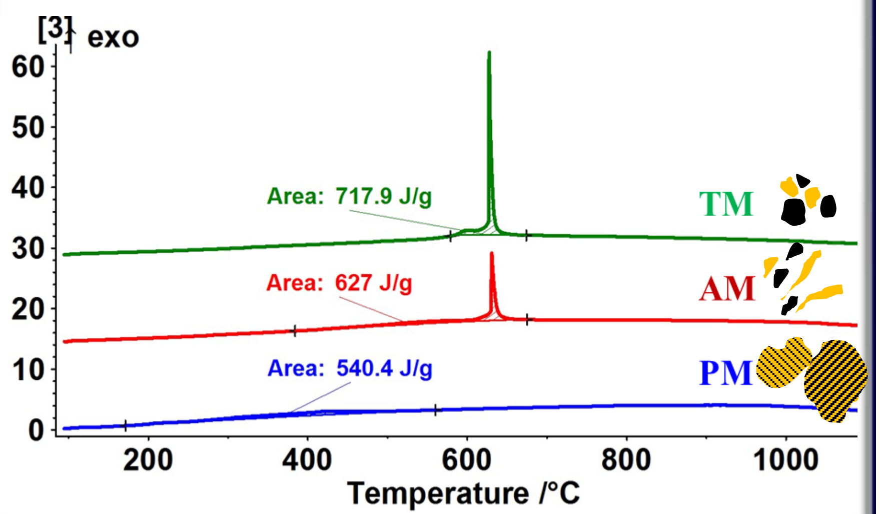
➢ **In TM-powder, the needle shape of Ni is maintained, but Al particle is broken into several grains of 1 μm (grain refinement of Al particle)**

➢ **In AM-powder, the grain refinements are more pronounced, and most of Al grains represent sub-micron size**

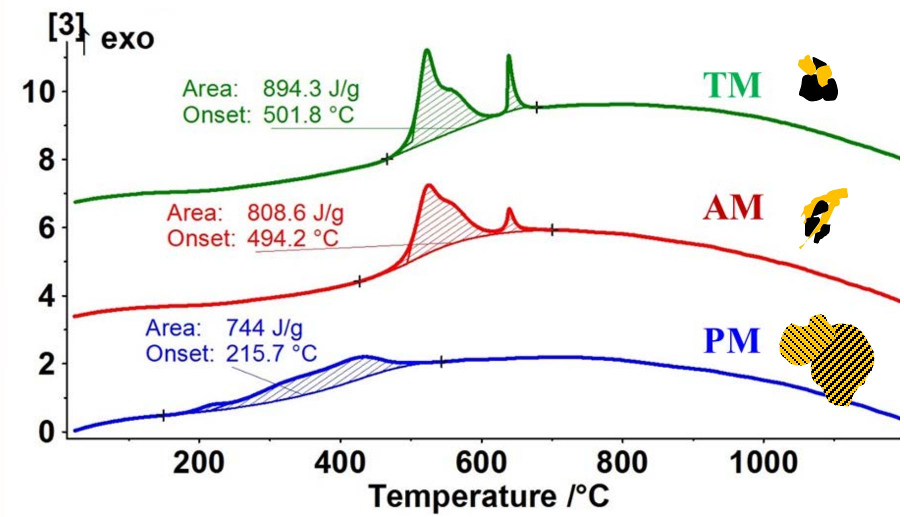
➢ **In PM-powder, the original shape of raw powder is completely collapsed and shows nano-lamella structure in which Al layer and Ni layer stacked alternatively and mixed at nano-level**

DSC analysis

Powder DSC Curve



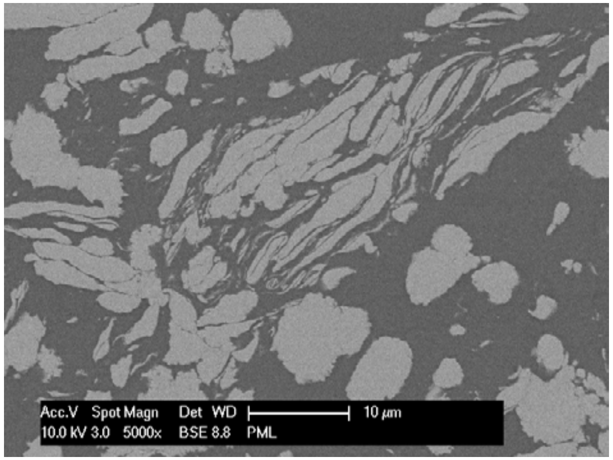
Compact DSC Curve



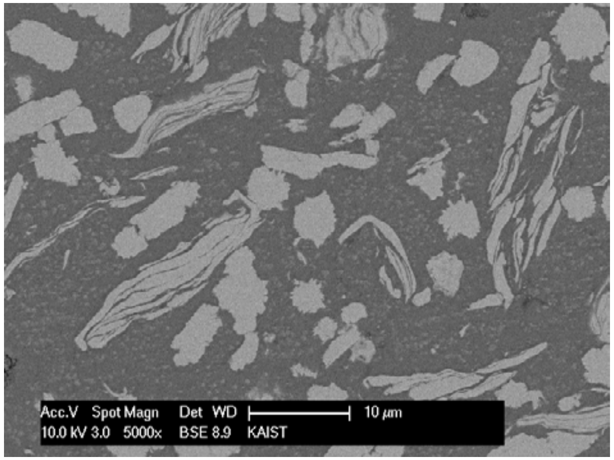
- TM- and AM- powder are reacted around Al melting point which is about 660 °C (hetero. Rx)
- PM-powder is reacted below Al melting point => PM-powder can react in solid state (homo. Rx)
- TM- and AM- compact are reacted at about 500 °C (the reaction initiation temperature changes)
  => In order for the reaction to initiate, it is important whether the interface between components is bonded or not
- The quantity of heat of reaction is gradually decreased with microstructure development
  => A small amount of components are already reacted in the mixing process.

Microstructure of the Al/Ni reactive powder

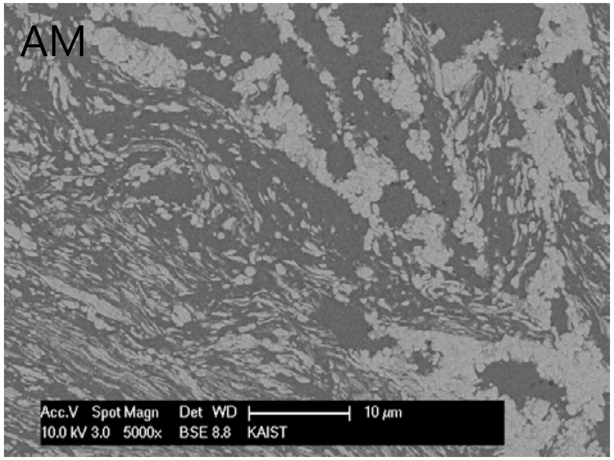
- Al (10 μm) + Ni (4 μm) -



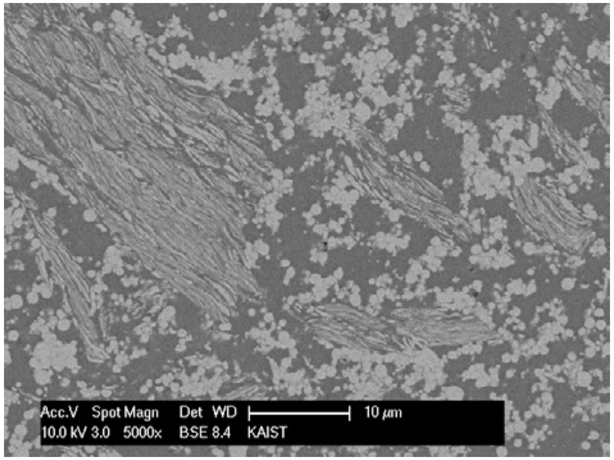
- Al (1 μm) + Ni (4 μm) - AM



- Al (10 μm) + Ni (1 μm) - AM

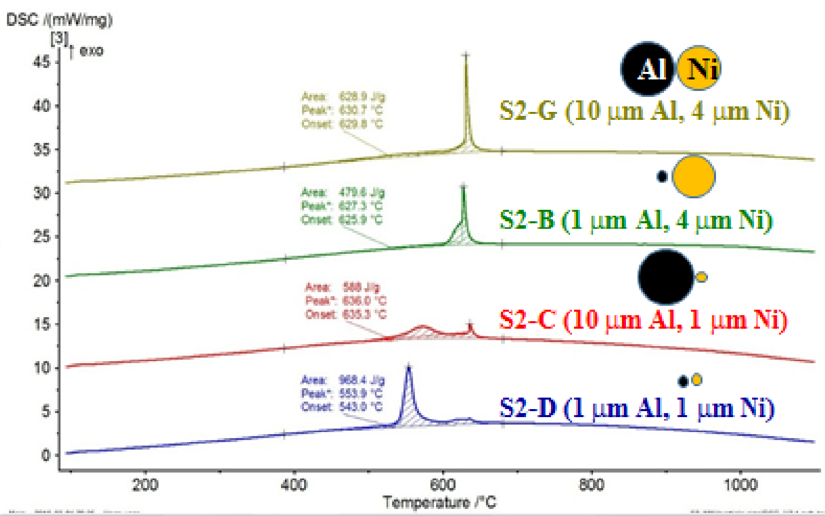


- Al (1 μm) + Ni (1 μm) - AM

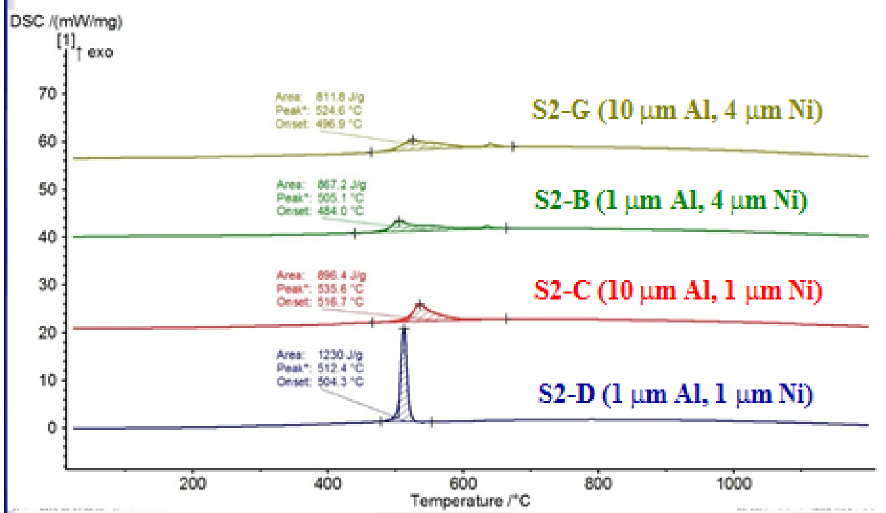


DSC analysis

Powder DSC Curve



Compact DSC Curve



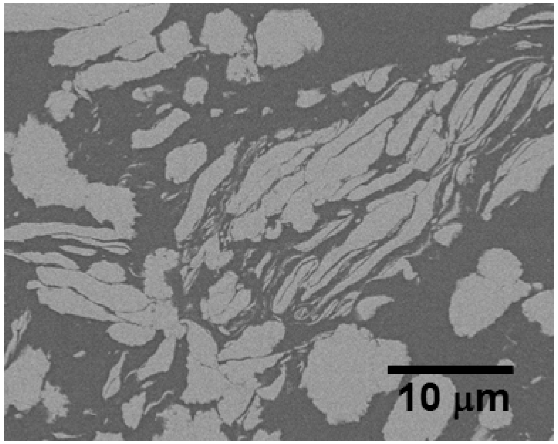
- The reaction initiation temperature is dropt only when using 1 μm Ni powder
  => In order for a RM to react, the mass transport of the component exhibiting a slow diffusion rate becomes important

- In the case of compact analysis, there are no big differences in terms of reaction initiation temperature

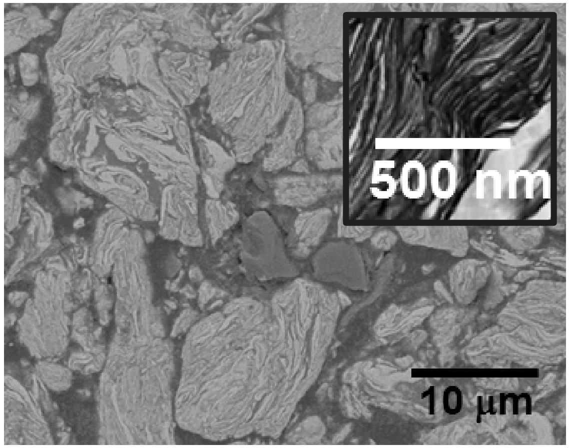
  => In order for the reaction to initiate, it is important whether the interface between components is bonded or not

Reaction rate (of RM compacts with changing microstructure)

- Attrition Milling (AM): The reaction is completed within about 100 ms to propagate 5 mm (0.05 m/s)



- Planetary Milling (PM): The reaction is completed within about 10 ms to propagate 5 mm (0.5 m/s)



Summary

- Various types of Al/Ni RM powders were prepared by varying mixing methods, and they are clearly distinguishable in terms of microstructure
- In DSC analysis, the reaction initiation temperatures of RM powder and RM compacts varied more than 200 ^oC with the changes of microstructure
- In order for the reaction to initiate, it is important whether the interface between components is bonded or not
- The reaction propagation rate varies greatly depending on the microstructure

➡ The reaction characteristics of the RM (or RMS) could be controlled by tailoring the microstructure of RM (or RMS)

Thank You

Q & A