High-temperature mechanical response of Aluminum- In-situ Polymer Derived Ceramic Composite prepared by Friction Stir Processing

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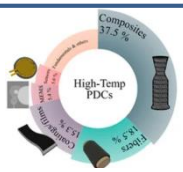
INTRODUCTION

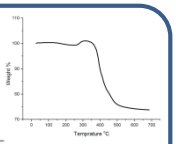
- Aluminum has light weight, high specific strength, corrosion-resistant, and easily recyclable but it drops its strength when exposed to high temperature
- Addition of PDC as reinforcement increases the mechanical properties at room temperature and microstructurally stable at high temperature [1].
- The Al-based PDC-MMCs are developed via Friction stir processing (FSP) in the present work.



Applications of PDC's

Polymer-derived ceramic (PDC)

- A silicon-based preceramic polymer, namely Polymethyl Hydrogen Siloxane (PMHS) cross-linked with DABCO is used.
- The decomposition of the polymer starts around 350 ˚C and is completed around 550ºC shown in the TGA curve (Weight % Vs. Temperature ˚C).


TGA of PMHS

Characteristics of PDC

- PDCs has wide range of applications in aerospace, MEMS, coatings etc.
- It has stable properties up to temperatures below 2000 ˚C


Structure of PMHS

MACHINES, METHODOLOGY AND PROCESS PARAMETERS


Figure: Five-axis FSW machine

Tool material

- High speed steel (HSS)
- Left hand tapered threaded tool with 1.5mm pitch

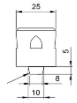


Figure: HSS Tool

Processing parameters

- Rotational speed = 1200 rpm
- Traverse speed = 25 mm/min
- Plunge depth = 5.6 mm

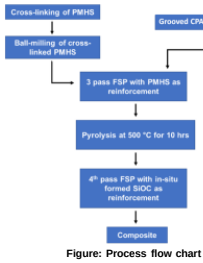


Figure: Process flow chart

Tensile test specimen & test conditions

- Gauge length=6mm
- Width, thickness=2mm, 1mm
- Strain rate =10^{-3}/sec
- Furnace mounted INSTRON machine used for high temperature tensile testing

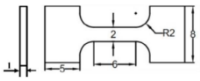


Figure: Tensile sample

RESULTS

Microstructure of CPAI, 4PCPAI, Composite (3P10h1P)

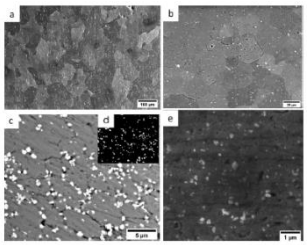


Figure: Microstructure shows grain size, particle distribution

a. CPAI has grain size ~ 100um
b. 4P CPAI has grain size ~ 25um
c. The composite grain size ~ 3um
d. Particles % in microstructure is 3.5 %
e. The presence of Nano-size PDC particles is seen.

Hardness variation

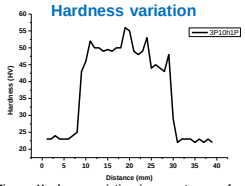


Figure: Hardness variation in nugget zone of composite

- Vickers hardness conducted with 100g load for 10 seconds dwell time,
- The composite has a 2.2 times increase in hardness

Microstructure at different temperatures

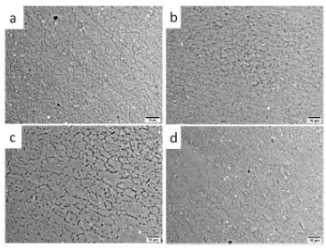


Figure: Microstructures at different temperatures

- a, b, c, d are the microstructures showing grain sizes at 200 ˚C, 300 ˚C, 400 ˚C, 500 ˚C
- The grain size variation is within ~ 5um, grains are stable due to particle pinning at grain boundaries [2]

Fractographs

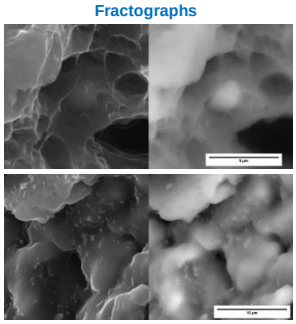


Figure: Presence of ceramic particle in fractured tensile sample at RT, and 500ºC

Stress-strain graphs of CPAI, 4PCPAI, Composite

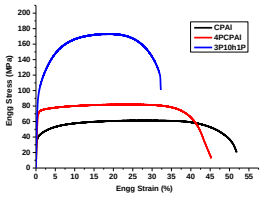


Figure: Engineering Stress-strain curves for CPAI, 4PCPAI, Composite (3P10h1P)

- Table shows the tensile properties of CPAI, 4PCPAI, and PDC composite at Room Temperature (RT)
- PDC composite has high strength and toughness at room temperature.
- UTS improved by 46.23%.

Table : Mechanical properties

Properties	CPAI	4P CPAI	3P10h1P
YS (MPa)	34±3	73±3	103±3
UTS (MPa)	60±2	82±2	173±5
Ductility (%)	38±3	40±2	30±3
Toughness (MJ/m^3)	35±1	29±1	50±1

Stress-strain graphs of composite at different temperatures

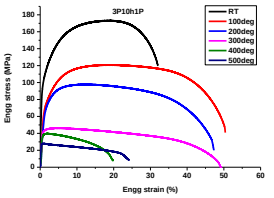


Figure: Engineering Stress-strain curves at various temperatures

- The tensile properties of PDC composite at RT, 200 ˚C, 300 ˚C, 400 ˚C, 500 ˚C
- Maintained 50% of its strength at 200ºC with a 150% increase in ductility.
- Drastic drop in ductility above 400ºC

Conclusions

- In this study Al-based PDC-MMC was developed by Friction stir processing
- It has a combination of high strength and toughness
- The microstructures show grain stability even at high temperatures; Thus, grain stability is due to particle pinning at grain boundaries by the In-situ formed PDC particles.
- The mechanical properties show stability in strength up to 200 ˚C and fracture progresses through the matrix. Whereas at 500 ˚C it fractures through the particle, matrix interface which leads to a sudden drop in ductility
- Therefore, it has grain stability and strength at high temperature

Acknowledgements

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References

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[2] Pariyar A, Toth LS, Kailas SV, Peltier L. Imparting high-temperature grain stability to an Al-Mg alloy. Scripta Materialia. 2021 Jan 1;190:141-6.