PRODUCTION AND CHARACTERIZATION OF ALUMINUM MATRIX COMPOSITES FOR SMALL-SCALE UNMANNED AIRCRAFT ENGINE PISTONS

Muammer DEMİRALP

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OUTLINE

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The main purpose of this work is to develop a special processing technique for production of an aluminum alloy-based ceramic particulate reinforced composite engine piston for unmanned light aircraft.

1- SiC particles corporation via vortex method,

2- SiC particles corporation via Rheo-Sintering.

Figure 1. Photograph of a diesel engine piston with fiber reinforcement[1].

E. A. Feest, Expoloitation of the Metal Matrix Composites Concept, Metals and Materials, 1988, pp. 273

1. Introduction

Conventional pistons are generally consisted of Al-Si alloys. Some additional elements such as Cu, Mg and Ni are also used to increase the strength.

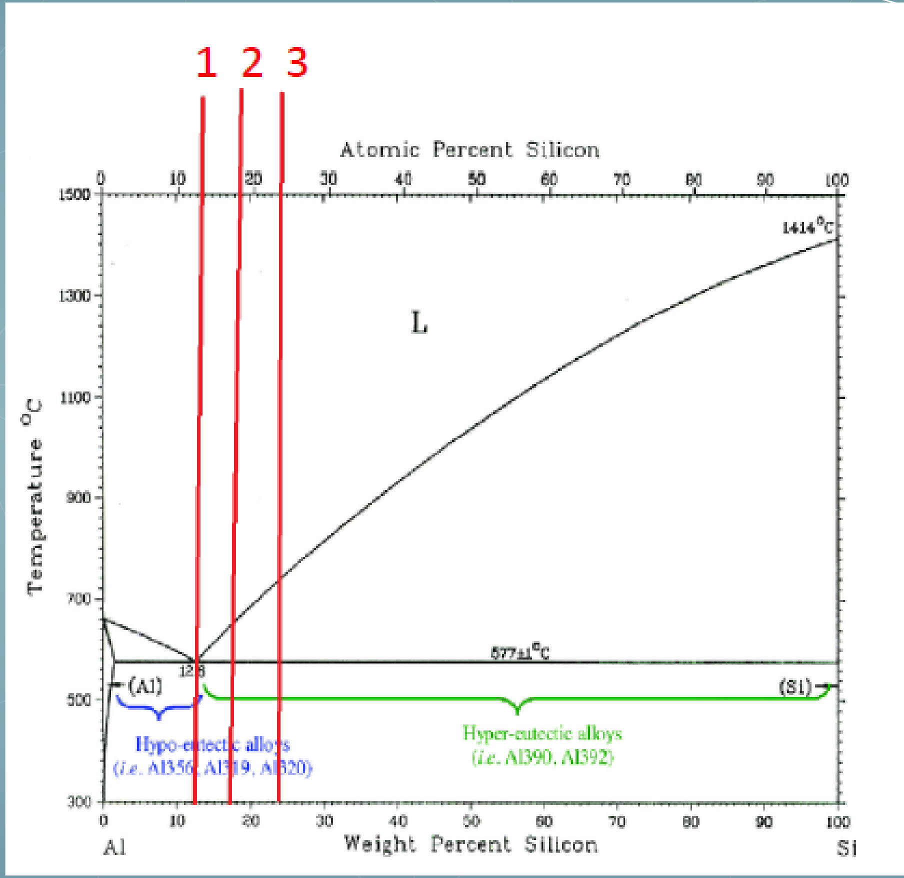


Figure 2. Photograph of a diesel engine piston with fiber reinforcement[2].
E. A. Feest, Expoloitation of the Metal Matrix Composites Concept, Metals and Materials, 1988, pp. 273

1. Introduction

The typical pistons used in small-scale engines for motorcycles and unmanned aircraft are produced by using two main techniques; forging and machining.

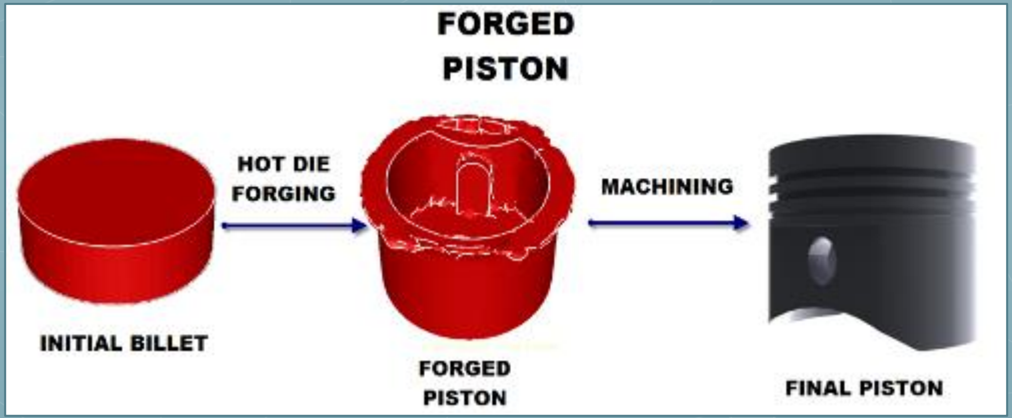


Figure 3. Manufacturing method of typical piston [3].
Engine Pistons Manufacturing method , Retrieved October 10, 2019, from http://msvs-dei.vlabs.ac.in/upsetting_process.php

1. Introduction

The heat treatment of piston alloy is generally T5 and T6 after production. They are consisted of three steps; solution treatment, quenching and ageing [4].

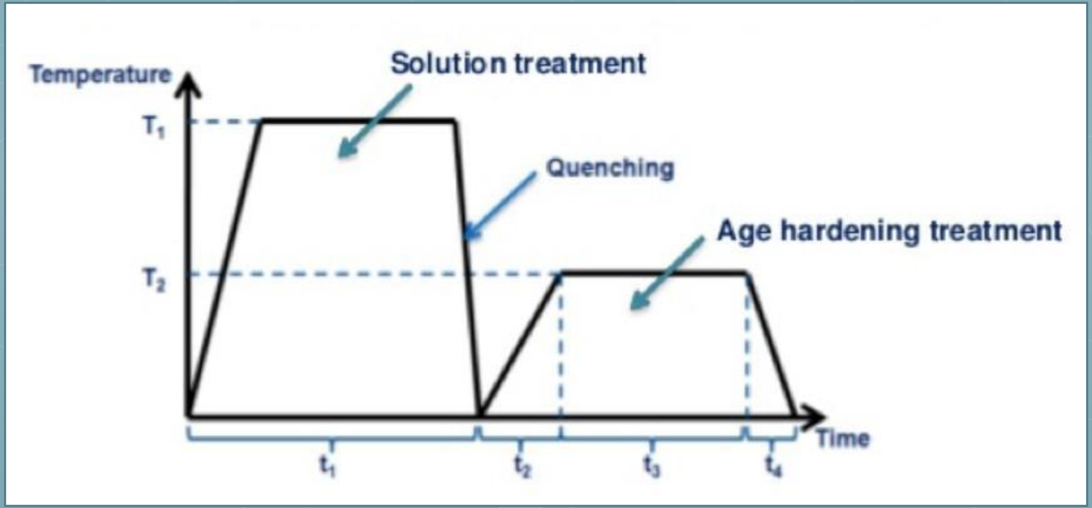


Figure 4. Schematic view of T6 heat treatment [5].
Industrial Heating, Retrieved May 10, 2018 from https://www.industrialheating.com/blogs /14-industrial-heating-experts-speak-blog/post/92943-heat-treatment-process-overview-for-fasteners-part-2

1. Introduction

The typical compositions are consisted of Al-Si alloy with adding some Cu, Ni and Mg as it is mentioned before. The microstructure of Al-Si consists of coarse Si primary phases, need-like eutectic phases and α (Al) phases.

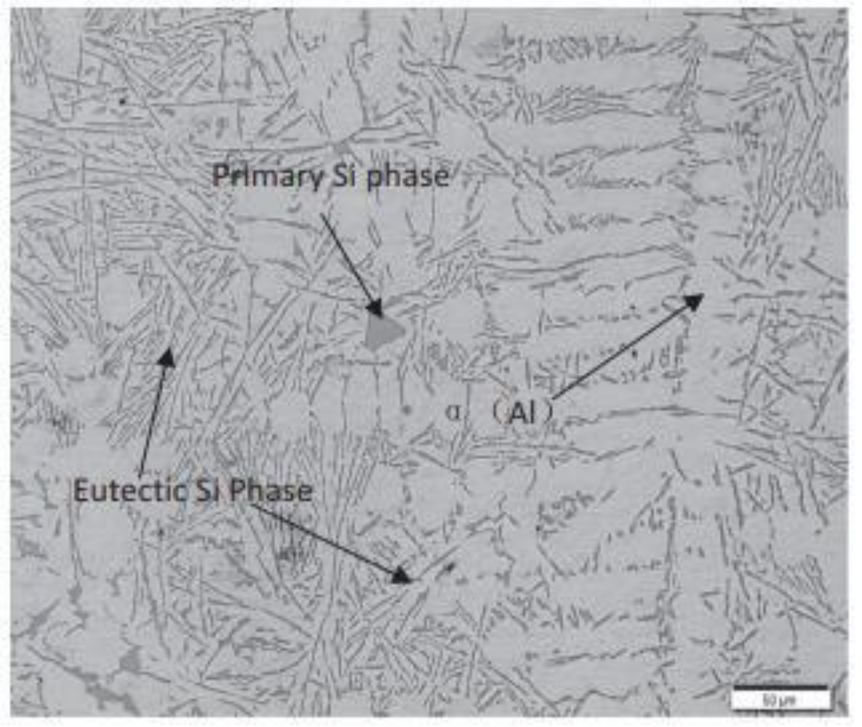


Figure 5. Optical image of initial hypoeutectic Al–10Si alloy with 50 μ*m* scale[6].
L. Diankun, G. Bo, Z. Guanglin, High-Current Pulsed Electron Treatment of Hypoeutectic Al–10Si Alloy, High Temp. Mater. Proc. 2017; 36(1), pp. 97–100

1. Introduction

Table 1. Mechanical properties of piston alloys [7].

	Eutectic Alloy AlSi12 CUMgNi cast	Eutectic Alloy AlSi12 CUMgNi forged	Hypereutectic Alloy AlSi18CuMgNi cast	Hypereutectic Alloy AlSi18CuMgNi forged	Special Eutectic Alloy AlSi12Cu4Ni2Mg cast
Yield Strength $R_{P0,2}$ (MPa) at Temperature					
20°	190 – 230	280 – 310	170 – 200	220 – 280	200 – 280
150°	170 – 220	230 – 280	150 – 190	200 – 250	–
200°	120 – 170	–	100 –150	–	150 – 200
Ultimate Tensile Strength R_m (MPa) at Temperature					
20°	200 – 250	300 – 370	180 – 230	230 – 300	210 – 290
150°	180 – 230	250 – 300	170 – 210	210 – 260	–
200°	160 – 200	–	160 – 190	–	170 – 210
Elongation to Fracture A_5(%)					
20°C	0,3 – 1,5	1 – 3	0,2 – 1,0	0,5 – 1,5	0,1 – 0,5
Hot Hardness after 200 hours at temperature: Hardness ($HB_{5/50/30}$)					
20°C	90 – 125	90 – 125	90 – 125	90 – 125	100 – 150
150°C	80 – 90	80 – 90	80 – 90	80 – 90	80 – 115
200°C	60 – 70	60 – 70	60 – 70	60 – 70	60 – 75
Fatigue Strength σ_w (N/mm^2)					
20°C	80 – 120	110 – 140	80 – 110	90 – 120	90 – 120
150°	70 – 110	90 – 120	60 – 90	70 – 100	90 – 120
250°	50 – 70	60 – 70	40 – 60	50 – 70	60 – 80

L. Diankun, G. Bo, Z. Guanglin, High-Current Pulsed Electron Treatment of Hypoeutectic Al–10Si Alloy, High Temp. Mater. Proc. 2017; 36(1), pp. 97–100

1. Introduction

Squeeze casting (SC) is the term of metal forming process which occurs under high pressure. It is a metal-forming process, which combines casting and forging. Although squeeze casting is now the accepted term for this forming operation, it has been variously referred to as “extrusion casting”, “liquid pressing”', “pressure crystallization” and “squeeze forming”.

1. Introduction

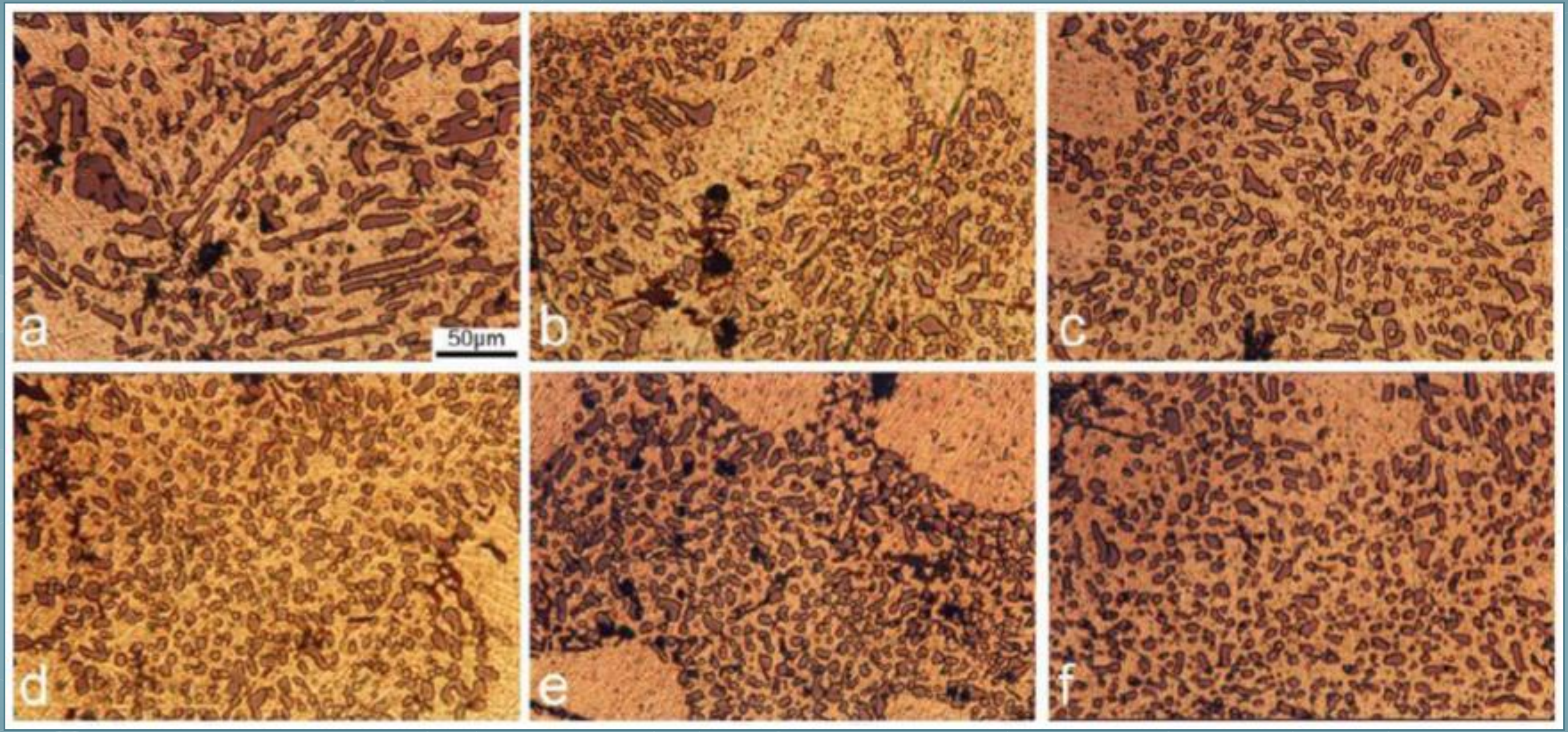


Figure 6. Effect of external pressure on the morphology of squeeze cast alloy: (a) 0 MPa, (b) 20 MPa, (c) 53 MPa, (d) 106 MPa, (e) 171 MPa (f) 211 MPa [8].

A.Maleki, A.Shafyei, B.Niroumand, Effects of Squeeze Casting parameters on the Microstructure of LM13 alloy, Journal of Materials Processing Technology 209, pp 3790- 3797, 2009.

1. Introduction

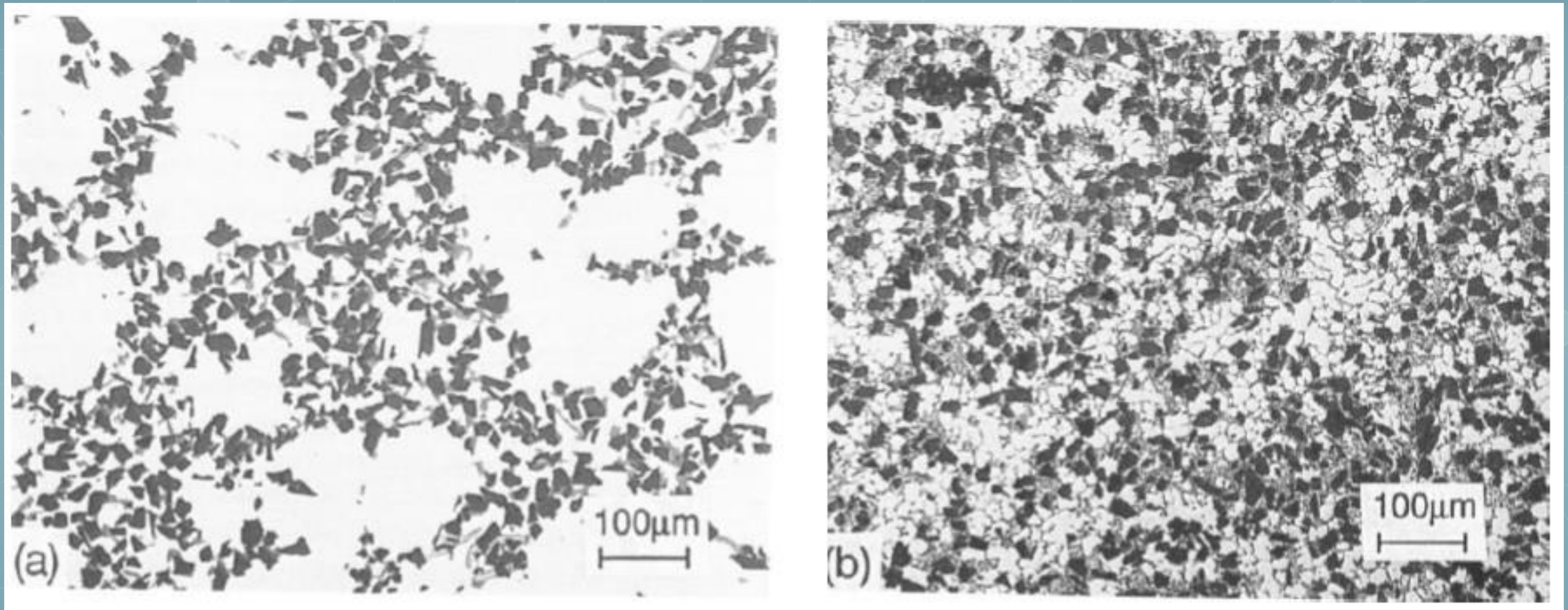


Figure 7. Microstructure of Al-7%wt Si + SiC particles (a)investment cast and (b) pressure die cast [9].
Lloyd, D. J. (1991) Factors Influencing the Properties of Particulate Reinforced Composites Produced by Molten Metal Mixing, in Metal Matrix Composites – Processing, Microstructure and Properties, National Laboratory: Denmark pp. 81-99

2. Methodology

Figure 8. The example of damaged pistons[10].
Comparison of Wear and New Pistons, Retrieved April 2018 from http://www.protectivecoatingsystems.com/zmax

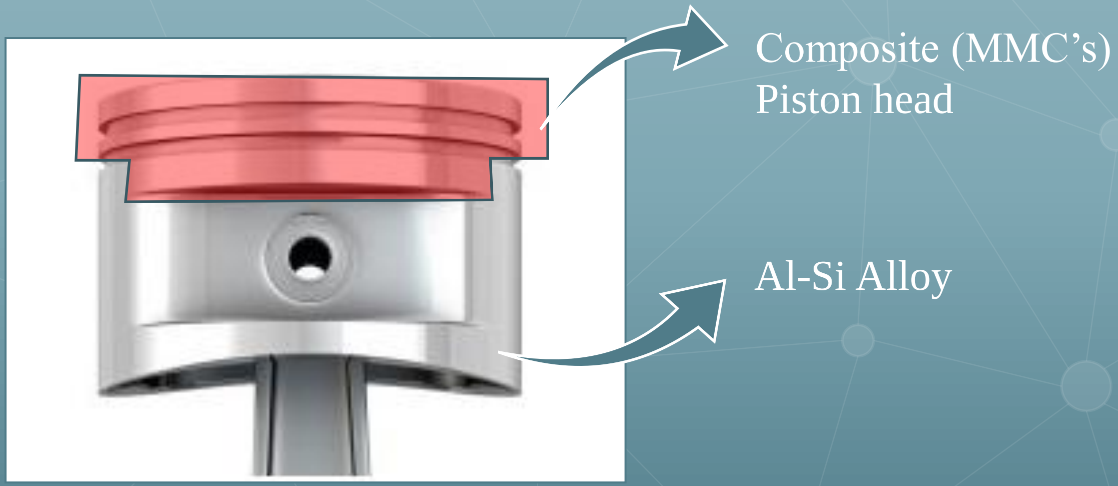
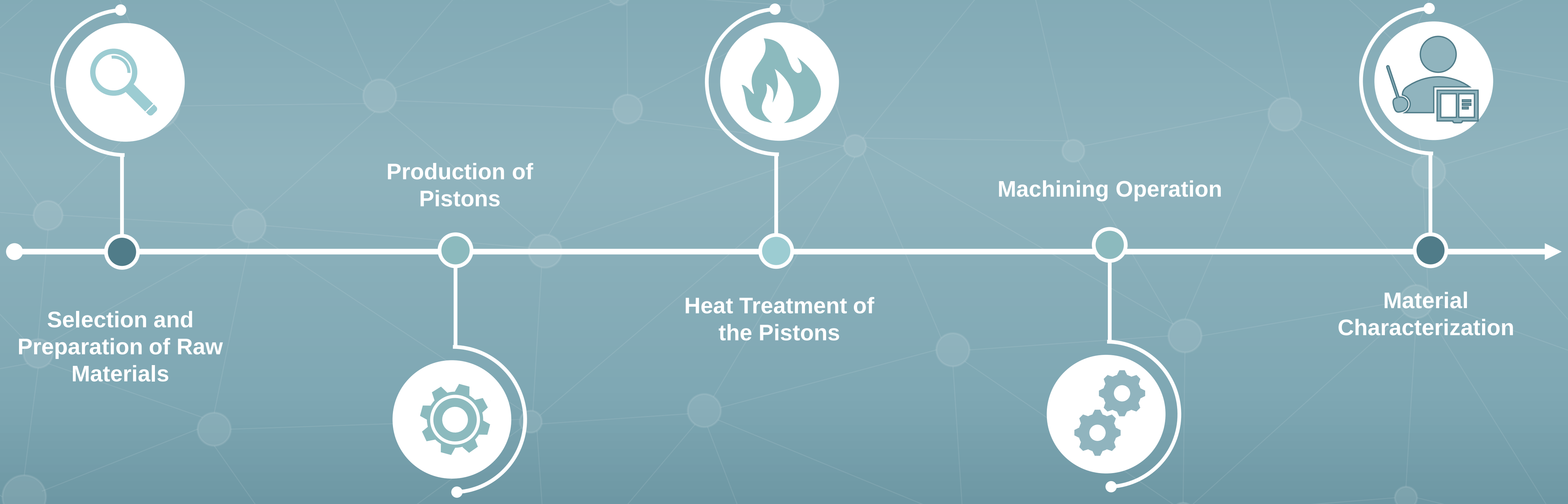


Figure 9. Production Parts of piston.

2. Methodology



2. Methodology

Selection and Preparation of Raw Materials

The composite part was created by three different ways and compositions.

- The first one was formed by only adding 10 wt. % silicon carbide particles to the Al-12Si-2.5Cu-1Mg which is mentioned before in liquid form. (Vortex Method)
- The second composite part was formed by using pure Al powder for matrix instead of Al alloy in liquid state. It is mixed with SiC powder. (Rheo-casting Method)
- The third composite part was formed by using Al-Si eutectic powder for matrix instead of Al alloy in liquid state. It is mixed with SiC powder. (Rheo-casting Method)

2. Methodology

Selection and Preparation of Raw Materials

Table 2. Detailed designation of the specimens.

Designation	Description
Conventional Piston	The piston which is already used in the engine. It is consisted of Al-12Si-2.5Cu-1Mg alloy.
Sample 1	Al-12Si-2.5Cu-1Mg alloy in liquid + 10 wt. % SiC powder preform infiltrated with Al-12Si-2.5Cu-1Mg alloy.
Sample 2	Pure Al powder + 10 wt. % SiC powder preform infiltrated with Al-12Si-2.5Cu-1Mg alloy.
Sample 3	Al-12Si powder + 10 wt. % SiC powder preform infiltrated with Al-12Si-2.5Cu-1Mg alloy.

2. Methodology

Production of Pistons

In this work, piston was produced in two parts as it is mentioned before. The first part is composite production for piston head and the second part is infiltration of Al alloy.

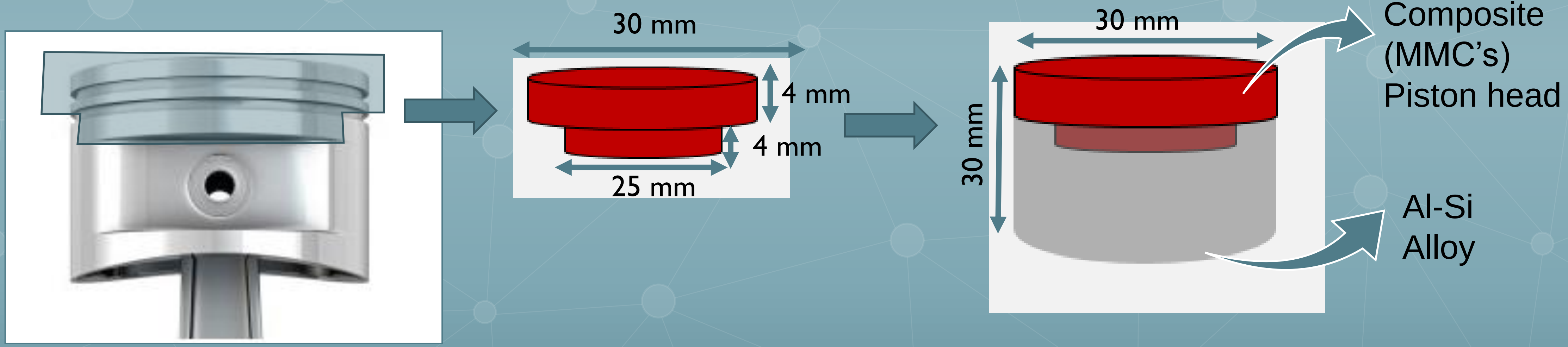


Figure 10. Production Parts of piston.

2. Methodology

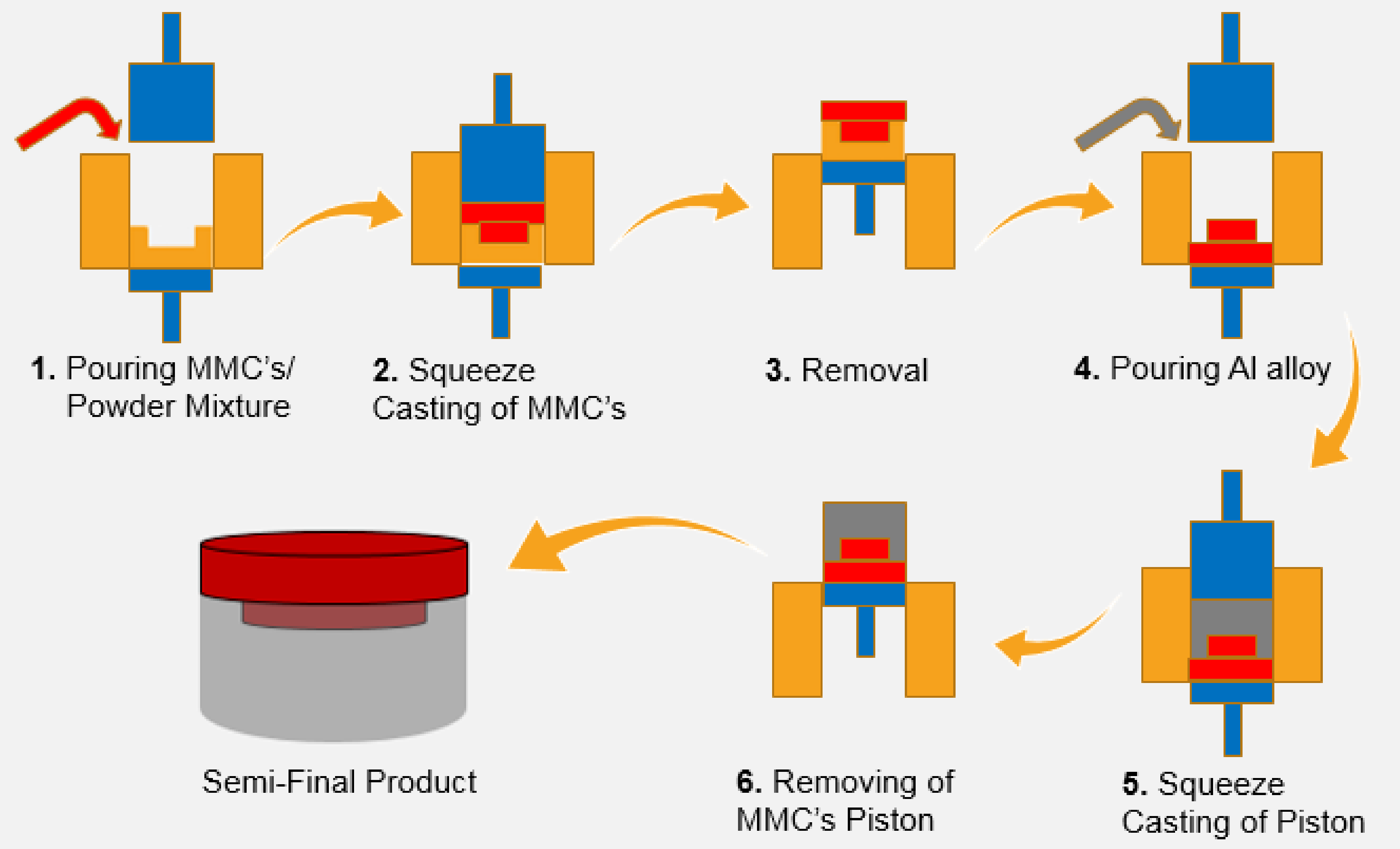


Figure 11. Production flow chart of squeeze cast pistons

2. Methodology

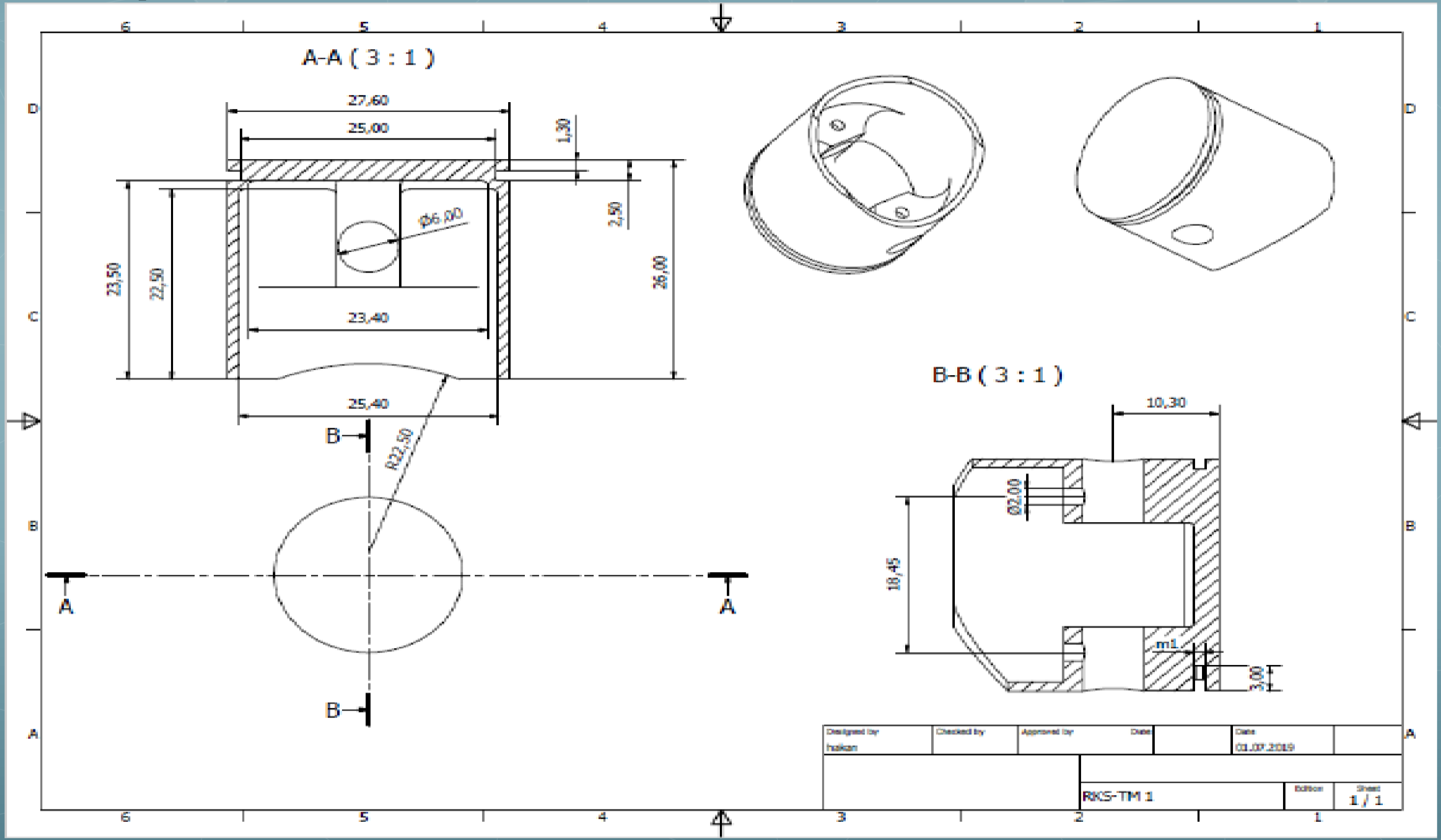
Heat Treatment of Pistons

After producing semi-final pistons, “sample 2” and “sample 3” were sintered at 560 ^{0}C for 85 minutes.

After sintering “sample 2” and “sample 3”, all semi-final products which were produced by using squeeze casting machine were heat treated. For these samples, T6 heat treatment was applied. The samples were heated to 520 ^{0}C with 3 ^{0}C/min heating rate, and hold on for 2 hours at this temperature. Then, it was rapidly cooled to room temperature in cold water. After that, they were aged. For ageing, products were heated to 180 ^{0}C for 6 hours.

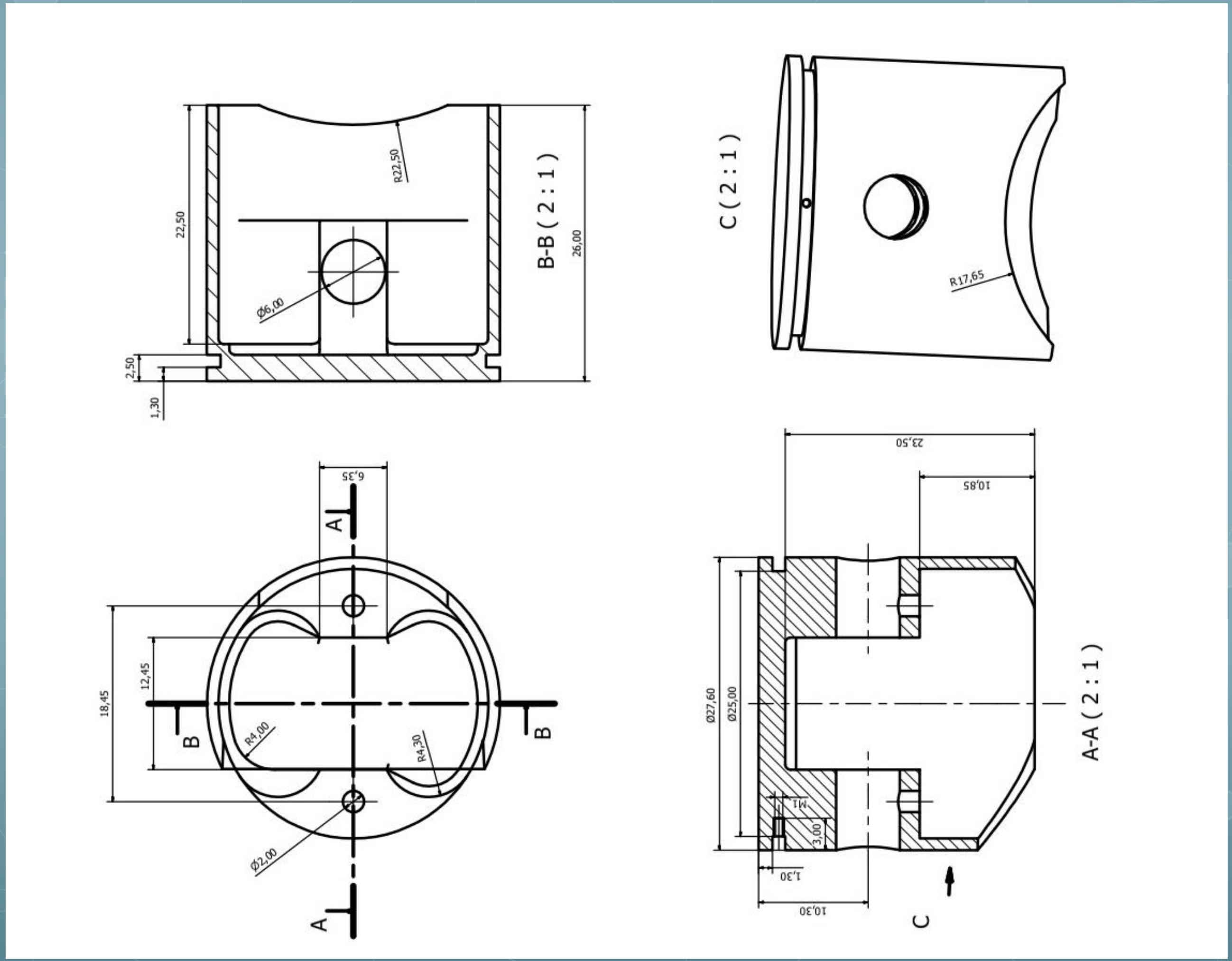
2. Methodology

Machining Operation



2. Methodology

Machining Operation



2. Methodology

Machining Operation

Figure 12. Pistons after squeeze casting and machining.

2. Methodology

Material Characterecication

The pistons were characterized according to their physical and chemical properties. The tests are listed below.

- Chemical analysis,
- Hardness test,
- 3-point bending test,
- XRD test,
- Optical and Electron microscope analysis.

3. Resuls & Discussion

Chemical Analysis Results

At the beginning of the study, the chemical analysis of the conventional piston (C. Piston) was done. According to this chemical composition, the material of the novel pistons is determined. The chemical analysis results of all specimens are shown in table 3 below. These results belong the Al alloy part of the novel pistons. All pistons are consisted of Al, Si, Cu and Mg.

Table 3. Chemical analysis results of the pistons.

	Al	**Si**	**Cu**	**Mg**
C. Piston	84.5	12.2	2.48	0.34
Sample 1	82.82	12.13	3.18	1.61
Sample 2	82.4	12.02	3.25	1.58
Sample 3	82.9	12.05	3.3	1.63

3. Resuls & Discussion

Hardness Test Results

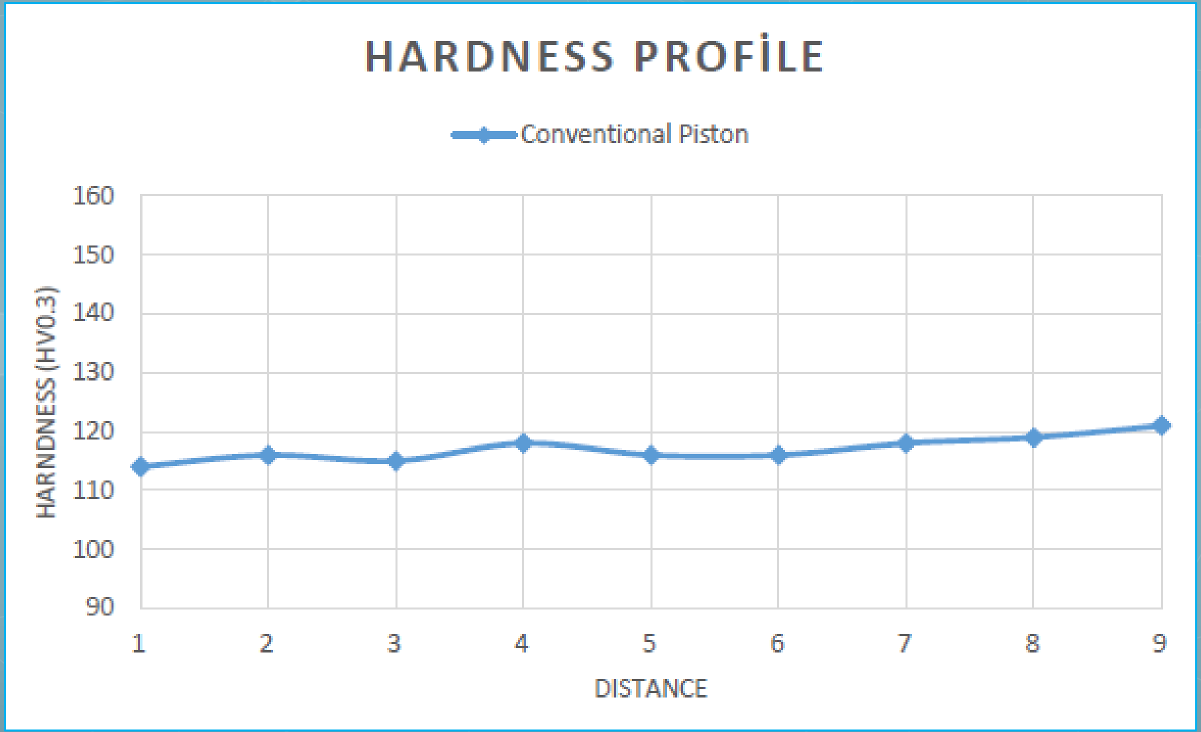


Figure 13. Vickers Hardness profile of the conventional piston.

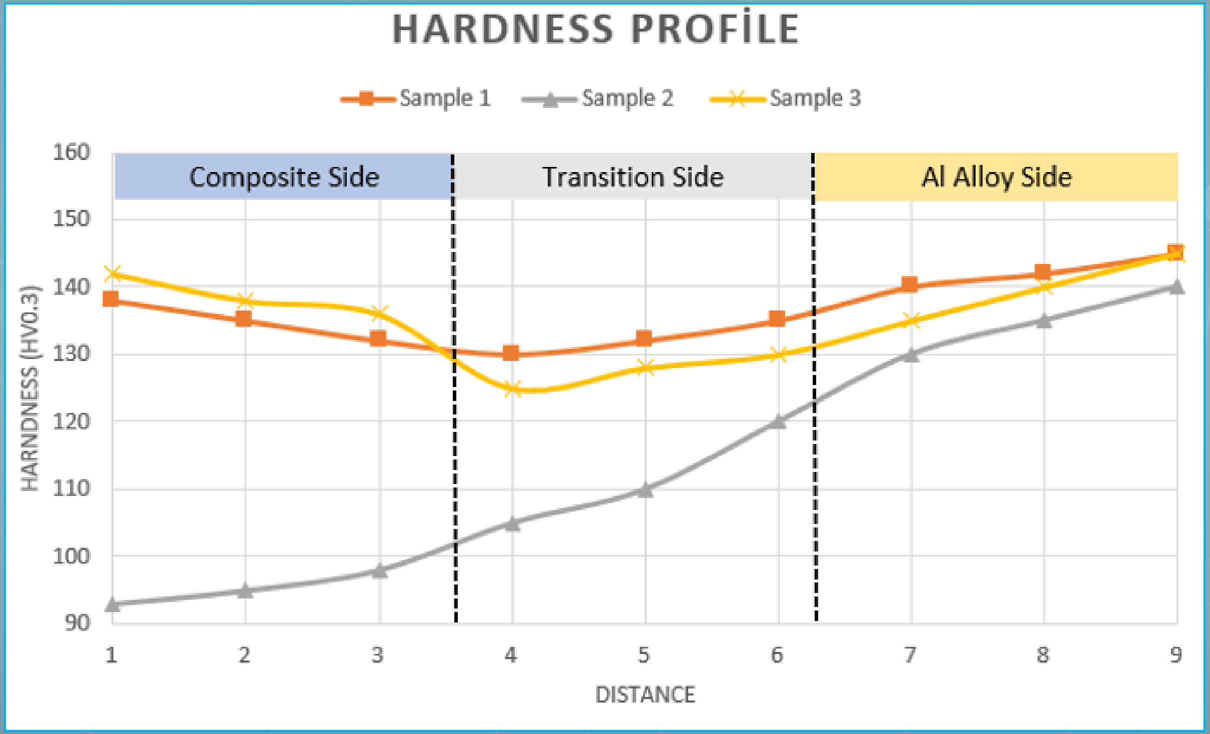


Figure 14. Vickers Hardness profile of MMC's pistons.

Sample 1: Al-12Si-2.5Cu-1Mg alloy in liquid state + SiC powder via vortex technique then infiltrated with Al-12Si-2.5Cu-1Mg alloy
Sample 2: Pure Al powder + SiC powder preform infiltrated with Al-12Si-2.5Cu-1Mg alloy
Sample 3: Al-Si eutectic powder + SiC powder preform infiltrated with Al-12Si-2.5Cu-1Mg alloy

3. Resuls & Discussion

3- Point Bending Test Results

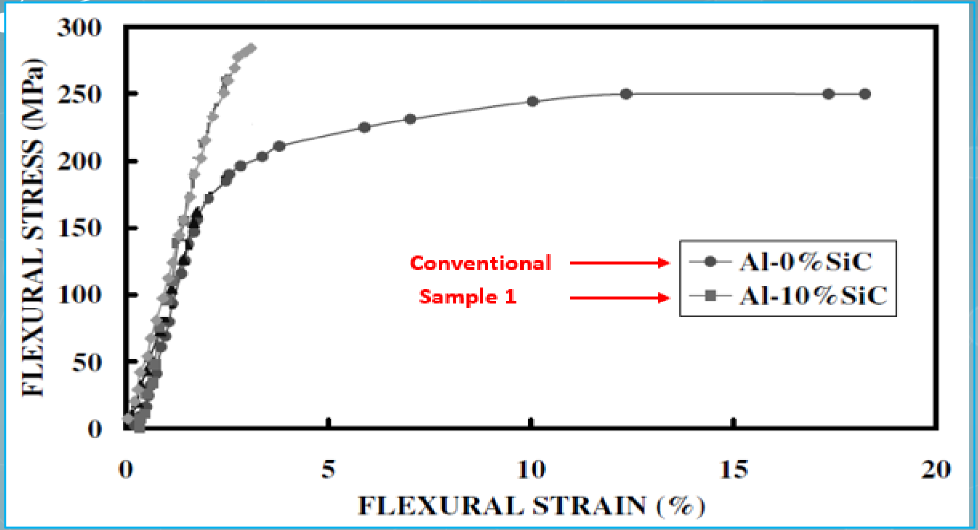


Figure 15. Flexural test results of conventional piston and sample 1 [11].
C. Kaynak, S. Boylu, "Effects of SiC particulates on the fatigue behaviour of an Al-alloy matrix composite", Materials and Design, Vol 27, January 2005, pp. 276-282

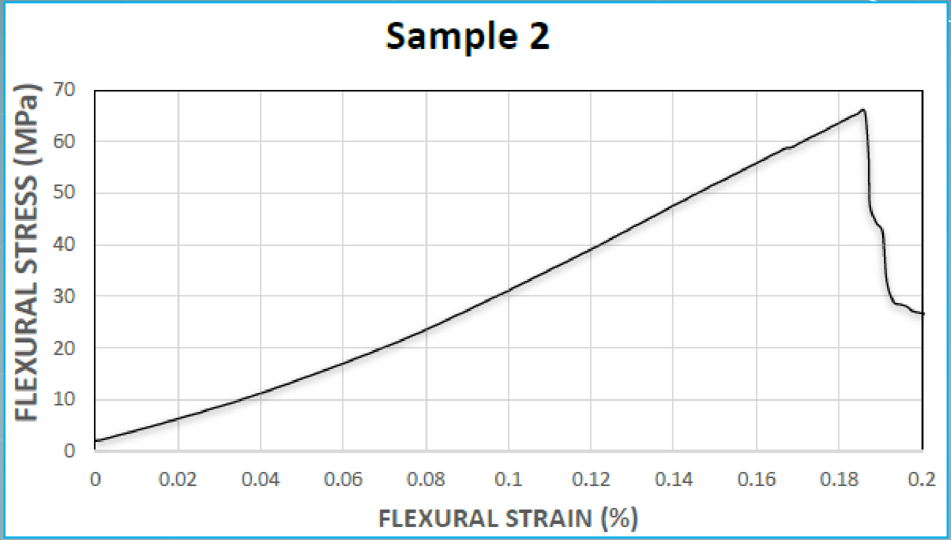


Figure 16. Flexural test result of sample 2.

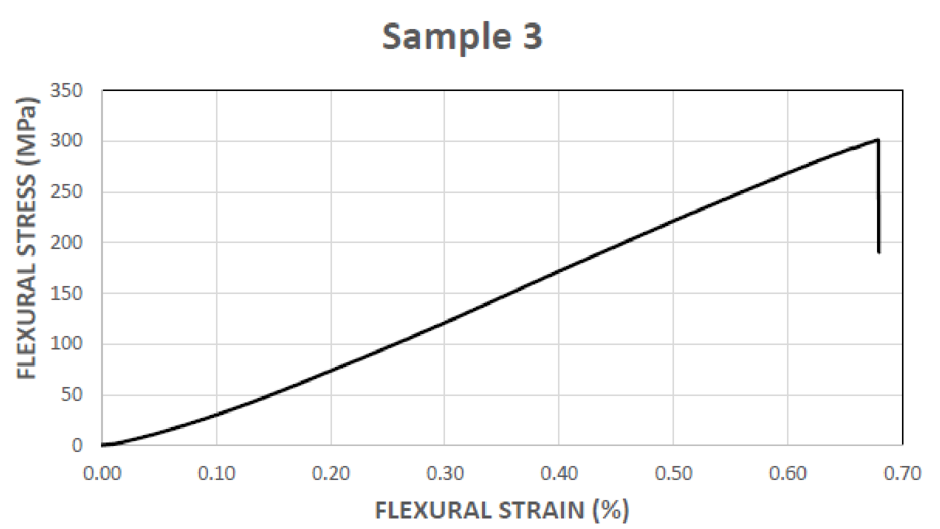


Figure 17. Flexural test result of sample 3.

3. Resuls & Discussion

XRD Test Result

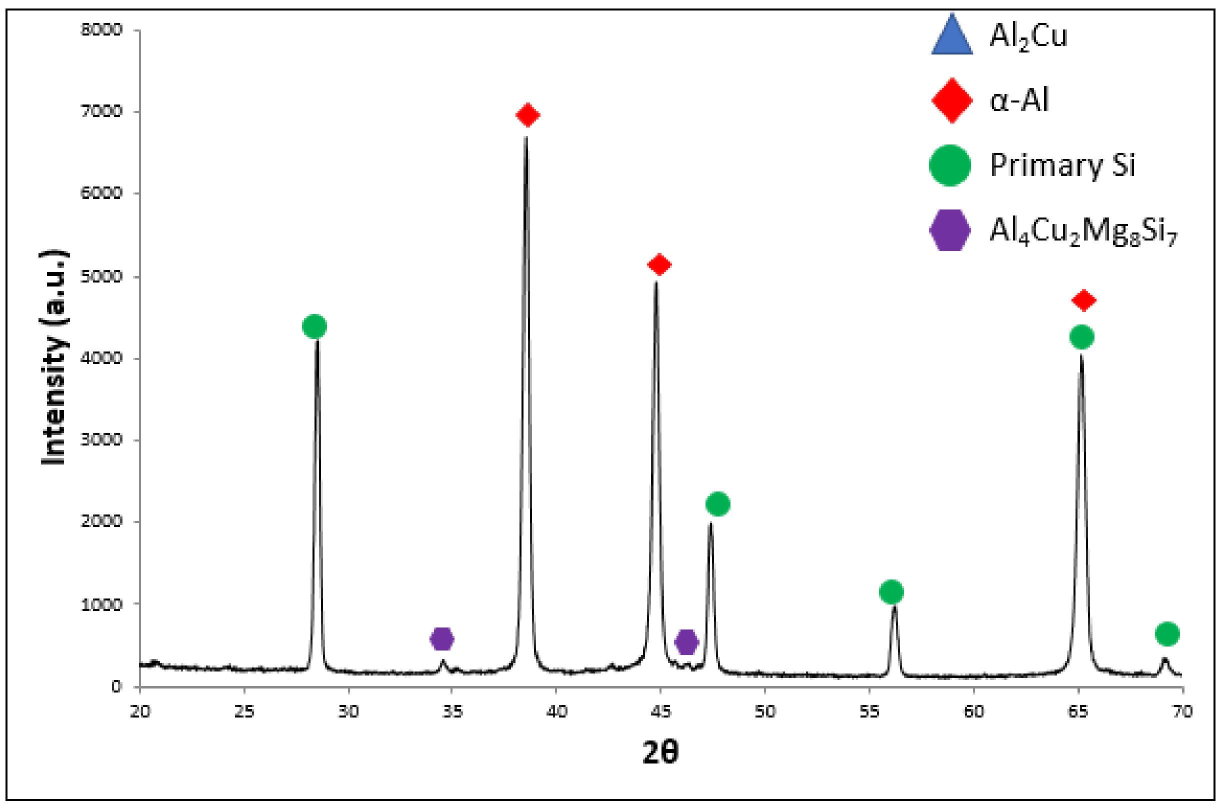
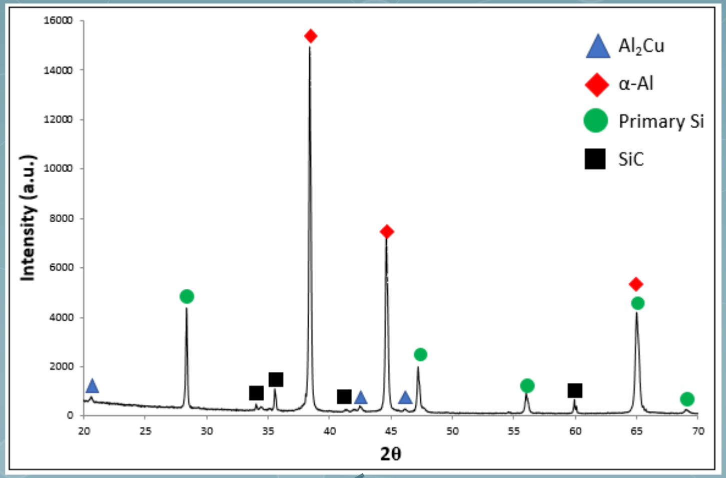
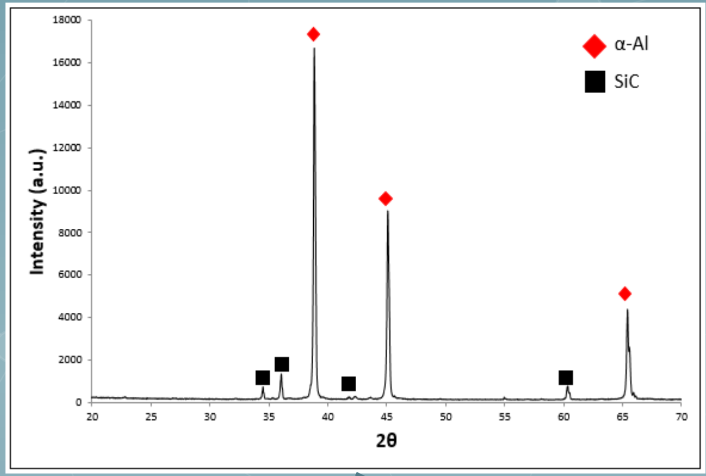


Figure 18. The XRD pattern of Al alloy part of novel pistons.

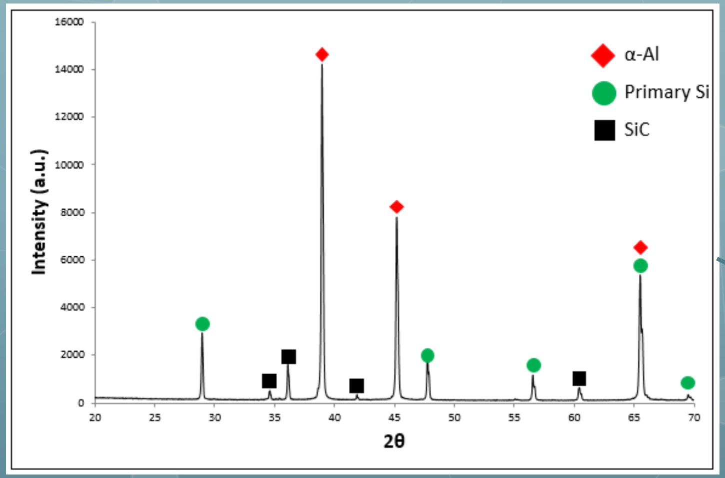
3. Resuls & Discussion



Composite part of Sample 1



Composite part of Sample 2



Composite part of Sample 3

3. Resuls & Discussion

Microstructural Analysis

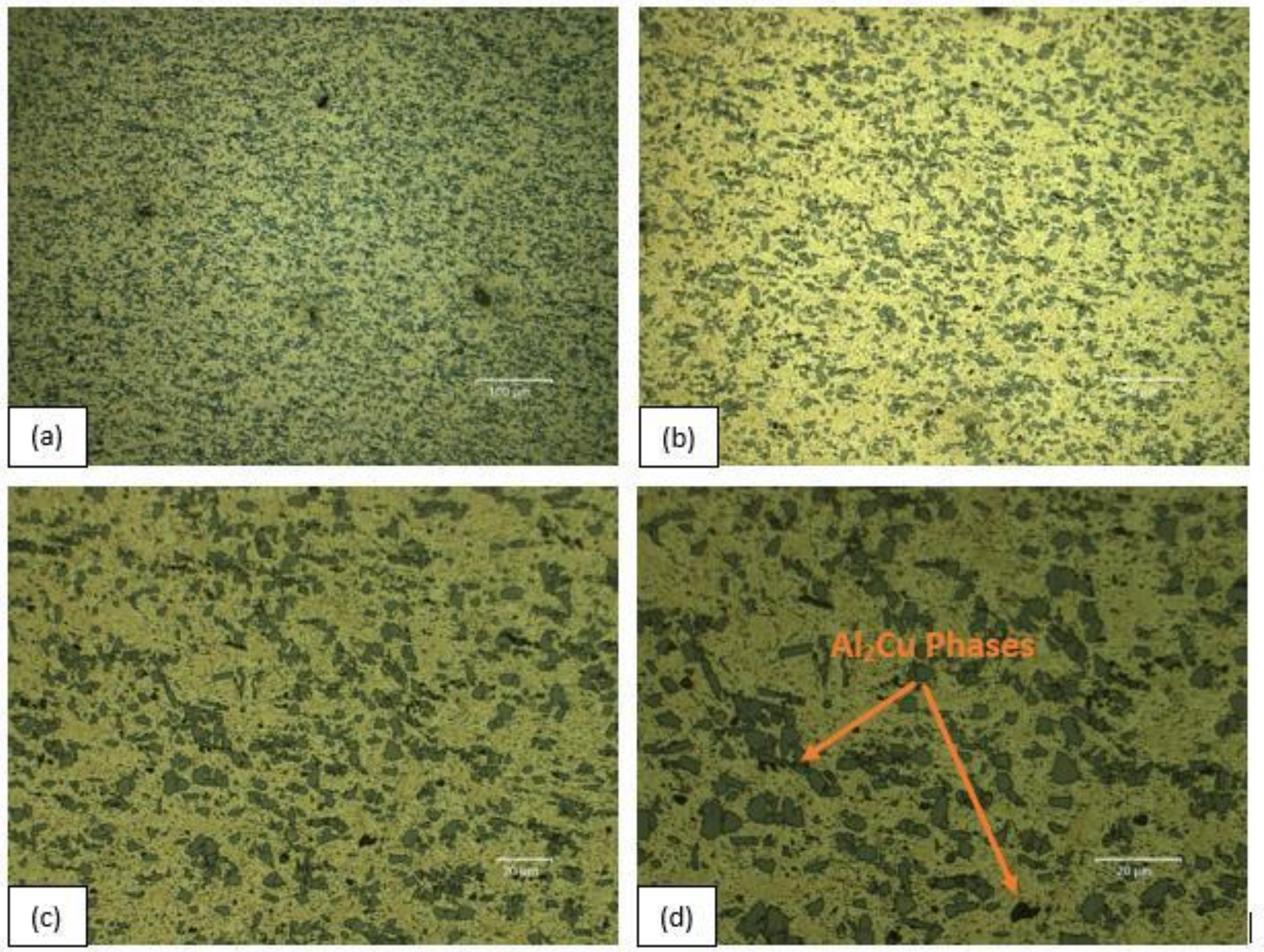


Figure 19. Microstructures of the conventional piston with different magnifications, (a) lower magnification to (d) higher magnification as etched with Keller solution.

3. Resuls & Discussion

Microstructural Analysis

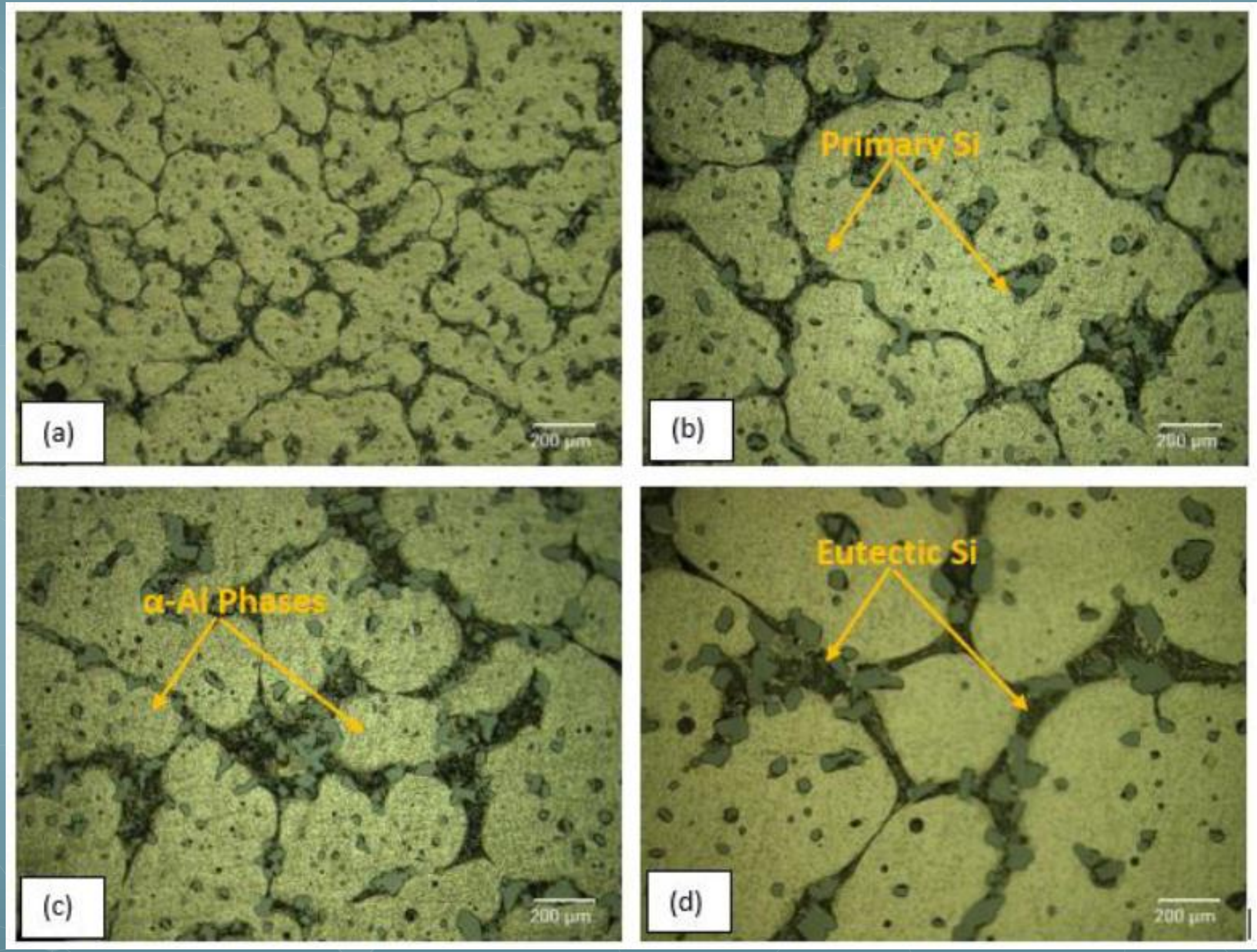


Figure 20. Microstructures of the Al alloy part with different magnifications, (a) lower magnification to (d) higher magnification as etched with Keller solution.

3. Resuls & Discussion

Microstructural Analysis

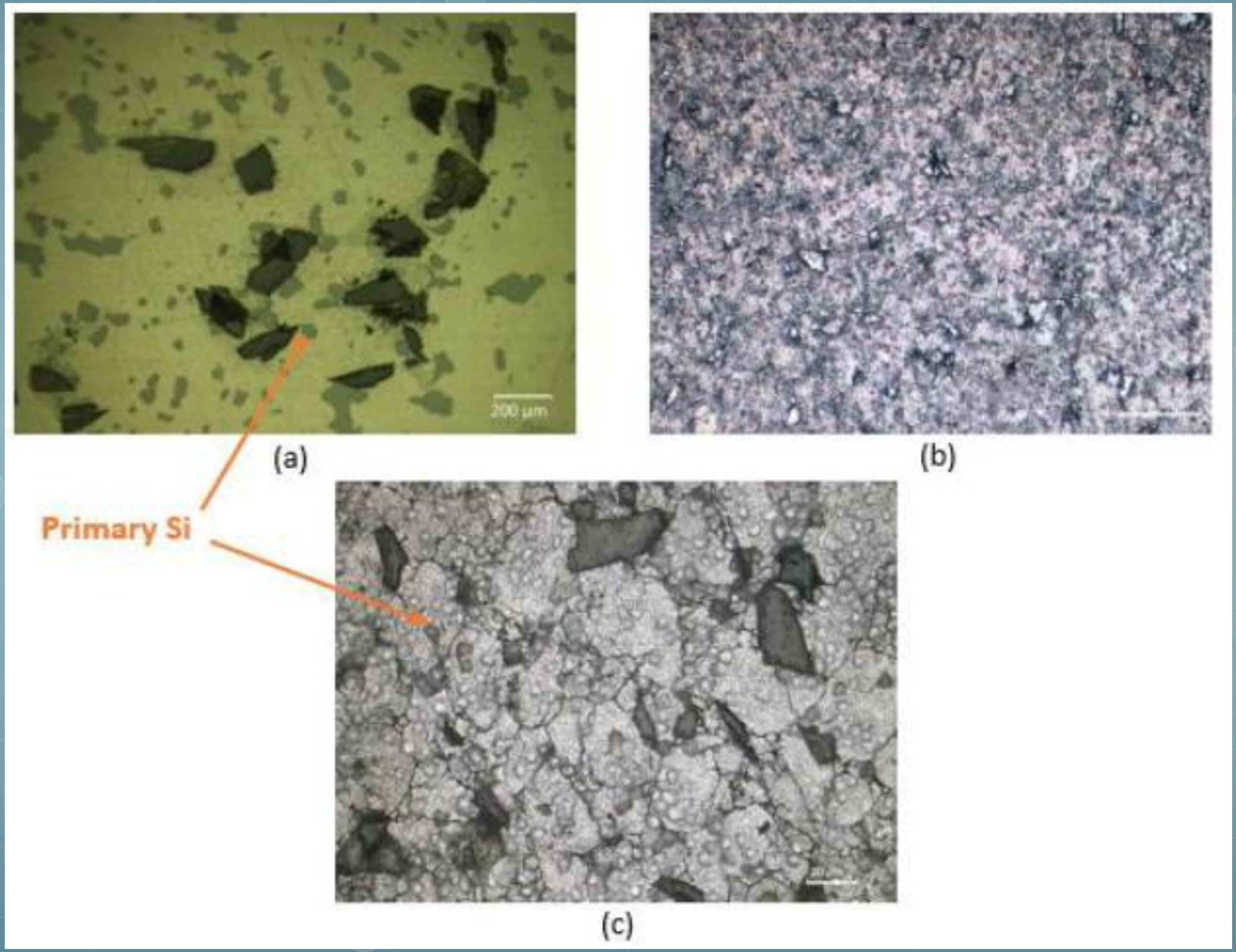


Figure 21. Microstructures of the composite parts of (a) sample 1 in 200x magnification, (b) sample 2 in 200x magnification, and (c) sample 3 in 200x magnification.

4. Conclusions

We have concluded that;

Pistons can be produced with composite materials.

- The composite produced via rheo-sintering method has superior properties than the piston produced via vortex method.

- SiC particle distribution is non-homogenous in the composite produced via vortex method. However, the distribution is homogenous in the piston produced by rheo-sintering method.

- Harder composite piston can be obtained via rheo-sintering method. In addition, approximately 300 Mpa flexural strength is also obtained.

5. Refences

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