

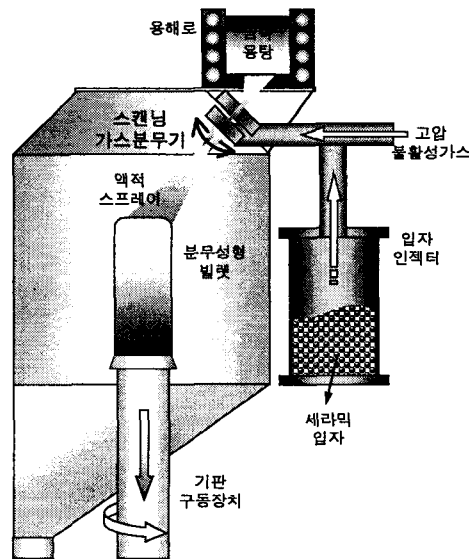
분무성형을 이용한 고품위 알루미늄
합금 제조 및 응용

제3회 최신 분말제품 응용기술 Workshop

박우진

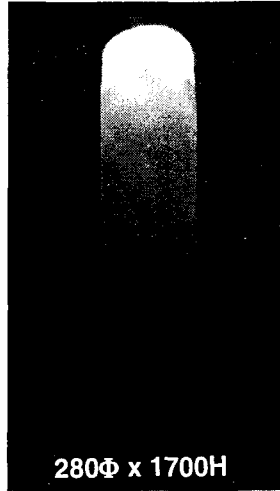
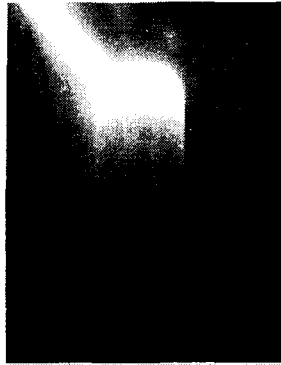
포항산업과학연구원 (RIST)

분무성형 공정 개요



Rist

분무성형 빌렛



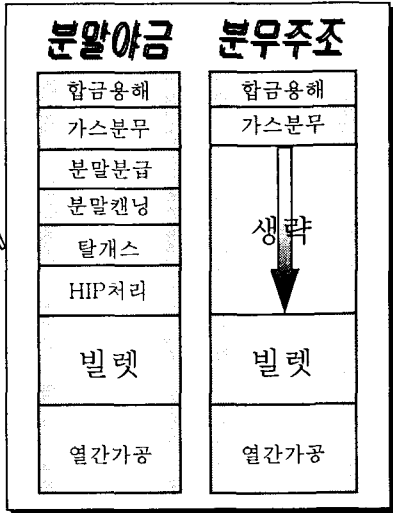
280Φ x 1700H

Rist

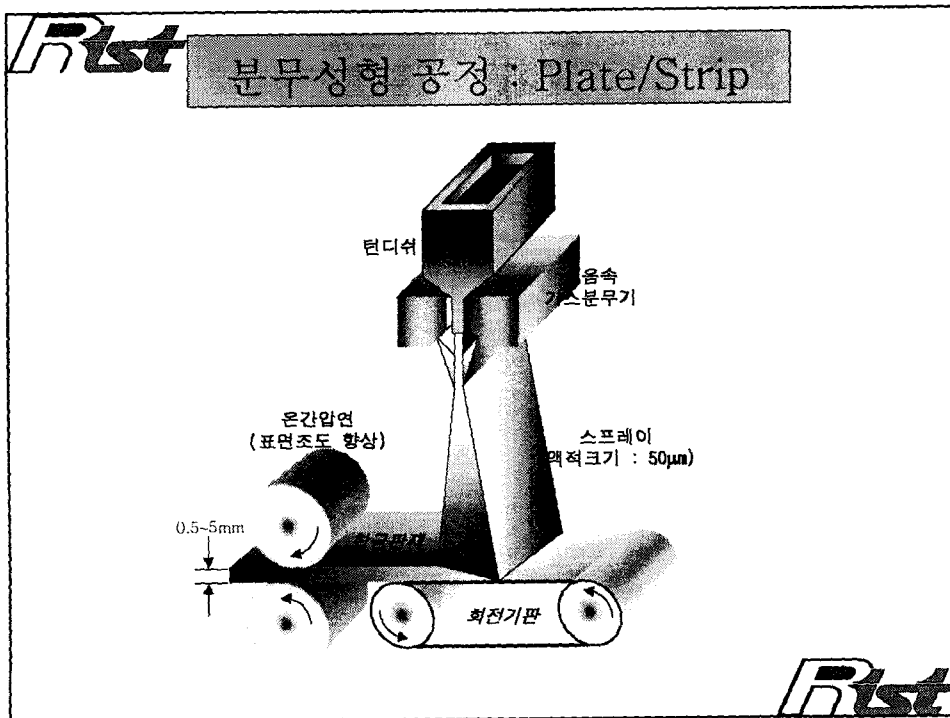
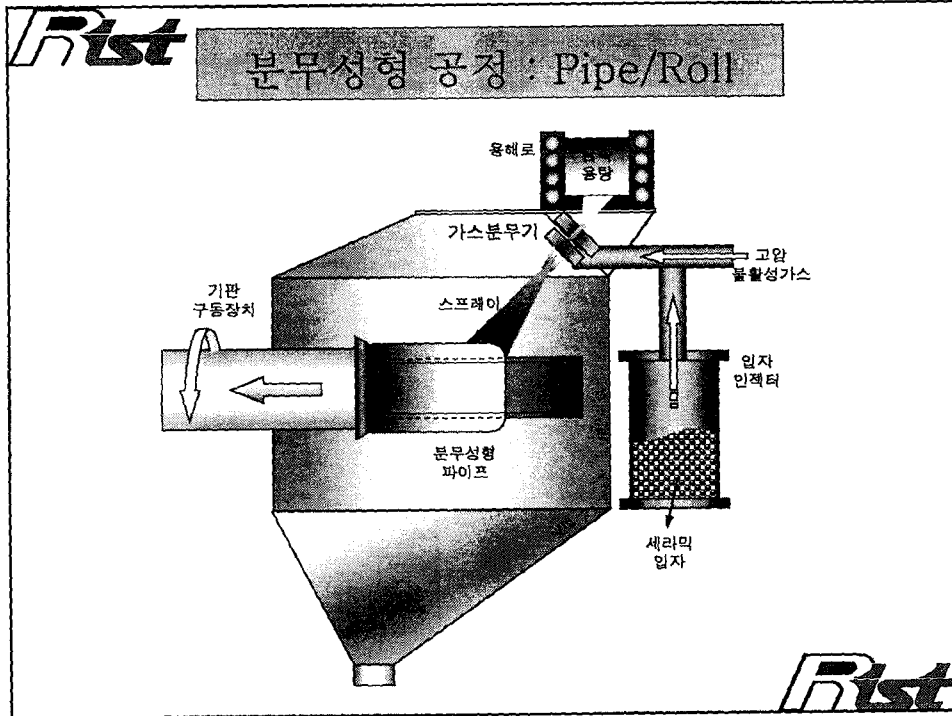
Rist

분무성형 공정의 장점

- 급냉응고 (가스분무)
 - segregation-free
 - extended solid-solubility
 - uniform second-phase distribution
 - fine microstructure
 - ⇒ High quality products
- 저비용 공정(공정단축)
- 다양한 응용성
 - particle injection : MMC
 - reactive spray forming : DS Alloy
 - near-net-shape (tube & ring)



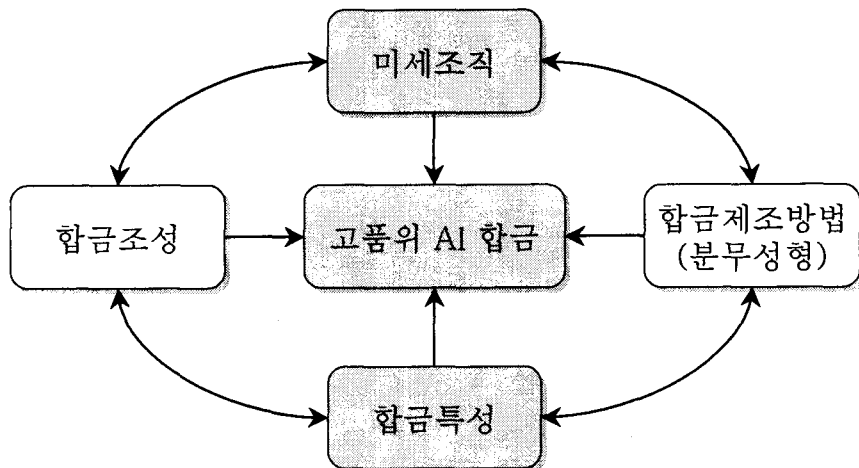
Rist



분무성형 개발동향

Al alloys	<ul style="list-style-type: none"> Alloy Billets : Al-Si-X MMC Billets : Al-Si-SiC_p 	<ul style="list-style-type: none"> Aluminum Plate Al-Li, Al-Si-X 	RIST PEAK Sumitomo L.M. Alcoa, Pechiney
Cu alloys	<ul style="list-style-type: none"> High Strength Alloy Billets : Cu-Ni-Sn, Cu-Cr-Zr 	<ul style="list-style-type: none"> Dispersion-Strengthened Alloy Billets : Cu-TiB₂ MMC Billets : Cu-Fe, Cu-V 	RIST Wieland Werke Swissmetal Olin Co.
Ni alloys	<ul style="list-style-type: none"> Turbine Engine Rings : IN718, Rene41, Waspalloy Superalloy Tube 	<ul style="list-style-type: none"> Inclusion-Free Alloys ESR / CIG 	Howmet Rolls Royce G.E. US Navy
Fe alloys	<ul style="list-style-type: none"> Mill Roll : Hi-Cr Iron Tool Steel Billets : D2 Seamless Pipe : Stainless Steel 	<ul style="list-style-type: none"> Mill Roll : High Speed Steel Cutting Tool Steel Billets : High Speed Steel Multi-Layer Tubing Spray Hardfacing 	RIST Sumitomo H.I. Sandvik British Rollmaker ForgeMaster Babcock & Wilcox

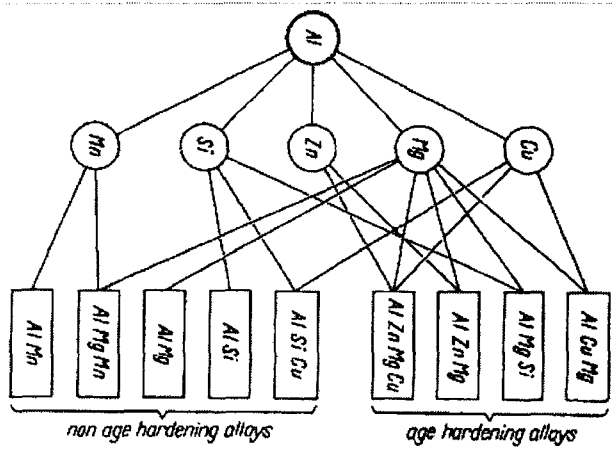
고품질 분무성형 알루미늄 합금



알루미늄 합금계

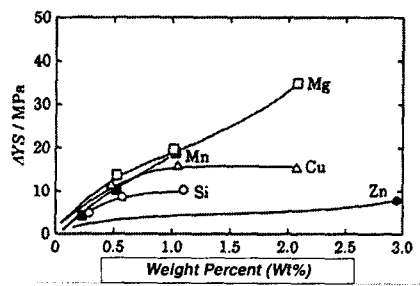
Wrought alloys	Series	Cast alloys	Series
Al (99.00 % minimum or greater)	1xxx	Al (99.00 % minimum or greater)	1xx.x
Alloys grouped by major alloying elements			
Cu	2xxx	Cu	2xx.x
Mn	3xxx	Si + Cu or Mg	3xx.x
Si	4xxx	Si	4xx.x
Mg	5xxx	Mg	5xx.x
Mg and Si	6xxx	Zn	7xx.x
Zn	7xxx	Sn	8xx.x
Other element	8xxx	Other element	9xx.x
Unused series	9xxx	Unused series	6xx.x

알루미늄 합금계

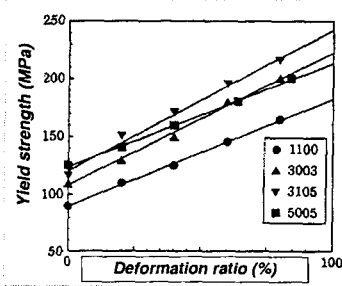


알루미늄 합금의 강화 특성

고용강화

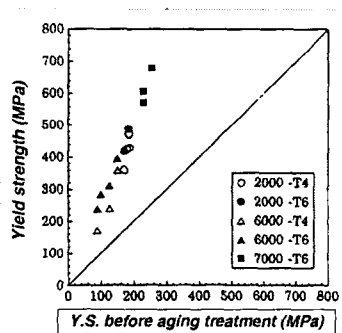


가공경화

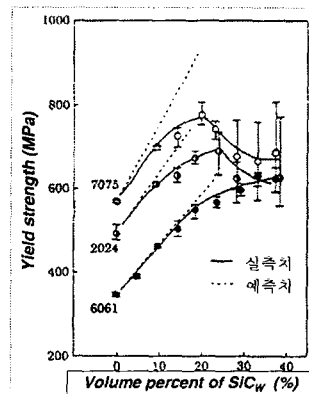


알루미늄 합금의 강화 특성

석출강화



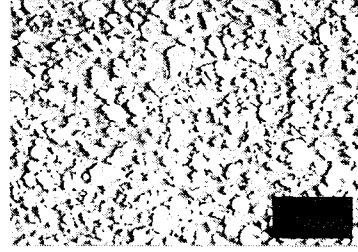
복합강화



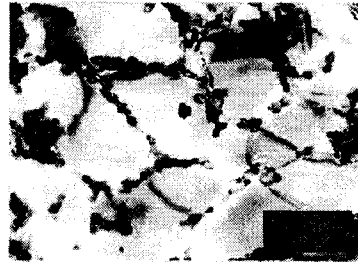


알루미늄 합금의 강화 특성

- 내마모성 향상 : Si 입자 강화
 - 내마모 알루미늄 합금
 - Al-(17~25)Si-Cu-Mg



- 내열특성 향상 : 분산강화
 - 내열 알루미늄 합금
 - FVS0812 : Al-8.5Fe-1.3V-1.7Si
 - FVS1212 : Al-12.0Fe-1.3V-1.7Si



분무성형 알루미늄 합금 개발 (I)

- 내마모/고강도 알루미늄 합금
 - ⇒ 설계목적 : 내마모성, 비강성, 인장강도, 성형성 향상
 - ⇒ 합금설계 방안
 - 내마모성 및 강성 향상 : 25wt% Si 첨가
 - 인장강도 및 강성 향상 : Cu, Mg 첨가량 변화
 - 성형성 향상 : 첨가원소 제어
 - ⇒ 합금조성 선정
 - Al-25Si,
 - Al-25Si-2.0Cu-1.0Mg,
 - Al-25Si-2.0Cu-1.0Mg-2.0Mn
 - Al-25Si-2.0Cu-1.0Mg-1.0Mn-1.0Ni
 - ⇒ 연구내용
 - 합금조성별 분무주조 빌렛 제조
 - 열간성형성 평가 및 압출재 제조
 - 열간압출재의 인장특성 및 미세조직 특성 평가



Al-Si계 합금 조직의 특성

IM processed

As-spray Cast

Al-22Si-Na

Al-25Si-5Fe

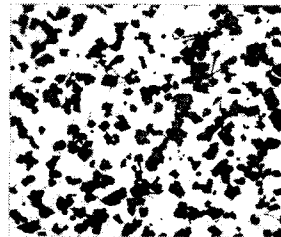
Al-25Si-X



20µm



50µm



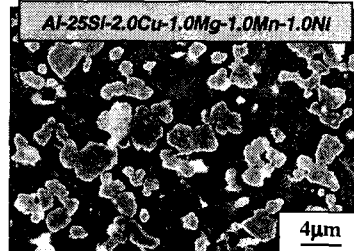
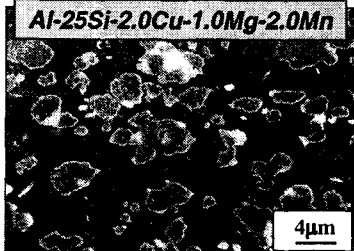
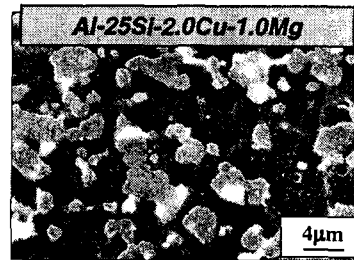
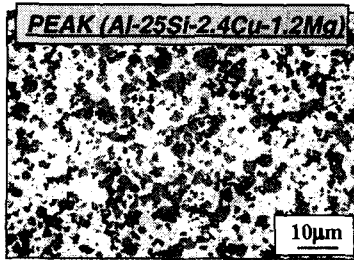
20µm

- Coarse primary Si particles
- Eutectic matrix (α -Al + Si)
- Dendrites of α -Al

- Primary Si particles in Al matrix (uniform size and distribution)
- Acicular intermetallic phases

Al-Si계 합금 조직의 특성

- The distribution of intermetallics in Al matrix -



Rst

Al-Si계 합금 조직의 특성

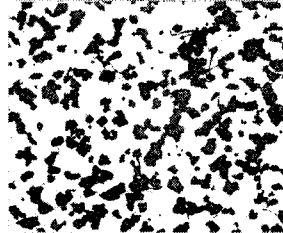
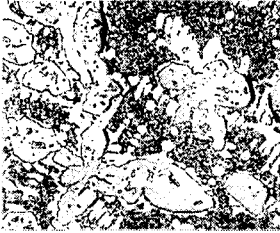
IM processed

As-spray Cast

Al-22Si-Na

Al-25Si-5Fe

Al-25Si-X



20µm

50µm

20µm

- Coarse primary Si particles
- Eutectic matrix (α -Al + Si)
- Dendrites of α -Al

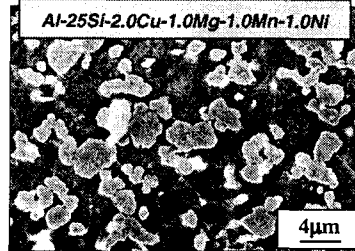
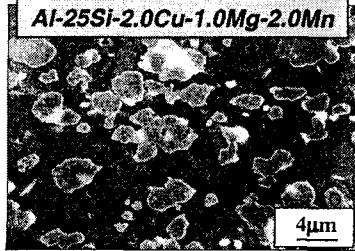
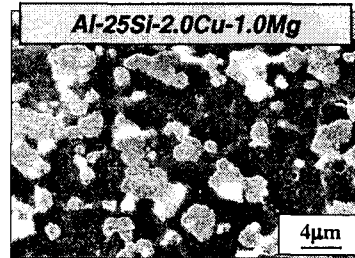
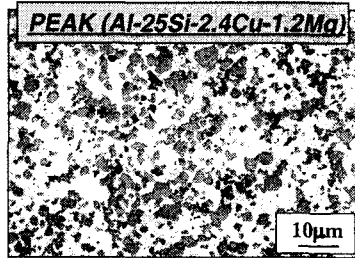
- Primary Si particles in Al matrix (uniform size and distribution)
- Acicular intermetallic phases

Rst

Rst

Al-Si계 합금 조직의 특성

- The distribution of intermetallics in Al matrix -

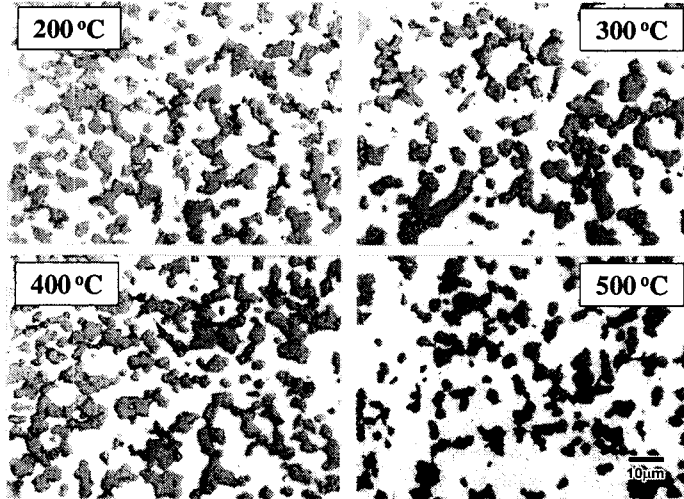


Rst

Rist

Al-Si계 합금의 Si 입자 안정성

- 각 온도에서 세시간 유지후 급냉 -

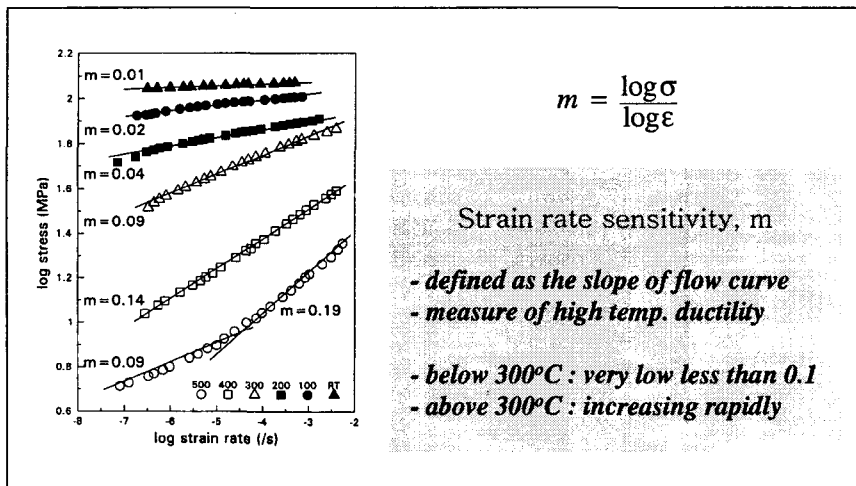


- 500°C이하에서 Si 입자의 조대화 없음 -

Rist

Rist

Al-Si계 합금의 점형성



$$m = \frac{\log \sigma}{\log \dot{\epsilon}}$$

Strain rate sensitivity, m

- defined as the slope of flow curve
- measure of high temp. ductility
- below 300°C : very low less than 0.1
- above 300°C : increasing rapidly

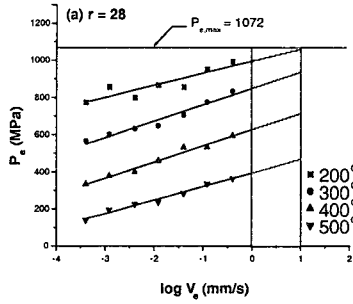
Rist

Al-Si계 빌렛의 압출조건 도출

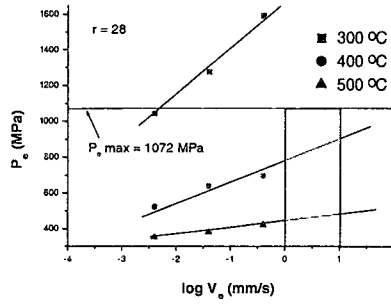
- Extrusion Pressure vs. Ram Speed -

- Endurance limit of extruder ($P_{e,max}$) : 1072 MPa (550 ton/80φ)
- Conventional ram speed (V_{e^0}) : 1 ~ 10 mm/s

Al-25Si

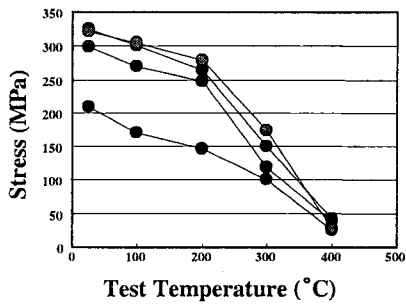


Al-25Si-2.5Cu-1.0Mg

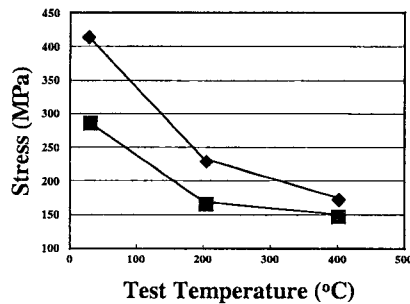


Al-Si계 압출재의 인장특성

before aging



after aging

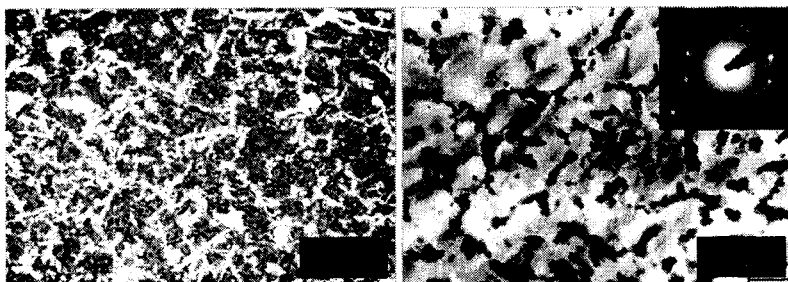


- Al-25Si
- Al-25Si-2.0Cu-1.0Mg
- Al-25Si-2.0Cu-1.0Mg-2.0Mn
- Al-25Si-2.0Cu-1.0Mg-1.0Mn-1.0Ni

- ◆ Al-25Si-2.5Cu-1.0Mg (RIST : peak-aged)
- Al-25Si-2.4Cu-1.2Mg (PEAK: as-received)

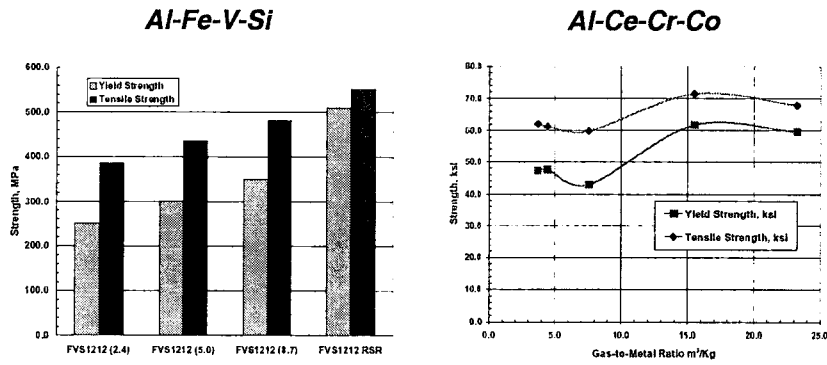
분무성형 알루미늄 합금 개발 (II)**□ 내열 알루미늄 합금**

- ⇒ 설계목적 : 내열특성 향상
- ⇒ 합금설계 : 다량의 열적 안정성이 우수한 분산상 형성
 - 낮은 확산계수
 - 낮은 고용도
 - 높은 액상용해도
- ⇒ 합금계
 - Al-Fe-Si
 - Al-Fe-V-Si
 - Al-Ce-Cr-Co
 - Al-Cr-Zr

내열 알루미늄 합금의 미세조직**- Al-6.0Fe-0.7V-1.1Si -**

* from PennState

내열 알루미늄 합금의 인장특성



* from PennState

분무성형 알루미늄 합금 개발 (III)

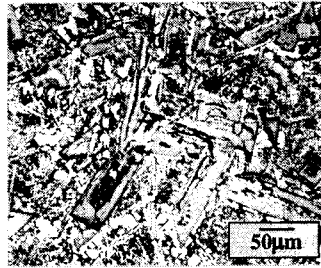
□ 내마모 / 내열 알루미늄 합금

- ⇒ 설계목적 : 내마모 / 내열 특성 향상
- ⇒ 합금설계 : 고경도의 Si-입자 형성
 - 다량의 열적 안정성이 우수한 분산상 형성
 - 내마모성 향상 : 15~30wt% Si 첨가
 - 내열특성 향상 : 천이금속 (Fe, Mn, V) 첨가
- ⇒ 합금계
 - Al-Si-Fe
 - Al-Si-Fe-V
 - Al-Si-Mn

내마모/내열 알루미늄 합금의 미세조직

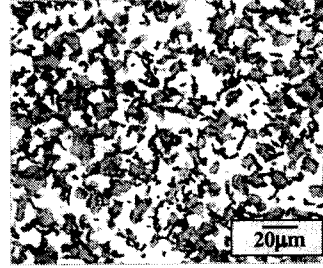
IM processed

Al-25Si-5Fe



As-spray Cast

Al-25Si-5Fe



내마모/내열 알루미늄 합금의 특성

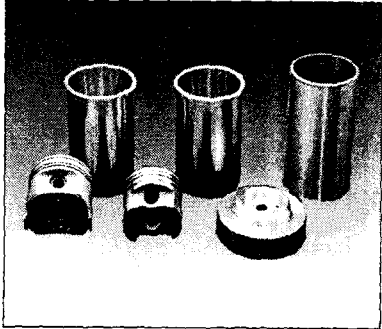
Composition (wt%) [Base metal]	17Si-5Fe [2024]	20Si-5Fe [2024]	20Si-8Ni [2024]
Density (g/cm ³)	2.83	2.78	2.81
Thermal exp.(×10 ⁻⁶ /K)	17.2	16.8	16.2
Young's modulus (GPa)	100	103	107
Hardness [T6] (HRB)	84~92	88~94	90~96
Tensile strength [T6] (MPa)	RT.	470	460
	473K	320	310
Fatigue strength(MPa)	200	-----	-----

* from Sumitomo electric industries Ltd.

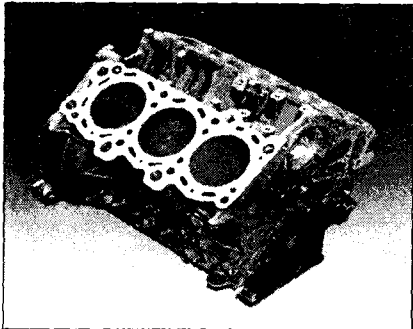
Rist

Benz의 Al-Si-X 실린더 라이너

알루미늄 실린더 라이너



알루미늄 엔진블록



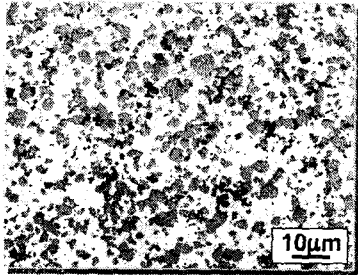
Al-Si-X 알루미늄 라이너가 장착된 엔진블록 (Daimler-Benz & PEAK)

Rist

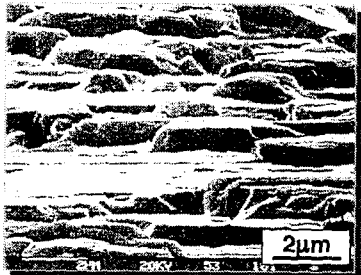
Rist

분무성형 실린더라이너 표면조직

분무성형 + 압출



압출재의 에칭 표면



* from PEAK's report

Rist



Al-25Si-X 실린더라이너의 장점

- gray cast iron 대비 -

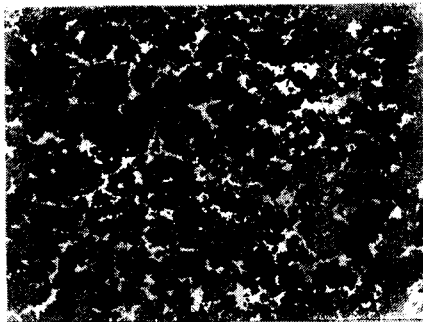
□ 경량화	Approx. 0.5kg per liner
□ 열전도도	엔진 효율 증가
□ Design running surface	피스톤의 마모량 감소 오일 소모량 감소 (~30%) HC emissions 감소 (~30%) 마찰 감소 (~5%)
□ 열팽창 계수	피스톤 clearance 감소 → 소음 감소, power 증가
□ Metallic bonding	실린더의 왜곡 감소 blow-by effect 감소 → power 증가 크랭크케이스 stiffness의 증가
□ 우수한 기계가공성	
□ 용이한 recycling	

* from PEAK's report

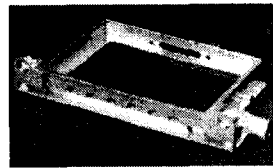


Al-80%Si Electronic Packaging

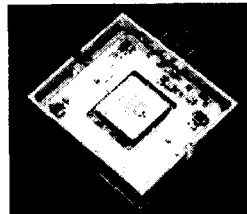
* from Osprey Metals



Spray formed Al-80%Si



Channel amplifier housing

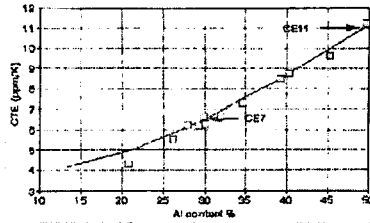


Power amplifier housing





Si-Al Electronic Packaging



Material	CTE (at 20°C) × 10 ⁻⁶ /K	k Watts/in K	ρ g/cm ³
Aluminum	23.6	230	2.7
Copper	17.6	391	8.9
Copper-75% tungsten	8.8	190	14.6
Beryllium-30% beryllia	8.7	210	2.1
Beryllium-51% beryllia	7.5	220	2.3
Beryllia	7.2	260	2.9
Copper-85% tungsten	7.2	180	16.1
Al-68SiC	6.9	150	3.0
Copper-85% molybdenum	6.7	160	10
Alumina	6.7	20	3.9
Kovar	5.8	17	8.2
Titanium	5.6	15	4.5
Molybdenum	5.1	140	10.2
Aluminum nitride	4.5	180	3.3
Silicon-50% aluminum (CE11)*	11.0	140	2.5
Silicon-30% aluminum (CE7)*	6.8	120	2.4



분무성형 알루미늄 합금의 적용가능분야

범위	품명	종래소재	적용효과
자동차 부품	Cylinder liner	주철	경량화
	Al-Wheel	주철	경량화, 고강도화
	Con-rod	주철	경량화
	Piston	공정 AC8A 주철	내열, 내마모성 향상
	Synchro-ring Shift fork Housings	황동 Al diecast Al diecast	경량화 내마모성 향상 강도, 내마모성, 품질 향상
컴프레서 부품	Vane	과공정 390 주철	신뢰성, 보류율 향상
	Shoe disk	과공정 390 주철	신뢰성, 보류율 향상
	사판	과공정 390 주철	경량화
	Rotor	과공정 390 주철	경량화
	Con-rod	Al diecast	내마모성 향상
기타	VTR cylinder	A2218 단조	내마모성 향상
	Pully	Al diecast	내마모성 향상
	Gears	주철	경량화
	Shafts	SUS	경량화
	IC 기판		
	항공기 구조재		

