Material Research Report with MX-Lab

High Entropy Alloys
Metal Matrix Composites
Functionally Graded Materials
Bimetallic Joint

InssTek

MX-Lab

DED & Material research machine

Features

Simple system for easy entrance of DED

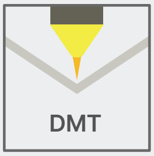
Focus on material research

3-Axis system & DMT Technology

Accurate & stable CVM Powder Feeding System applied (built-in)

Hexa-Feeding system for multi materials

LFM-1 technology applied (built-in)



Cartridge Type Optics

Simultaneous 3Axis Control

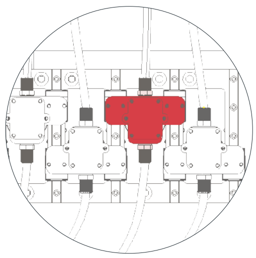
CVM Power System

CVM Powder System

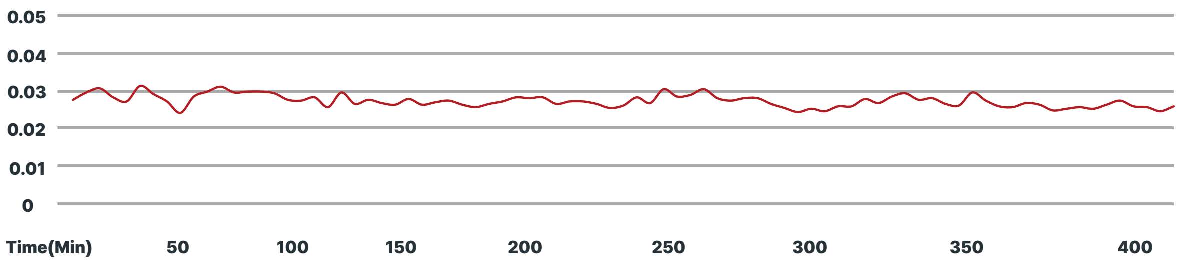
Next generation of powder feeding system

CVM (Clogged Vibration Method) system is a new type of powder feeding system. It has impressively stable powder feed rate, semi-permanent life time and broad feeding rate range. It can feed the titanium powder from 0.03g/min to 2.0g/min with no hardware change. Also this system is applicable with gravity powder supply method and direct powder supply method with gas in DED process.

- CVM (Clogged Vibration Method) type powder feeder
- Feeds multi materials at the same time
- Feed rate range 0.03 - 2g/min (based on Ti-6Al-4V)
- Gravity / direct feeding available
- Impressively stable powder feed rate



CVM Feeder Block

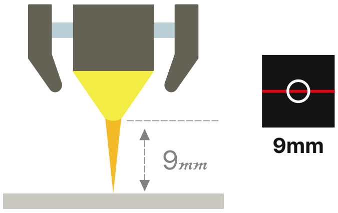


Ti Powder Feeding Test for 7 Hours (Target Value: 0.03g /min)

Features of MX-Lab

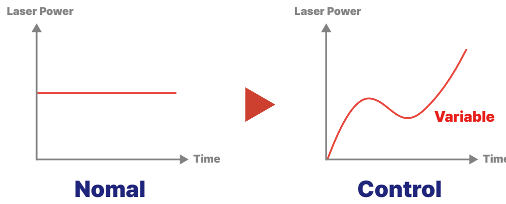
Auto Z

Automatically adjusts the distance between sample and nozzle to WOP(9mm) layer by layer during deposition.



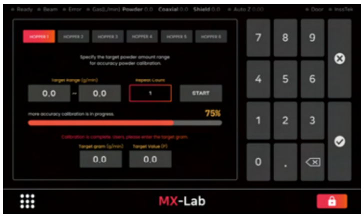
Laser Control

Sets the appropriate laser power for the material at the desired location based on NC-Code when producing a multi material sample.



Auto Powder Calibration NEW

The powder calibration process, which used to be manual, became automatic making itself much faster, more comfortable, and more precise than before.



Monitoring System NEW

MX-Lab Monitoring System monitors the printing process of the MX-Lab and provides data extraction capabilities.

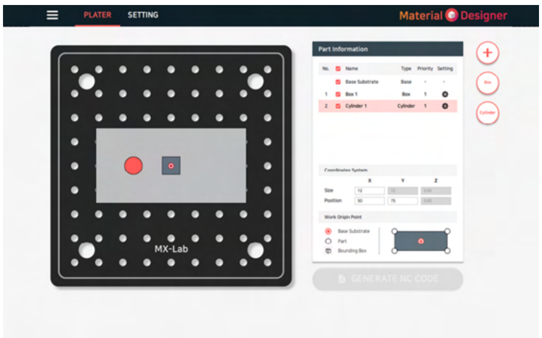
Monitorable Parameters

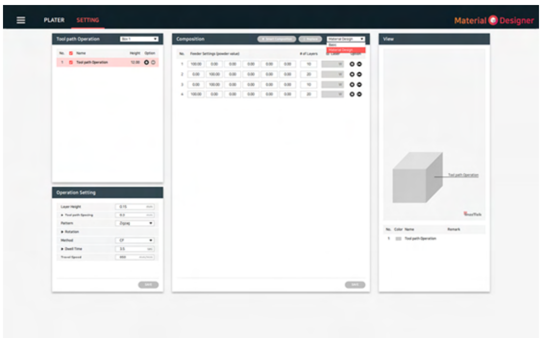
- Laser power
- Melt pool image (Vision camera)
- Coordinate system (X,Y,Z)
- Powder feeding system (P-Value)

Material Designer

Software dedicated for MX-Lab

3D CAD-free Software
Easy to set composition for various alloy
Self-developed CAM system





High Entropy Alloys

HEAs(High Entropy Alloys) are alloys that are formed by mixing equal or relatively large proportions of five or more elements

Usually 5~35 at% for each element

Close to a Single Phase

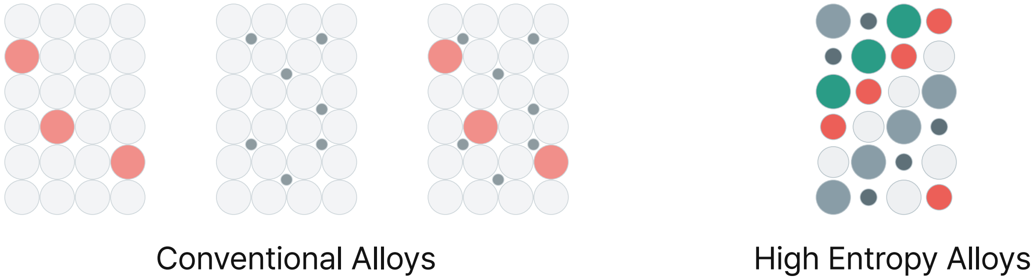
Even if the alloy composition increases, various intermetallic compounds are not formed and a solid solution is formed

Innovative Materials

Changing the paradigm of new material development

High Oxidation Resistance

Slower diffusion rate than ordinary alloys



High Strength

Superior strength than conventional alloys

High Hardness

Acts as a strong deformation resistance

High Corrosion Resistance

Provides a good environment to control the growth of precipitates after nucleation

NiCoMoTiAl

High entropy alloys

The MX-Lab equipment is based on six feeders and DED technologies. All systems are integrated into one product.

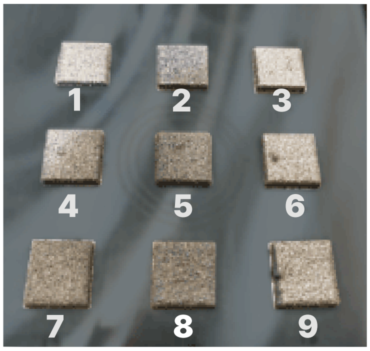
This Metal High Entropy Alloy shows how easy it is to research new material with the MX-Lab equipment

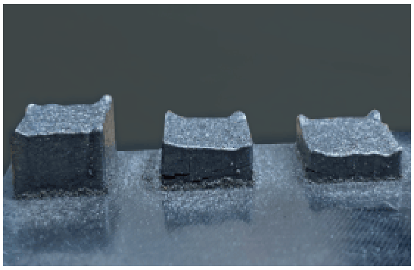
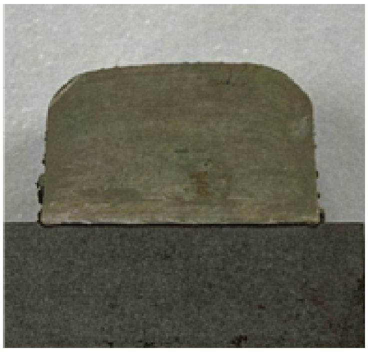
In this study, we supplied 5 pure metal powder by each hopper. The composition is designed for HEA manufacturing and the feeding rate of pure metal powder is calculated using MX-Lab equipment and Material Design Program

After deposition, the specimens of High Entropy Alloys were analyzed by SEM & EDS & XRD

Test Sample

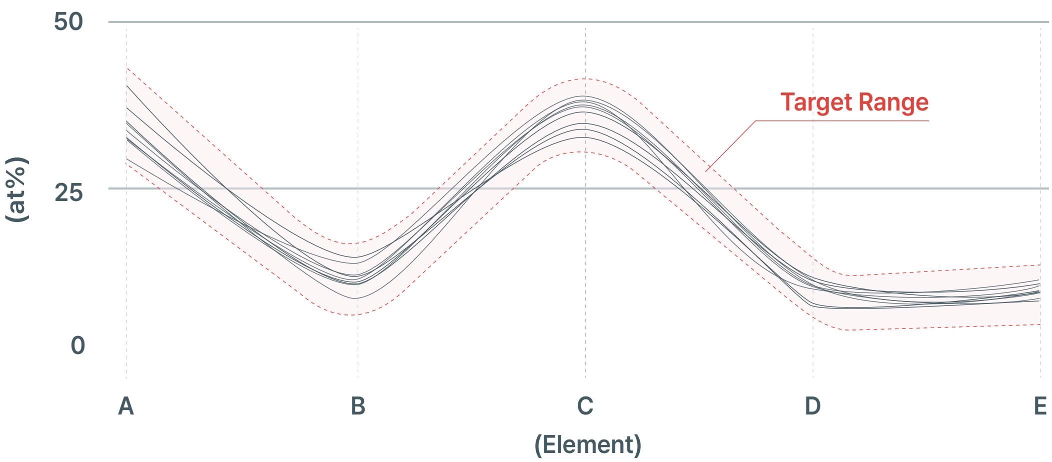
"NiCoMoTiAl" build-up test



Failure Case : Cracks occur for chemical reasons in certain range of combinations.

By avoiding the range where cracks are not generated,
samples are stacked at once in various compositions & conditions.

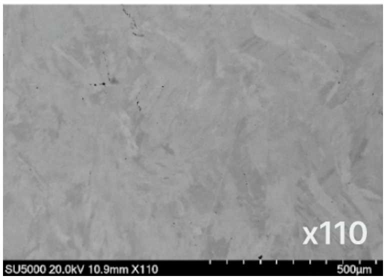


The Target Range of High Entropy Alloy can be found easily and quickly by using the Multi Hopper Feeder.

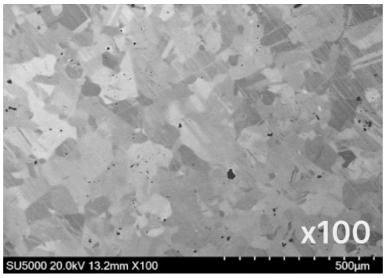
By producing HEA through 3D printing, samples of various compositions can be simultaneously manufactured, which can reduce the opportunity cost by reducing alloy design and verification time.

Microstructure

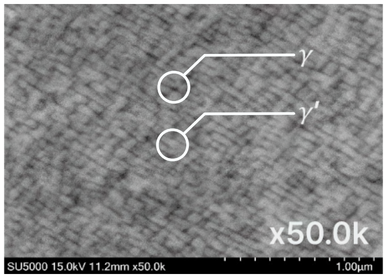
SEM / XRD analysis result



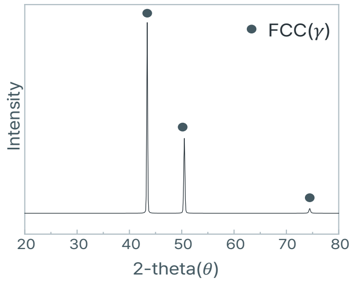
As-deposit

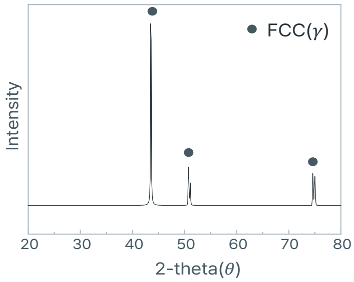


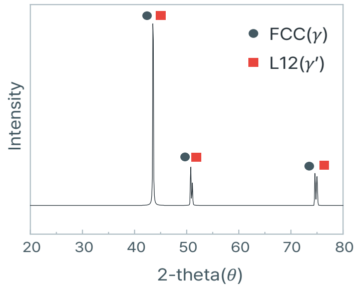
1250°C, 24h Homogenization



900°C, 24h Aging

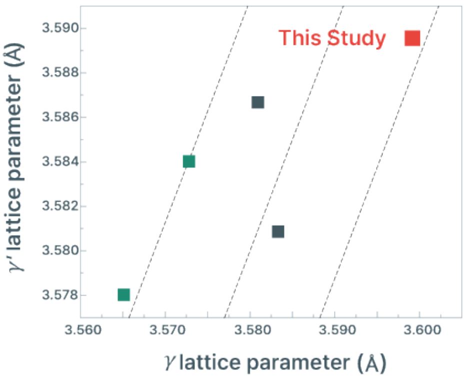




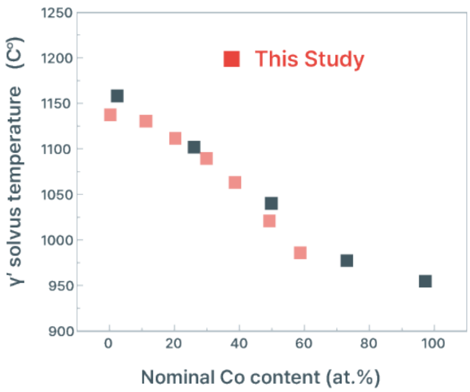


Property of Materials

XRD / DSC analysis



- Lattice misfit adjustment (~ 0.4%)
- γ' vol. fraction increase (~ 65%)
- γ' solvus temperature increase (> 1100°C)
- Measure high-temperature properties



Achieved γ' solvus temperature of about 1202°C

1. W. Li et al., Journal of Alloys and Compounds, 826 (2020) 154182.
C.H. Zenk et al., Scripta Materialia, 112 (2016) 83-86.
S.C.H. Llewelyn et al, Acta Materialia 131 (2017) 296-304.

Metal Matrix Composites

Metal matrix composites (MMCs) are a group of materials (such as metals, alloys or intermetallic compounds) incorporated with various reinforcing phases, such as particulates, whiskers or continuous fibres.

Developments in High Temperature Corrosion and Protection of Materials, 2008

Application

MMCs can be used in various areas, such as automative engineering, aerospace industry, and other light and heavy industries. Light alloy composites are already used in the fabrication of valve trains, piston rods, piston and piston pins, cylinder head, crankshaft main bearing, and part-strengthened cylinder blocks in the automotive industry.

Titanium matrix composites have been proven to be viable as a material for propulsion components in the aerospace industry. Piston rods in the F-119 engine of F-22 fighter aircraft are made from titanium matrix composites. MMCs possess high-temperature capability, high thermal conductivity, low CTE, and high specific stiffness and strength and these potential benefits generated optimism for MMCs for critical space system applications in the late 1980s.

Aluminum–graphite composites are used in power electronic modules because of their high thermal conductivity, the adjustable coefficient of thermal expansion, and the low density. Dymalloy, an MMC consisting of 20% copper and 80% silver alloy matrix with type 1 diamond is used in microelectronics as a substrate high power and high density multichip modules, where it aids with removal of waste heat.

MMCs are also commonly used in the manufacture of high- and low-performance cutting tools. Cobalt matrix is usually used in the high-performance tools while other metals, such as bronze are used in low-performance tools.

S.M. Sapuan, in Composite Materials, 2017

Case Study

In this case study, a mixture of Fe, Ni, Co, Cu, and Al powders and W, WC, YSZ & Al_2O_3 powders were used.

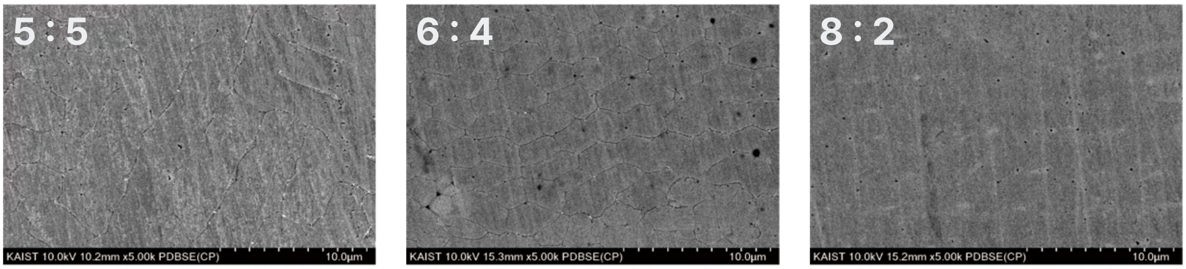
After deposition, Metal Matrix Composite specimens were analyzed for EDS and hardness.

1. SS316L + T800
2. IN625 + YSZ
3. Al + Al_2O_3
4. Al-Bronze + CoCrW
5. Stellite6 +WC

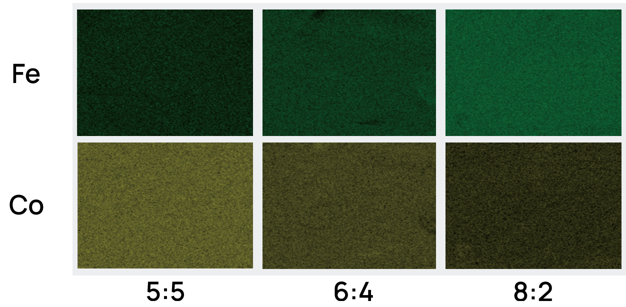
1 SS316L + T800

MMCs of SS316L and T800 mixing powder in 5:5, 6:4, 8:2 ratio

SEM Analysis (x5.0K)



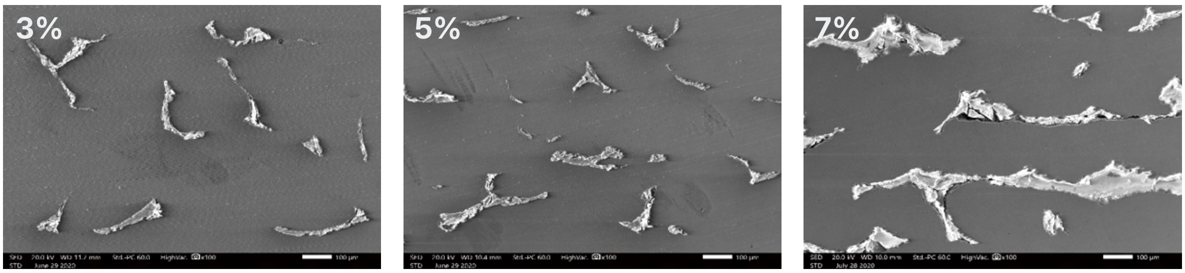
EDS Analysis & Hardness



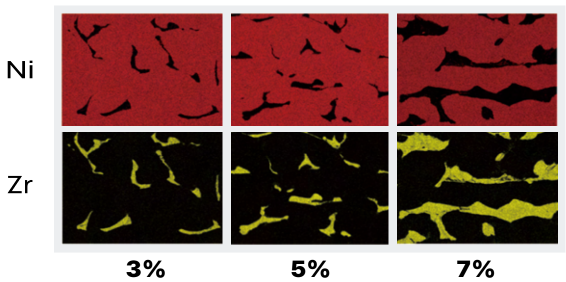
2 IN625 + YSZ

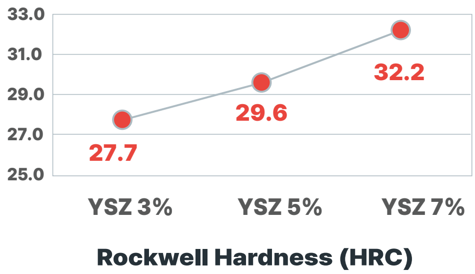
MMCs of 3%, 5%, and 7% YSZ powder with IN625 powder

SEM Analysis (x100)



EDS Analysis & Hardness

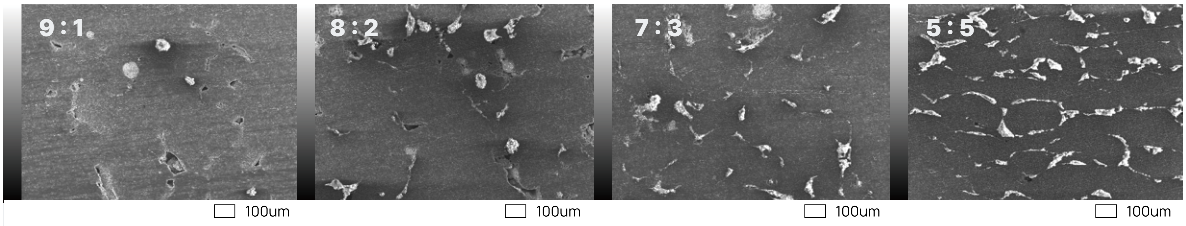




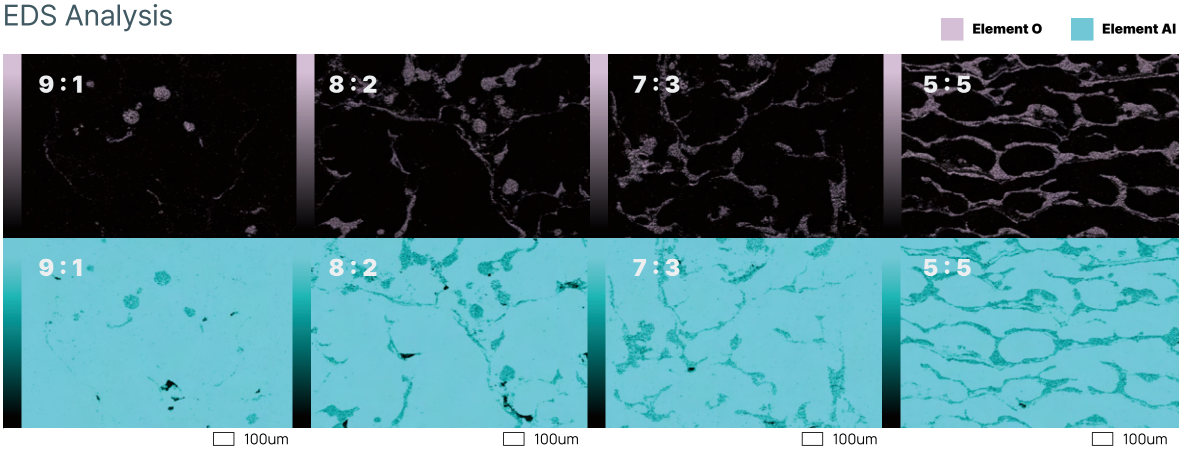
3 Al + Al_2O_3

MMCs of Al and Al_2O_3 mixing powder in 9:1, 8:2, 7:3, 5:5 ratio

SEM Analysis



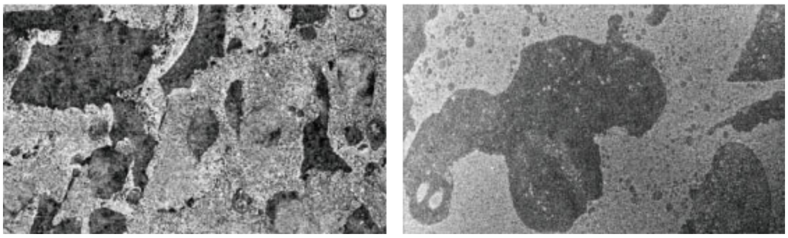
EDS Analysis

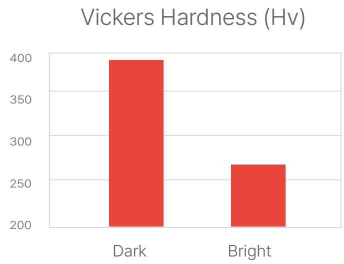


4 Al-Bronze + CoCrW

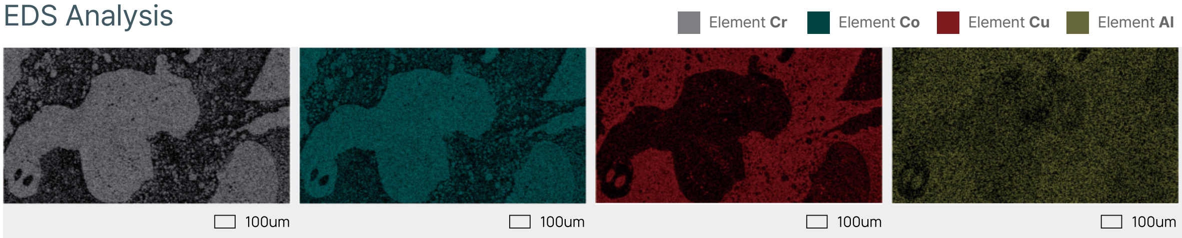
MMCs of Al-Bronze and CoCrW mixing powder in 7:3 ratio.

SEM Analysis (x100 / 250)





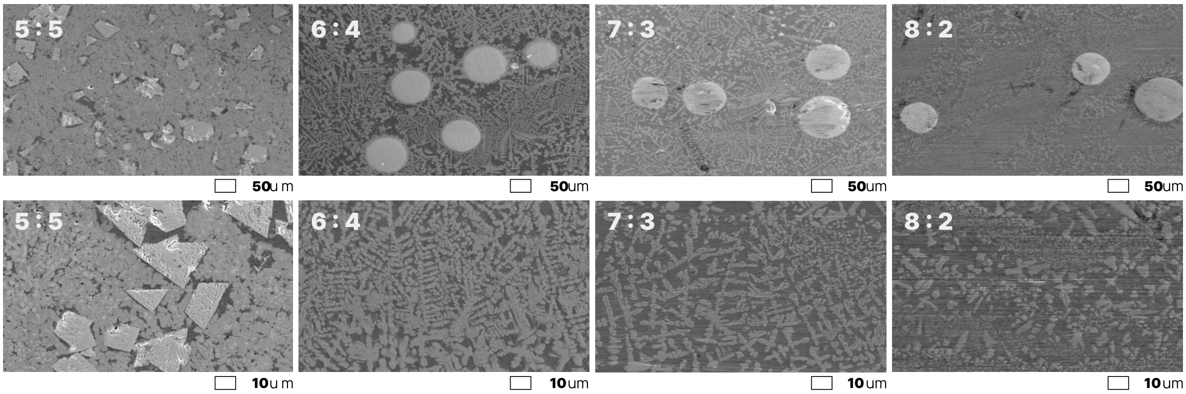
EDS Analysis



5 Stellite6 + WC

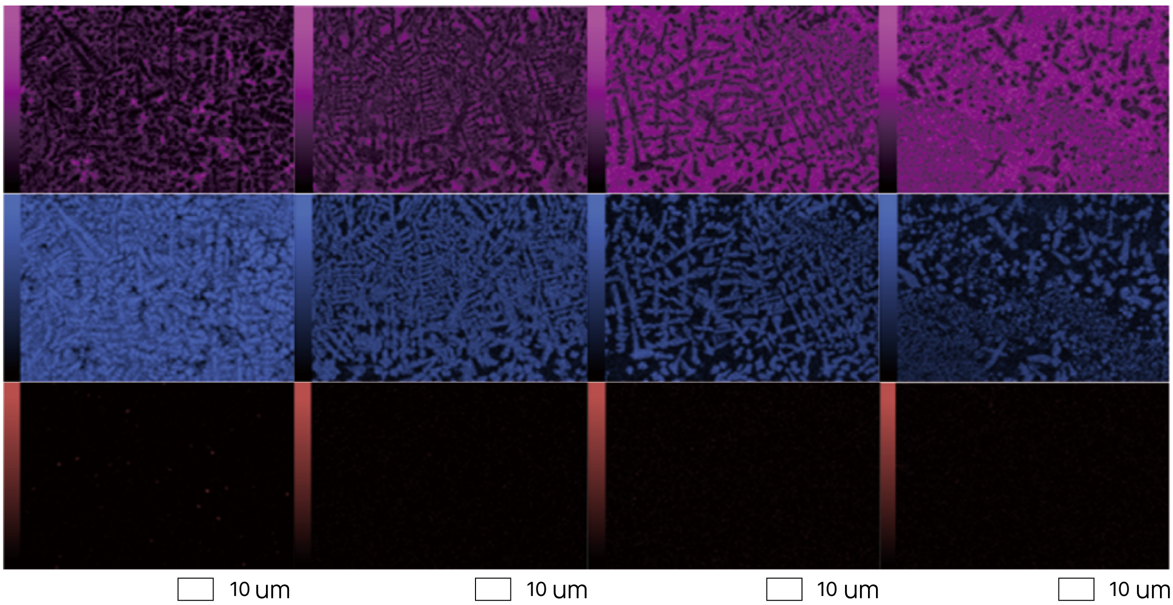
MMCs of Stellite6 and WC mixing powder in 5:5, 6:4, 7:3, 8:2 ratio

SEM Analysis (x300 / 1000)

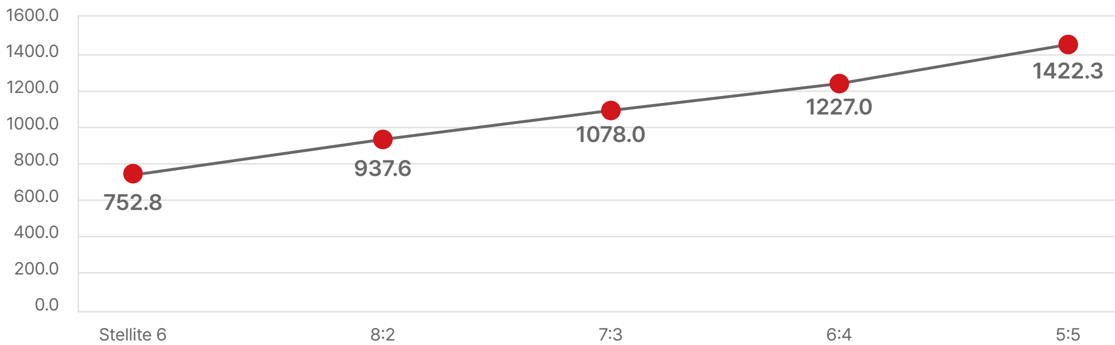


EDS Analysis

Element **Co**
Element **W**
Element **C**



Micro Vickers Hardness (Hv)



Functionally Graded Materials

In materials science Functionally Graded Materials (FGMs) may be characterized by the variation in composition and structure gradually over volume, resulting in corresponding changes in the properties of the material.

The materials can be designed for specific function and applications.

Resources: Functionally Graded Materials, Univ.Prof. Dr. O. Kolednik, 2008

Application

There are many areas of application for FGM. The concept is to make a composite material by varying the microstructure from one material to another material with a specific gradient. This enables the material to have the best of both materials. If it is for thermal, or corrosive resistance or malleability and toughness both strengths of the material may be used to avoid corrosion, fatigue, fracture and stress corrosion cracking.

The transition between the two materials can usually be approximated by means of a power series. The aircraft and aerospace industry and the computer circuit industry are very interested in the possibility of materials that can withstand very high thermal gradients.

Case Study

In this case study, we stated with Fe, Ni, Co, Cu, Ti and deposited the material gradually changing to other alloys.

After deposit, the specimens were analyzed by SEM & EDS & Hardness and the composition of the material gradually changed.

1 SS316L + CoCrNi

2 SS316L + IN625

3 SS316L + IN718

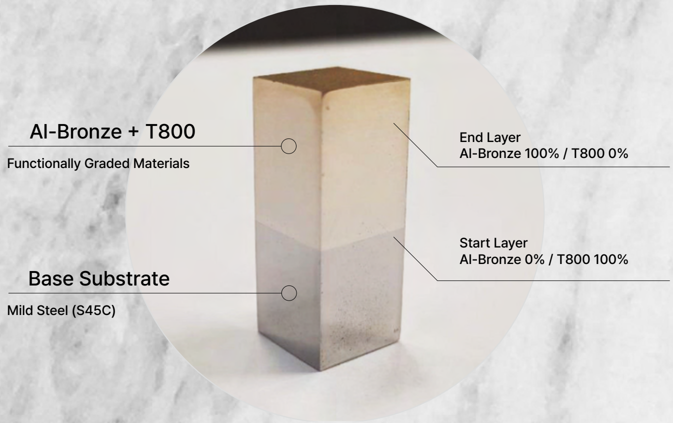
4 SS316L + Invar36

5 IN625 + T800

6 Ti-6Al-4V + Mo

7 SS316L + Al-Bronze

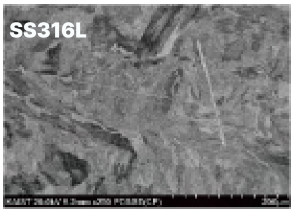
8 Stellite6 +SS316L

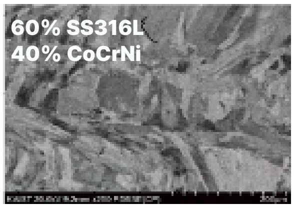


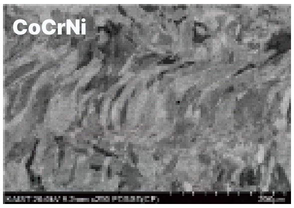
1 SS316L + CoCrNi

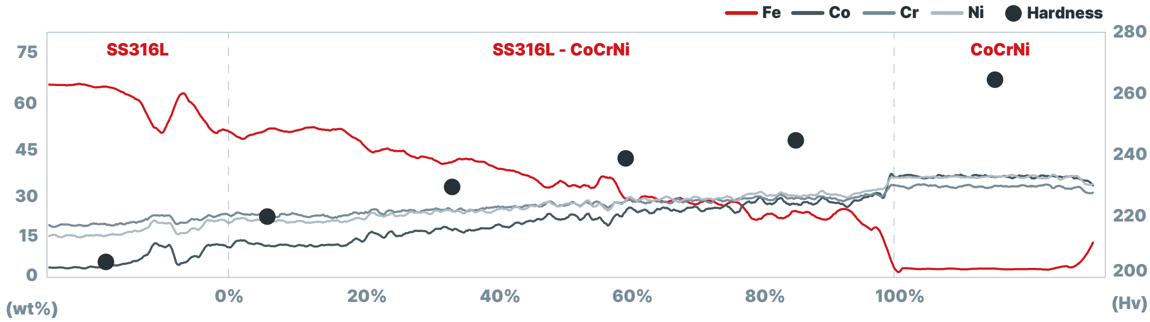
FGMs of Fe & CoCrNi balanced alloys

SEM Analysis (x250)







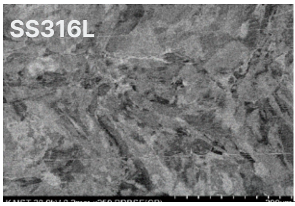


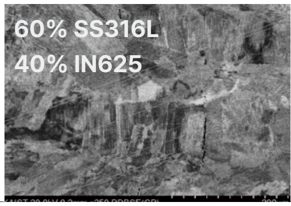
< SS316L - CoCrNi Gradient Deposition Chemical Properties (wt%) & Hardness (Hv) >

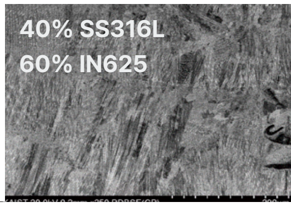
2 SS316L + IN625

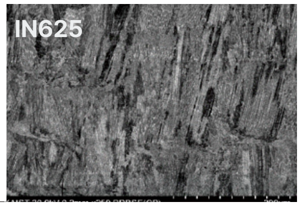
FGMs of Fe & Ni balanced alloys

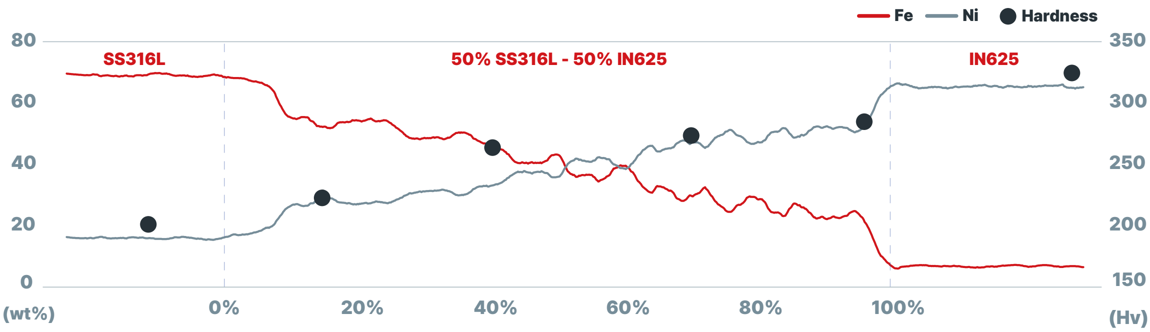
SEM Analysis (x250)









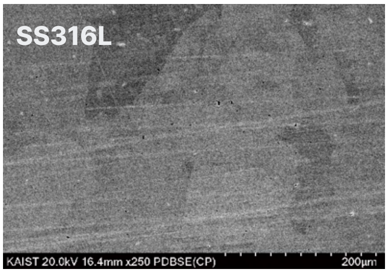


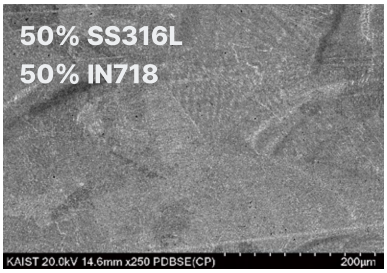
< SS316L - IN625 Gradient Deposition Chemical Properties (wt%) & Hardness (Hv) >

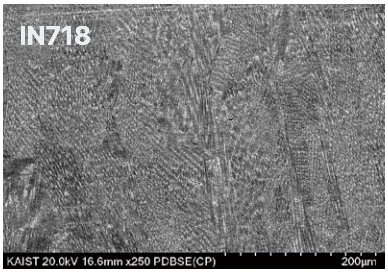
3 SS316 + IN718

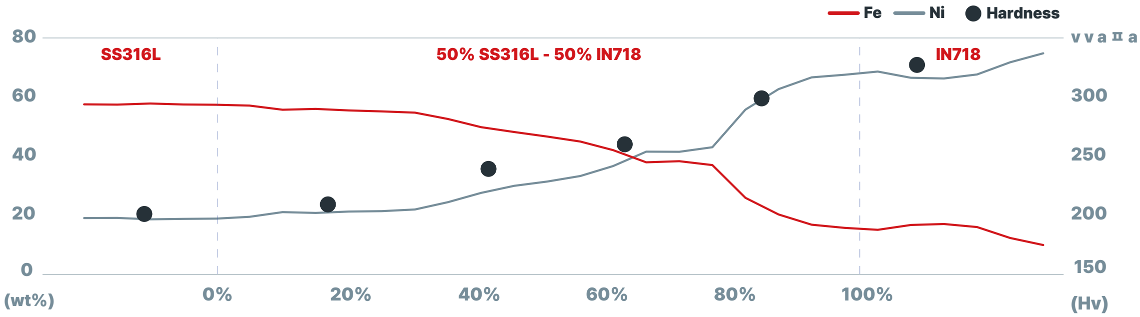
FGMs of Fe & Ni Balanced Alloys

SEM Analysis (x1000)







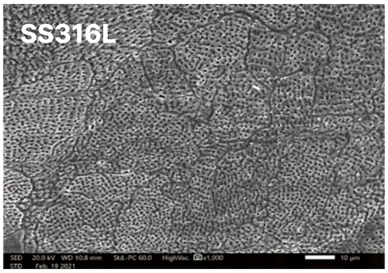


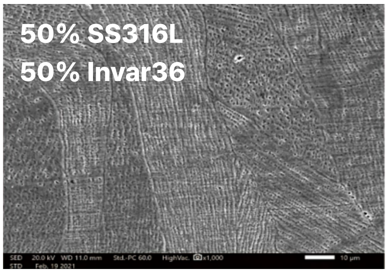
< SS316L - IN718 Gradient Deposition Chemical Properties (wt%) & Hardness (Hv) >

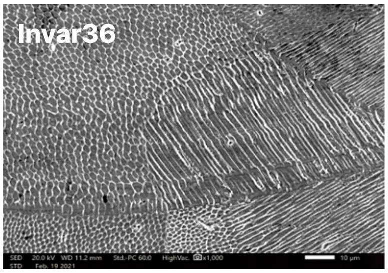
4 SS316L + Invar36

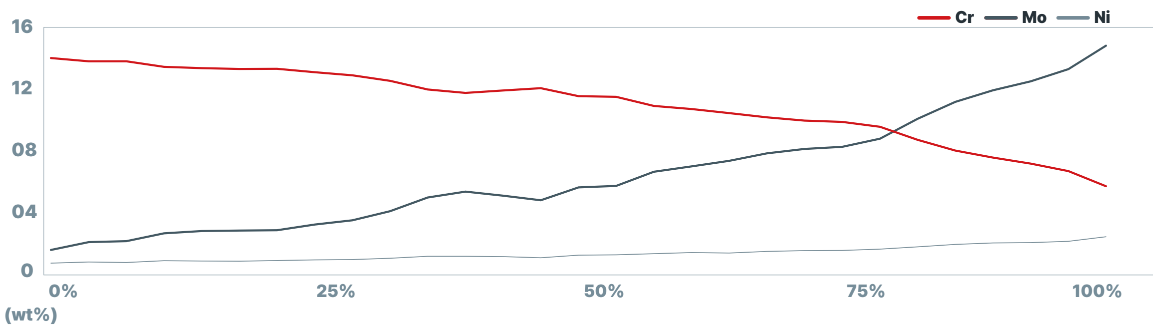
FGMs of Fe & Ni Balanced Alloys

SEM Analysis (x1000)







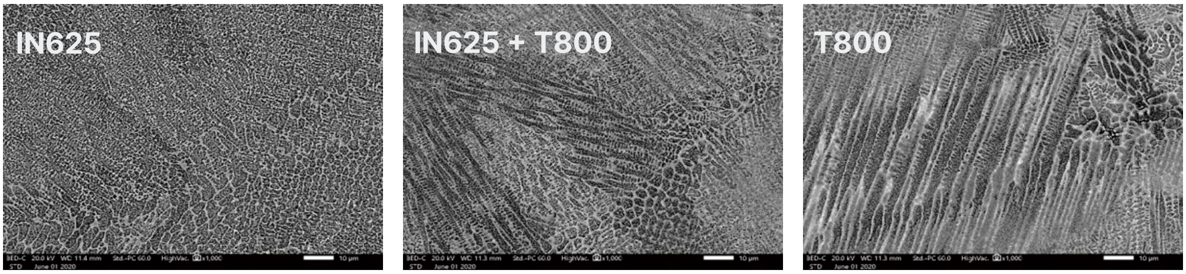


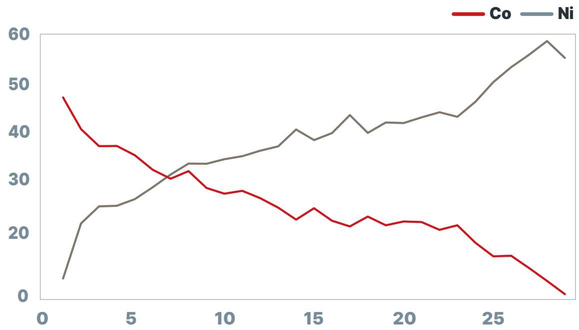
< SS316L - Invar36 Gradient Deposition Chemical Properties (wt%) >

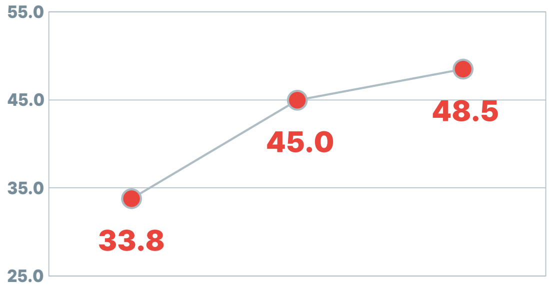
5 IN625 + T800

FGMs of Ni & Co Balanced Alloys

SEM Analysis (x250)





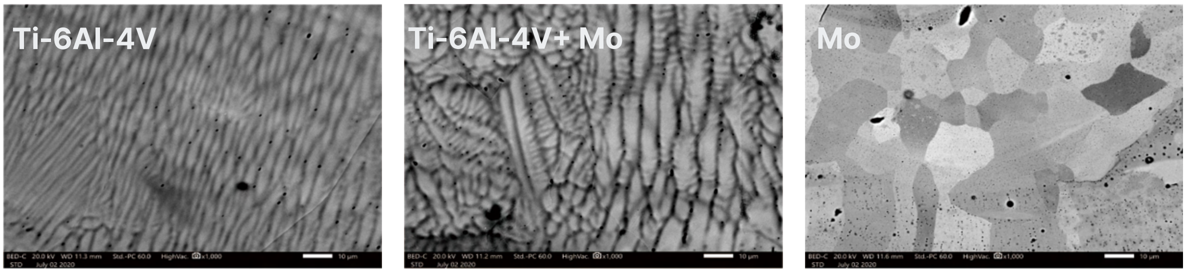


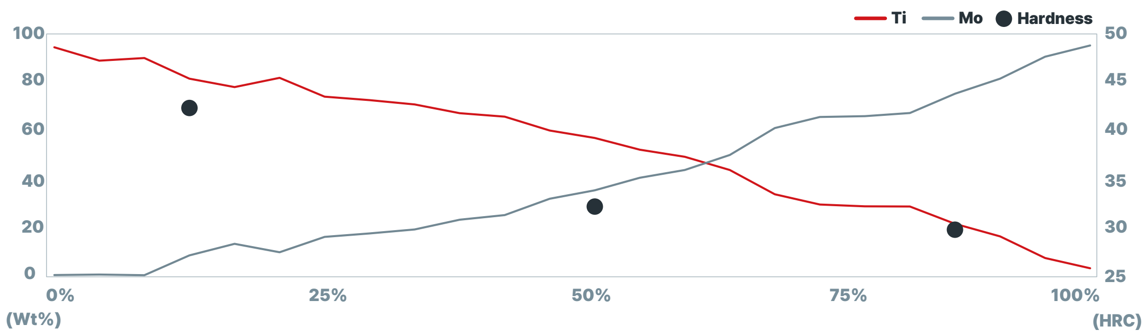
< IN625 - T800 Gradient Deposition Chemical Properties (wt%) & Hardness (HRC) >

6 Ti-6Al-4V + Mo

FGMs of Ti alloys & pure Molybdenum powder

SEM Analysis (x250)



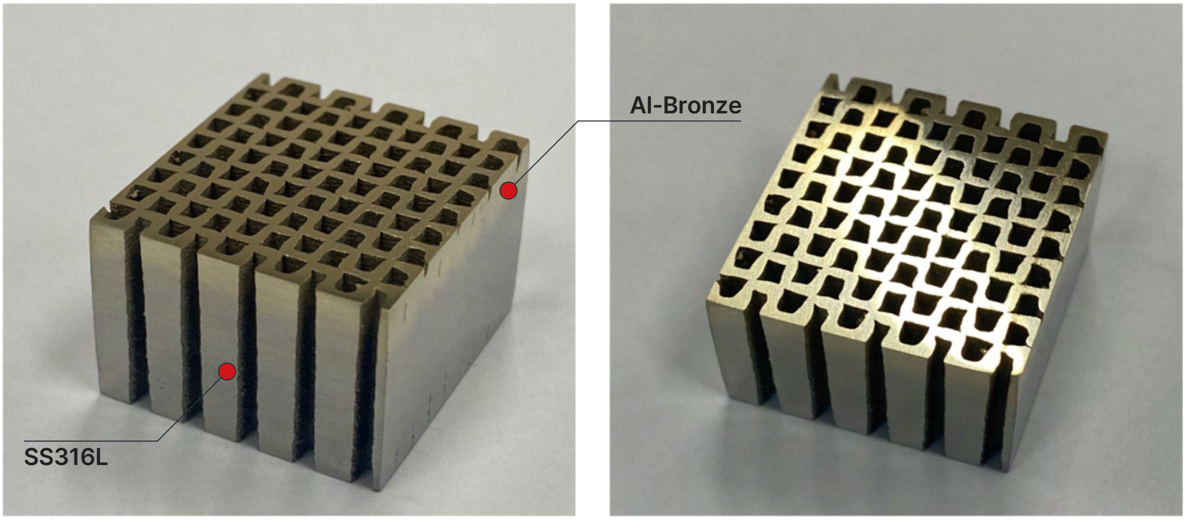


< Ti-6Al-4V - Mo Gradient Deposition Chemical Properties (wt%) & Hardness (Hv) >

7 SS316L + Al-Bronze

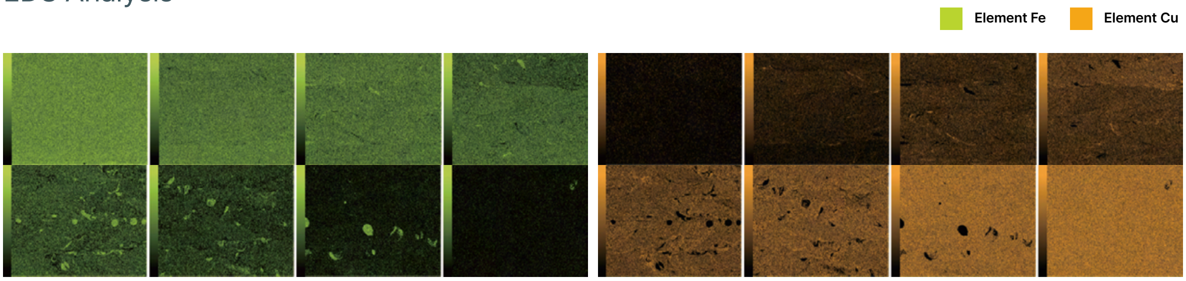
FGMs of Fe & Cu balanced alloys

See one of our lattice structure sample by MX-Lab.
With the basic 3axis structure of equipment, it performs remarkable complex shape and output in metal 3Dprinting.
In this demonstration, we referred to SS316L and gradually deposited the material that was changed to Albronze.
After deposition, the sample was analyzed with SEM & EDS and the composition of the material gradually changed.

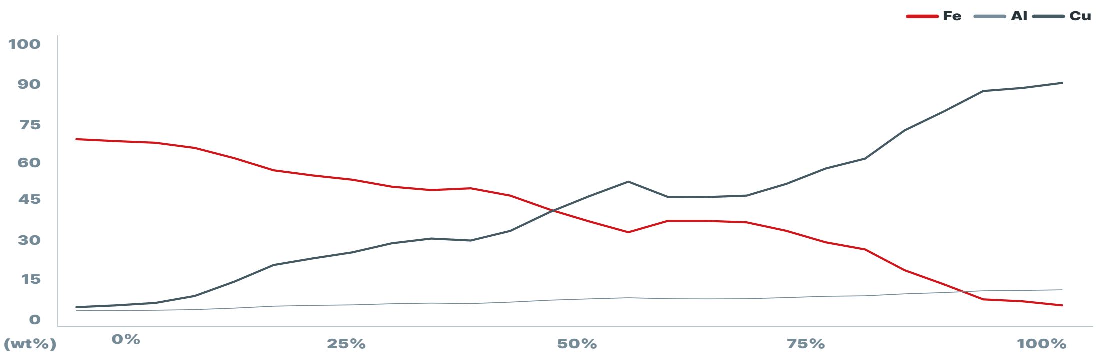


< Lattice Pattern Gradient Sample >

EDS Analysis



< SS316L - Al-Bronze EDS Analysis >



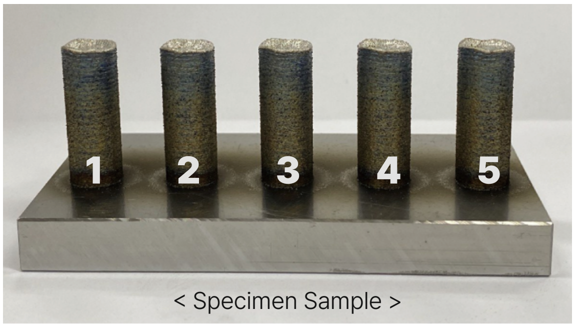
< SS316L - Al-Bronze Gradient Deposition Chemical Properties (wt%) >

8 Stellite6 + SS316L

FGMs of Co & Fe balanced alloys

The component analysis of five Stellite6 + SS316L FGM(Functionally Graded Material) samples stacked at once shows a similar compositional distribution. Through this test, we confirmed that the feeder of MX-Lab can supply and control powder consistently.

By producing FGM through the CVM powder feeding system of MX-Lab, samples of various compositions can be simultaneously manufactured, which can reduce the opportunity cost by reducing alloy design and verification time.



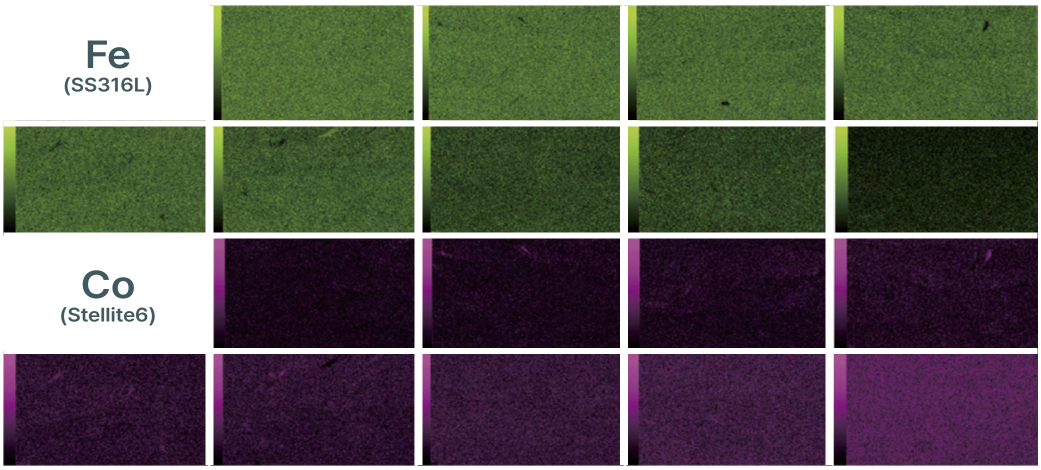
< Specimen Sample >

Materials (Chemical Composition)

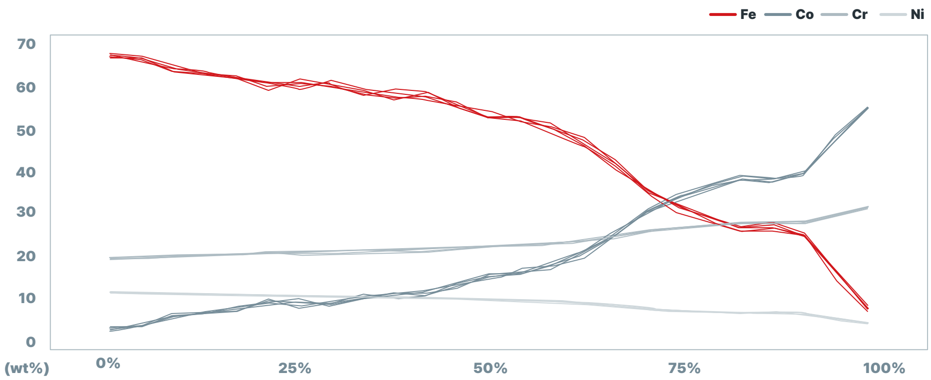
Alloys	Co	Cr	W	Ni	Fe
Stellite6	Bal.	30.0	6.0	3.0	3.0

Alloys	Fe	Cr	Mo	Ni	Mn
SS316L	Bal.	17.01	2.03	10.02	1.38

SEM Analysis



< Stellite6 - SS316L EDS Analysis>



< Stellite6 - SS316L 5ea Samples Gradient Deposition Chemical Properties (wt%) >

Bimetallic Joint

Emerging trends in manufacturing such as light weighting, increased performance and functionality increases the use of multi-material, hybrid structures and thus the need for joining of dissimilar materials. The properties of the different materials are jointly utilized to achieve product performance.

Resources: Joining of dissimilar materials, CIRP Annals, 2015

Application

Design engineers are increasingly faced with the need to join dissimilar materials as they are seeking creative new structures or parts with tailor-engineered properties. Sometimes a part needs high-temperature resistance in one area, good corrosion resistance in another. Structures may need toughness or wear resistance in one area combined with high strength in another location. Improving the ability to join dissimilar materials with engineered properties are enabling new approaches to light-weighting automotive structures, improving methods for energy production, creating next generation medical products and consumer devices, and many other manufacturing and industrial uses.

Dissimilar Materials Joining, EWI, 2012

With successes of dissimilar metal welding have come new opportunities. Applications requiring joining of dissimilar materials have continued to grow in a number of industries including electronics, medical devices, consumer goods, automotive and aerospace.

Welding Dissimilar Metals for New Product Designs, Prima Powder Laserdyne, 2017

Many industries and applications require dissimilar materials to be joined for chemical, structural, and economic reasons. Combining dissimilar metals in a Weldment or for a weld overlay allow the use of the best properties of each metal. All industries benefit for this and is a primary importance when the overlay [cladding] is used in industrial process involving high temperatures and pressure, thermal cycling, and dynamic corrosive environments.

An introduction to laser welding for dissimilar metals, John Haake, 2021

Case Study

In this case study, Fe, Ni, and Cu powders were used.
After deposition, Dissimilar metal specimens were tested for mechanical properties.

1 Al-Bronze + Inconel718

2 SS316L + Inconel625

3 SDSS + SS316L

1 Al-Bronze + Inconel718

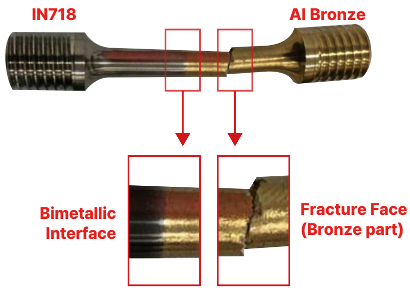
Bimetallic joint of Cu & Ni balanced alloys

Tensile Test Sample

Sample by MX-Lab

Machining

Tensile Test



The fracture in tensile test occurred not at the bimetallic interface, but at the Al- Bronze part.

Result of Tensile Test

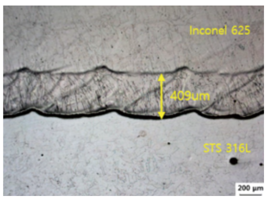
Material	Max Load (N)	Tensile Strength (MPa)	0.2% Offset Yield Strength (Mpa)	Strain (%)
Al Bronze + IN718 (Z direction)	15784	561.975	335.983	8.08
	15380	543.971	322.721	10.04

2 SS316 + Inconel625

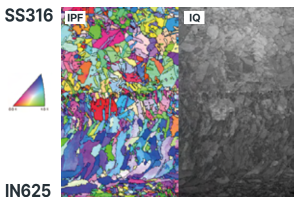
Bimetallic joint of Fe & Ni balanced alloys

Mechanical Property Sample

Microstructure Analysis



OM



EBSD

Mechanical Property Test Result

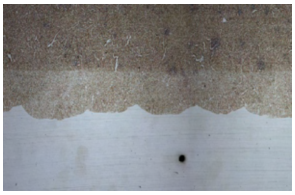
Heat treatment	Ultimate Tensile Strength (MPa)	Yield Strength (Mpa)	Elongation (%)
As-Built	621	384	43
Heat Treatment	573	252	52

3 SDSS + SS316L

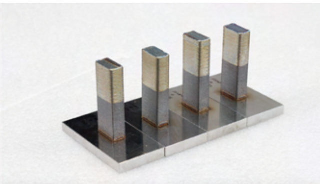
Bimetallic joint of Fe balanced alloys

SDSS Microstructure

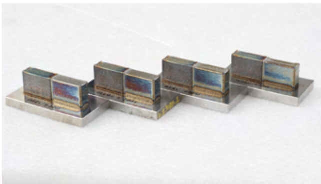
Interfacial Microstructure



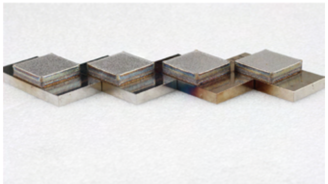
Mechanical Property Test Sample



Tensile Test Sample



Impact Test Sample



CPT Test Sample

Mechanical Property Test Result

Heat treatment	Tensile Strength (MPa)	Elongation (%)	Impact (-46°C,J)
As-Built	615 / 617	36 / 37	335.983
Heat Treatment	570 / 564	40 / 41	322.721

<Tensile Test & Impact Test>

Heat treatment	30°C	35°C	40°C	45°C	50°C	55°C	60°C	65°C	70°C
As-Built	0 (no pitting)	13 (pitting)	39.8 (pitting)	520.9 (pitting)	893.8 (pitting)				
Heat Treatment				0.2 (no pitting)	2 (no pitting)			239.6 (pitting)	590.8 (pitting)

<CPT Test>

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