INSTITUTE OF STRENGTH PHYSICS AND MATERIALS SCIENCE
SIBERIAN BRANCH OF RUSSIAN ACADEMY OF SCIENCES

"Regularities in formation of polymetallic materials using electron-beam additive technology"

Laboratory of local metallurgy in additive technology

Second year graduate student: Kseniya S. Osipovich
Research superviser: Evgeny A. Kolubaev

Tomsk - 2020

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Table of contents

Motivation

- *...material*
  - *Mono...*
    - only **one** material
    - only **one** structure
    - only **one** mechanical property
  - *Poly...*
    - **two** or **more** materials
    - **different** structure
    - inequal mechanical properties
    - light weight
    - reasonable cost

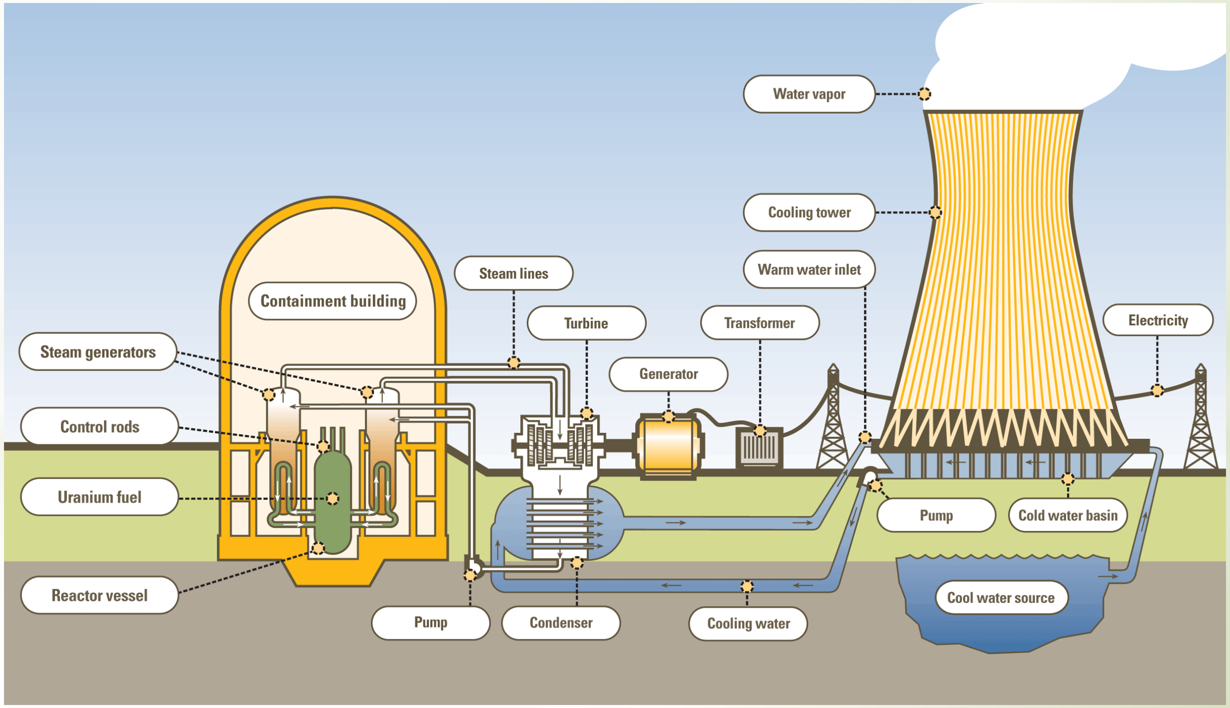
Polymetals are an optimal combination of physical, mechanical and chemical properties

Application

aerospace industry

nuclear power generation

factories



Literature analysis

Additive technology

Acta Materialia 108 (2016) 46–54

Contents lists available at ScienceDirect

Acta Materialia

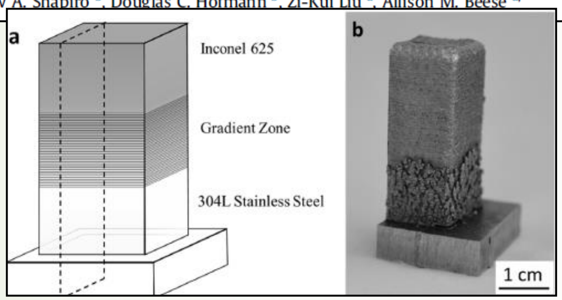
ELSEVIER

journal homepage: www.elsevier.com/locate/actamat

Full length article

Functionally graded material of 304L stainless steel and inconel 625 fabricated by directed energy deposition: Characterization and thermodynamic modeling

Beth E. Carroll [a], Richard A. Otis [a], John Paul Borgonia [b], Jong-ook Suh [b], R. Peter Dillon [b], Andrew A. Shapiro [b], Douglas C. Hofmann [b], Zi-Kui Liu [a], Allison M. Beese [a,*]



Materials and Design 93 (2016) 370–378

Contents lists available at ScienceDirect

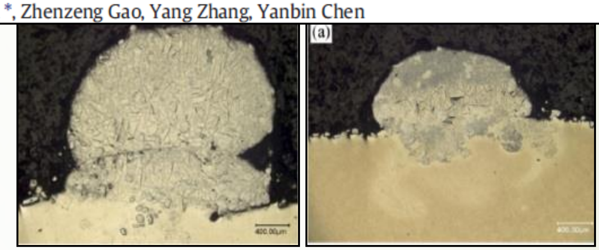
Materials and Design

ELSEVIER

journal homepage: www.elsevier.com/locate/matdes

Alloying effect of titanium on WC_p/Al composite fabricated by coincident wire-powder laser deposition

Fuquan Li *, Zhenzeng Gao, Yang Zhang, Yanbin Chen



Additive Manufacturing 21 (2018) 133–140

Contents lists available at ScienceDirect

Additive Manufacturing

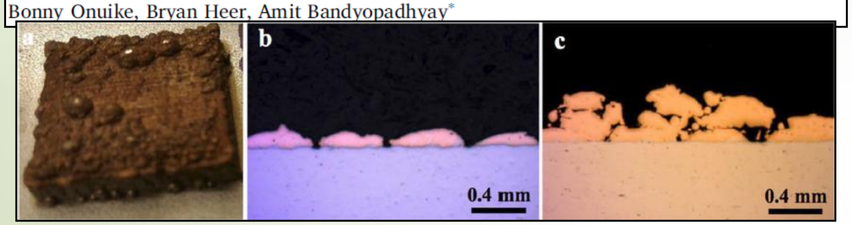
ELSEVIER

journal homepage: www.elsevier.com/locate/addma

Full Length Article

Additive manufacturing of Inconel 718—Copper alloy bimetallic structure using laser engineered net shaping (LENS™)

Bonny Onuike, Bryan Heer, Amit Bandyopadhyay*

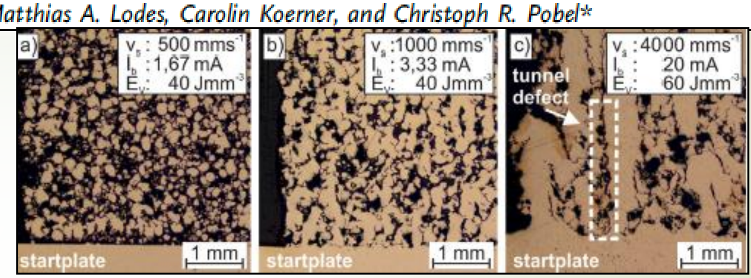


FULL PAPER

XXXX

Selective Electron Beam Melting of Oxide Dispersion Strengthened Copper

*Matthias A. Lodes, Carolin Koerner, and Christoph R. Pobel**



Literature analysis

Electron beam additive method

<u>Advantages</u>:

- ❖ Vacuum chamber;
- ❖ High energy intensity of the electron beam;
- ❖ High electron beam power capacity;
- ❖ High density of floating layers;
- ❖ High printing speed.

<u>Objective of research:</u>

to investigate features of the "steel-copper" bimetal structure produced by an electron-beam multi-wire additive technology

Materials

Cu-Fe

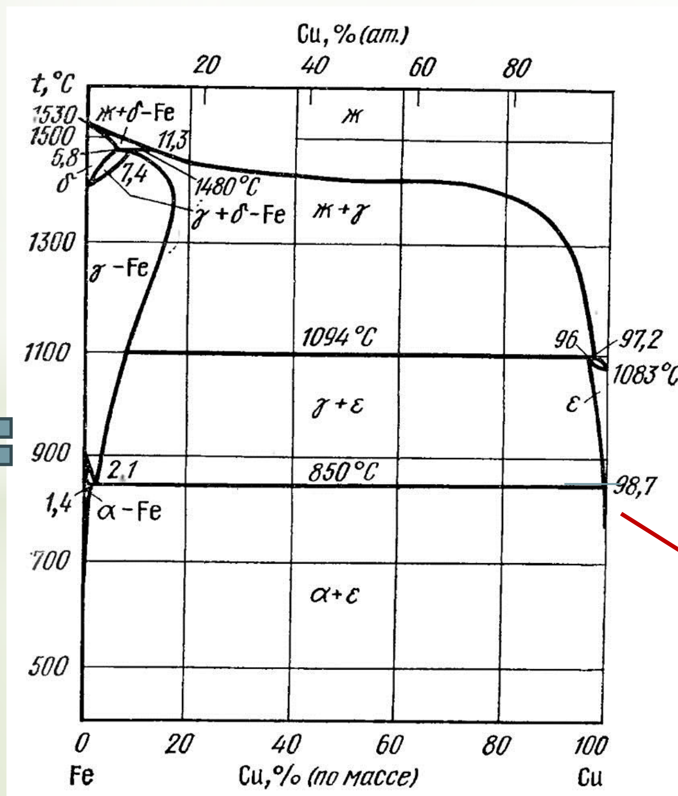
Material	Chemical component (wt. %)						
	Fe	Cu	Ni	Cr	Mn	Si	C
AISI 304	~ 67	≤ 0.3	8–9.5	17–19	≤ 2	≤ 0.8	≤ 0.12
C11000	≤ 0.005	99.9	≤ 0.002	–	–	–	–

Cu

+

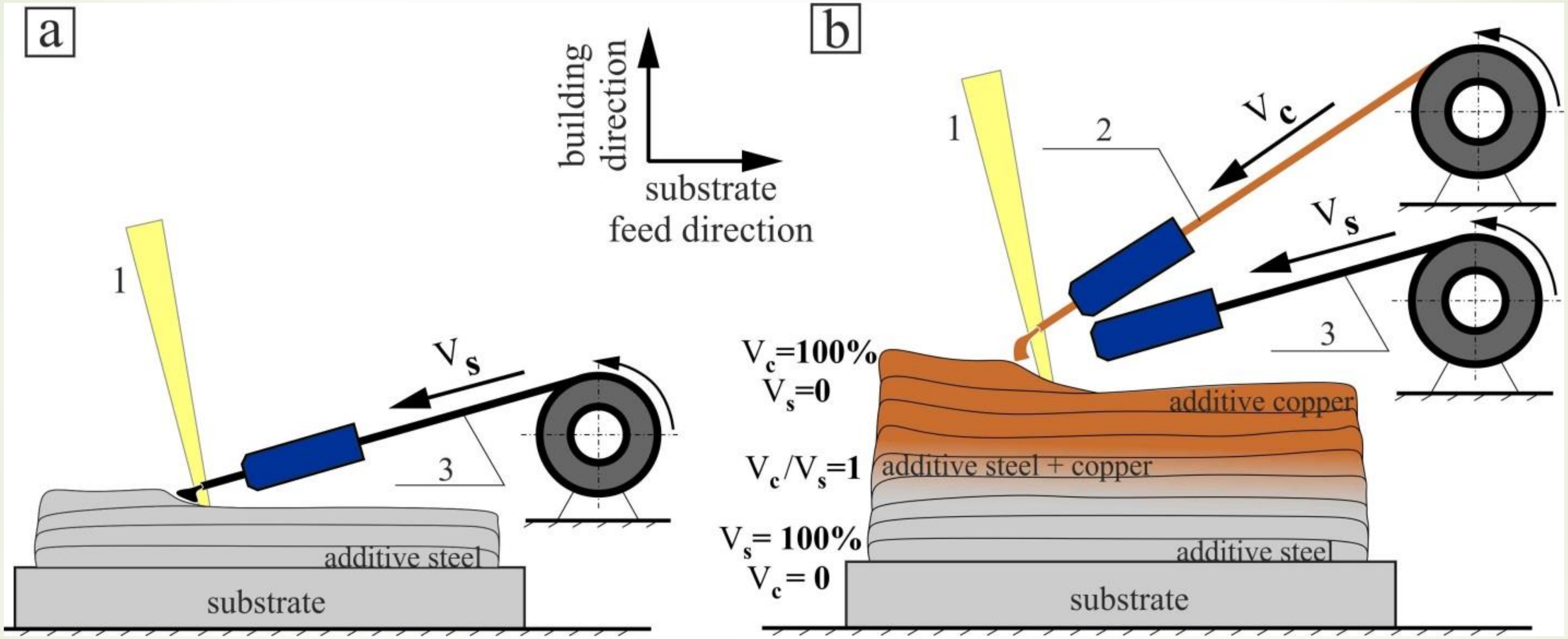
Fe

=



- ✓ no intermetallic compounds
- ✓ the solubility of copper in steel and vice versa is very low
- — significant difference in thermophysical properties (linear expansion coefficient, crystallization temperature, electromagnetic properties, heat capacity and thermal conductivity)

Methods



Scheme of a structurally gradient bimetallic material building using the electron-beam additive manufacturing: a – SS wire deposition; b – copper wire deposition.
1 – electron beam; 2 – copper wire; 3 – steel wire

Macrostructure

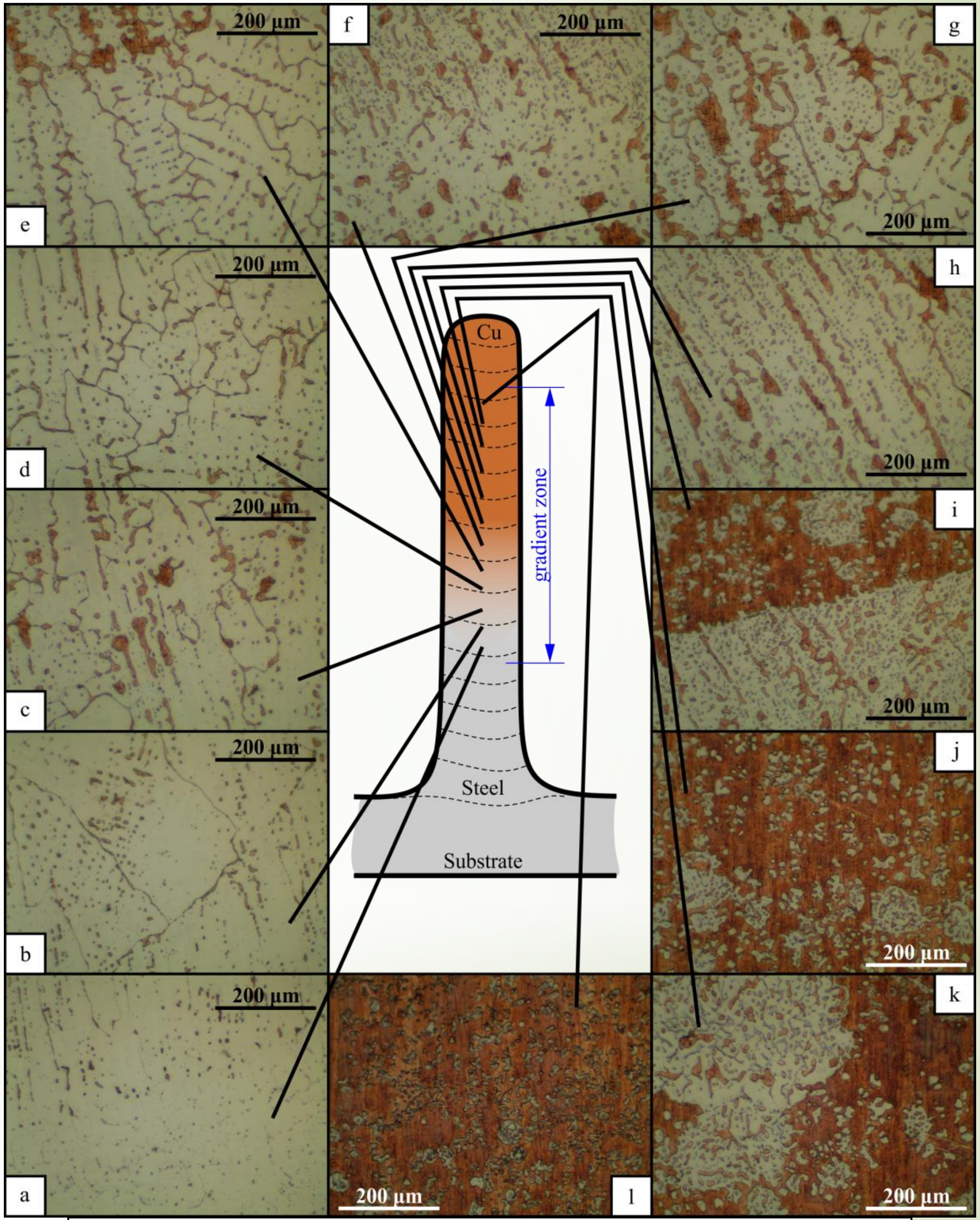
$v_{Cu} = 0$ – austenitic dendrite structure

$v_{ss} > v_{Cu}$ – solidification of copper particle network

$v_{ss} \approx v_{Cu}$ – more copper is solidified in grain bodies and along grain boundaries of austenite

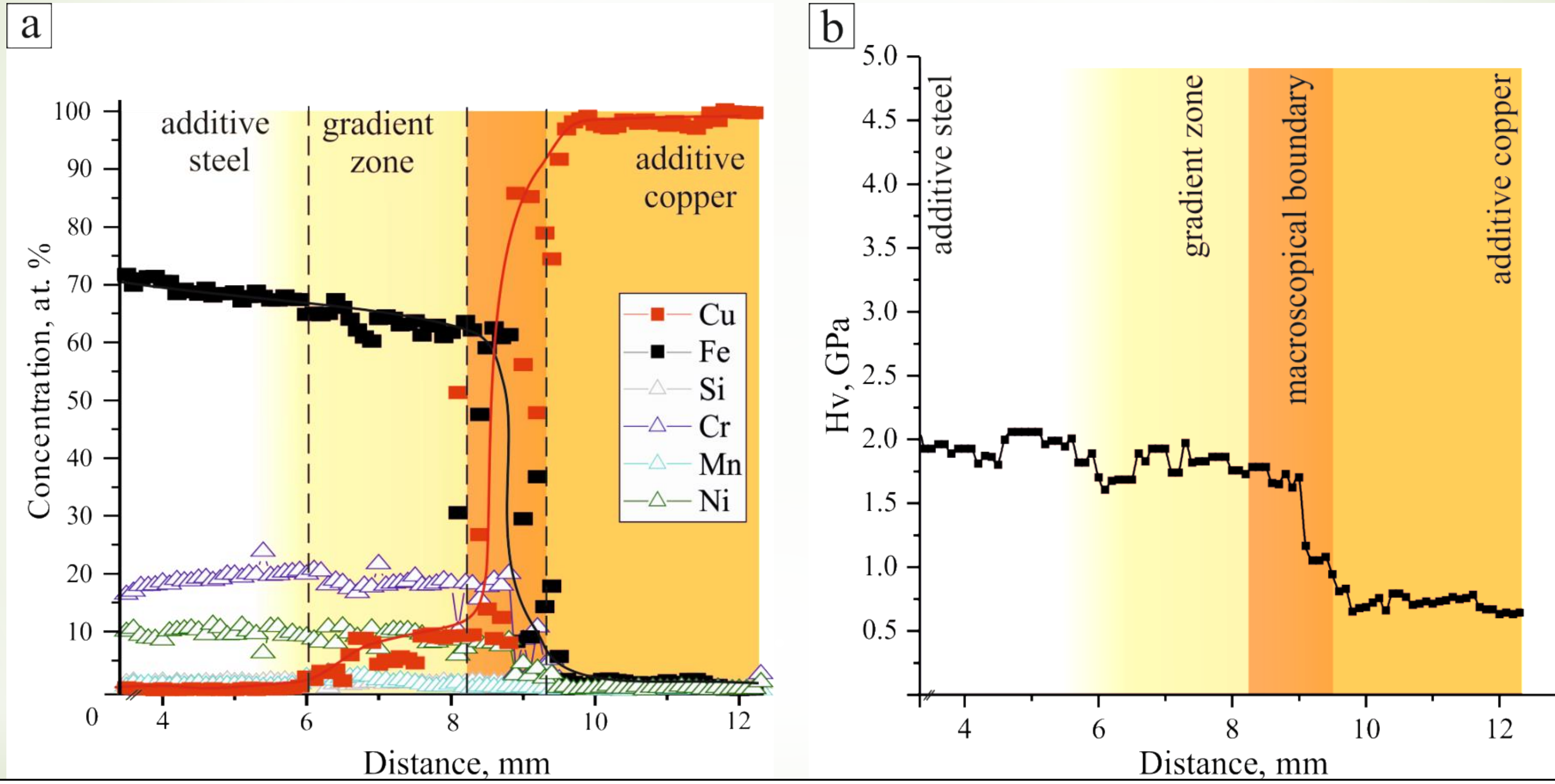
$v_{ss} < v_{Cu}$ – columnar austenitic structures with copper dendritic-type lamellae and coarse particles in austenitic grain bodies

$v_{ss} = 0$ – rather pronounced boundary with a sharp change in copper and steel contents



The optical microscopy images of the bimetallic sample in the gradient zone.

Microhardness and elemental composition

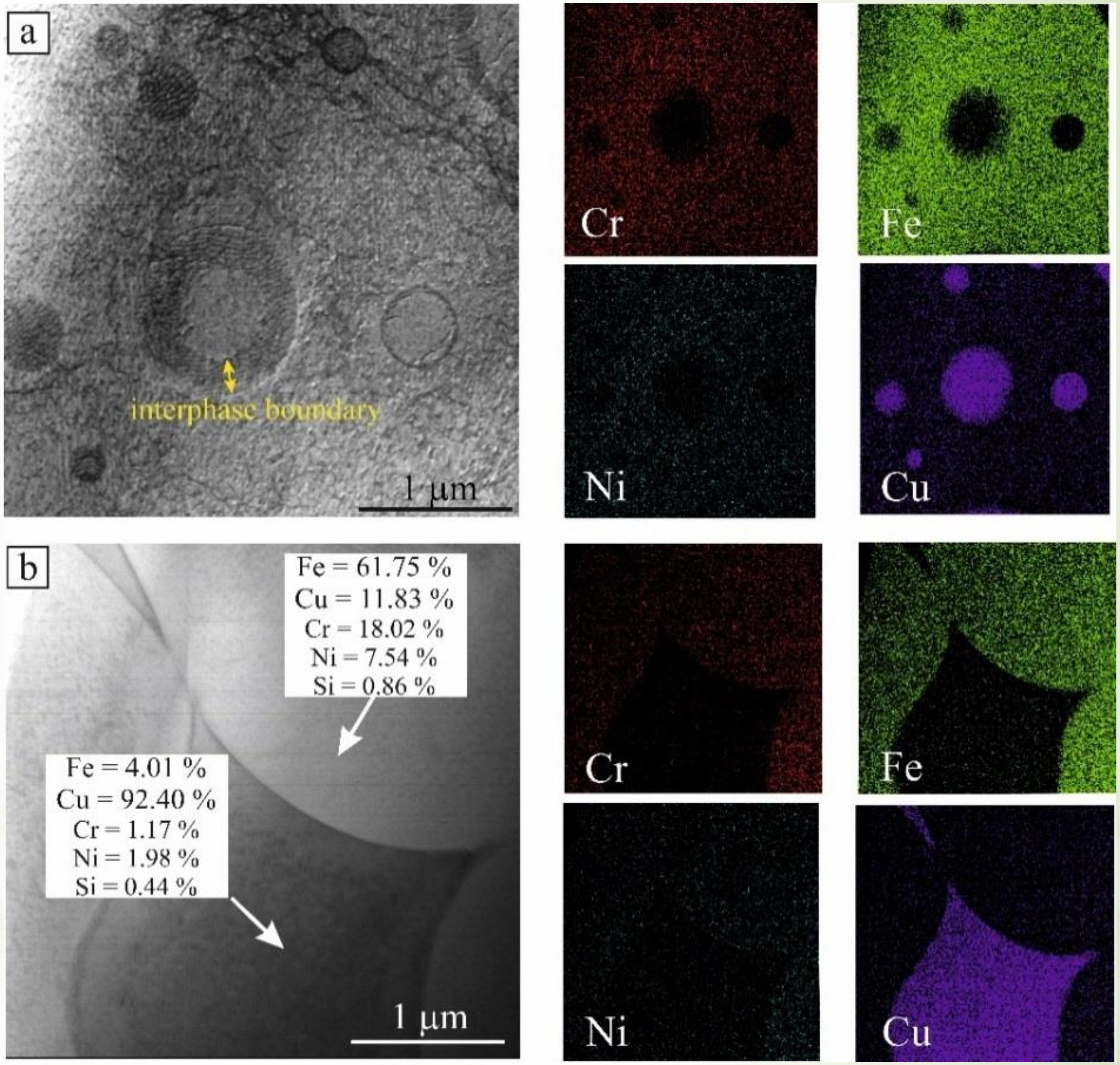


Changes in the elemental composition (SEM EDS analysis) (a) and microhardness (b) with the distance from the substrate in bimetallic material produced by electron-beam additive manufacturing.

Transmission electron microscopy

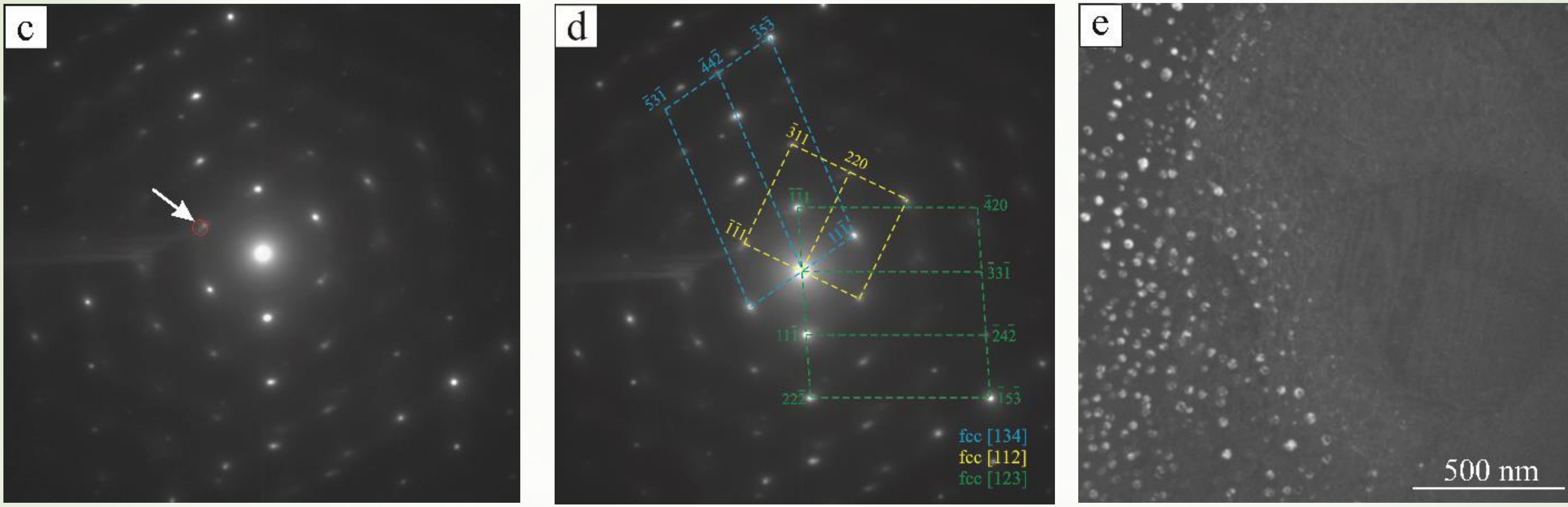
The average size of large particles is 510 nm.

The greatest dimension of the lamellas in TEM images reaches the value of 3.6 μm with the thickness of the interlayers 0.7 μm.



Transmission electron microscopy

The area corresponded to the selected area electron diffraction pattern in (c) is circled in (a). The Dark-field image (e) was obtained using the reflection marked by the arrow in (c).



According to TEM analysis, four main morphological elements could be determined in gradient zone: austenitic coarse grains (Fe-based), irregular-shaped Cu-based coarse grains, spherical Cu-based coarse and fine particles in austenitic grains.

Conclusion: scheme

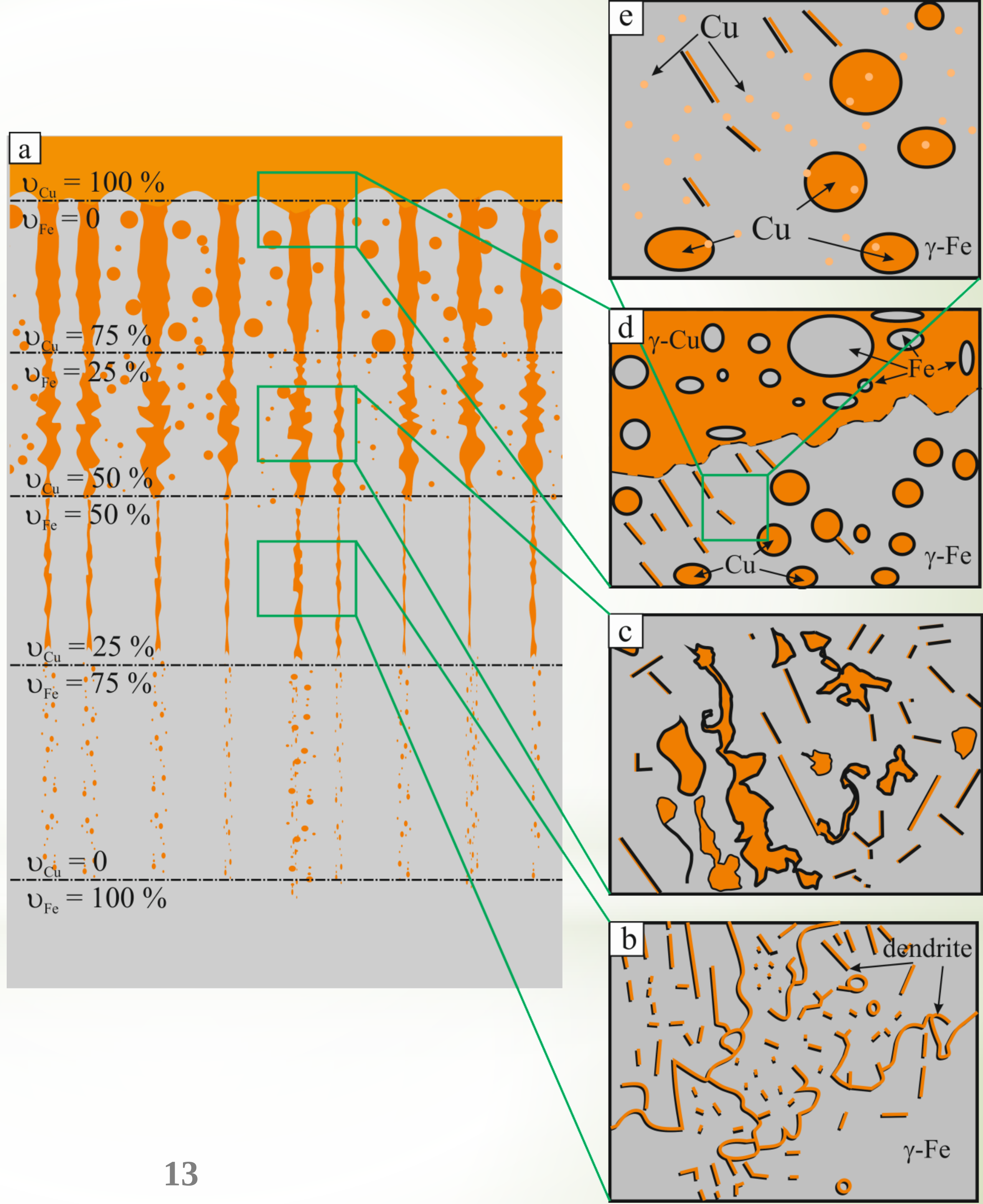
(0) $V_c = 0$: austenite dendrite solidifies first and fast so that no δ-ferrite arises in the lower part of the additively grown billet;

(i) $V_S >> V_C$: solidification starts by epitaxial growth of austenite dendrites while still liquid copper is forced out to the interdendrite spaces, where it solidifies during cooling below the copper melting point thus forming dotted interdendrite boundaries;

(ii) $V_S > V_C$: a solid solution hardening of austenitic steel by copper occurs at this stage;

(iii) $V_S \approx V_C$, $V_S < V_C$: when copper concentration exceeds the limit of dissolution in the Fe-based solid solution fine copper precipitates may formed within the austenitic structure during cooling;

(iv) $V_S = 0$: depositing only copper wire provides formation of a sharp boundary at both sides of which there are inclusions of copper or steel formed by intermixing in the molten pool during remelting the steel-containing underlying metal.



Conclusion: summary

1. The specimens of Fe-Cu bimetallic material with gradient zone were produced by the electron-beam 3D-printing method

2. The analysis of the bimetallic macrostructure shows the complete deposition of layers and the absence of defects such as flaws and cracks

3. Different stages of the gradient zone formation process:
   - grid distribution of copper into the iron matrix;
   - grouping of elements near the dendritic boundaries;
   - formation of the secondary phase Cu;
   - precipitation of nanosized copper particles from a supersaturated solid solution of Cu in austenite.

4. Particles of copper and steel were classified by their formation mechanisms.

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THANK YOU FOR YOUR ATTENTION

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