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DEVCOM ARMY RESEARCH LABORATORY

FeMnAl Technical Review Meeting 2021

by Krista R Limmer, Daniel M Field, and Katherine M Sebeck

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FeMnAl Technical Review Meeting 2021

Krista R Limmer and Daniel M Field
DEVCOM Army Research Laboratory

Katherine M Sebeck
DEVCOM Ground Vehicle Systems Center

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14. ABSTRACT
The third FeMnAl technical review meeting was held on August 11–12, 2021, as a two-day virtual meeting bringing together the academic and industrial community working with the US Army on low-density armor steel development to rapidly advance the material's maturation. This report contains the meeting agenda and abstracts, and the appendixes contain copies of the unclassified briefings presented during the meeting.

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1. Meeting Overview

The 2021 FeMnAl Technical Review meeting was hosted by the Lightweight Innovations for Tomorrow (LIFT) center using the Microsoft Teams platform on August 11–12, 2021. The objective of the meeting was to bring together the domestic academic, industrial, and defense communities working on the development of low-density armor steel to rapidly advance the material maturation. FeMnAl, a ferrous (iron[Fe]-based) alloy containing large amounts of manganese (Mn) and aluminum (Al), has been evaluated domestically as a cast and wrought armor material with 10% to 15% lower density than traditional armor steels since the mid-2000s.[1] The current development and maturation efforts began in 2016 and have grown to include many different organizations working on various aspects of the material development and maturation process.[2,3] Most of the current research projects have been funded through Department of Defense programs with technical coordination by the US Army Combat Capabilities Development Command (DEVCOM) Ground Vehicle Systems Center (GVSC) and DEVCOM Army Research Laboratory (ARL). The Steel Founder's Society of America has also coordinated projects under grants from the Defense Logistics Agency.

The virtual format for the meeting this year was required due to travel restrictions that remained in place from the COVID-19 coronavirus pandemic. Although in-person interactions were not possible, the discussions that took place in the meeting chat throughout the meeting as well as in the open discussion periods provided adequate interaction for attendees to remain engaged in and contribute throughout the meeting. While the discussions, both large group and sidebar, were not able to be as long or free-flowing as an in-person meeting allows, the meeting was still successful in bringing the community together for development and maturation updates.

This third FeMnAl technical review meeting virtually brought together 41 researchers, program directors, and end users representing 19 different government, academic, and industrial organizations. The first day focused on additive manufacturing of FeMnAl, welding, machining, and alternative processing methods. The second day emphasized developments in composition control effects, modeling and simulation, and performance evaluation. Each technical briefing was 20 min including questions, with a separate 20-min discussion block following each topic area. The meeting agenda is shown in Table 1.

Table 1. 2021 FeMnAl review meeting agenda; times in Eastern Daylight Time

Day 1		Day 2	
Time	**Title and Speaker**	**Time**	**Title and Speaker**
0900	Introduction and housekeeping	0900	Introduction and housekeeping
0910	A review of the Army FeMnAl program (K Sebeck)	0910	Composition dependent aging kinetics in FeMnAl (D Field)
0940	Powder development of FeMnAl steel for additive manufacturing (S Zacher)	0930	Grain refinement and mechanical properties of FeMnAl steels with Ni and Nb additions (M Piston)
1000	Additive manufacturing and characterization of FeMnAlC Armor steel (A Salem)	1000	Thermophysical properties of Fe30Mn4Al0.9C: a coupled computational-experimental approach (M Umanzor)
1020	Additive manufacturing of AM-Grade FeMnAl powder feedstock gas atomized in a mobile foundry from recycled scrap (A Kudzal)	1020	Phase-field modeling of κ-carbide in FeMnAl alloy (Y Gu)
1040	Discussion	1040	Discussion
1100	Lunch	1100	Lunch
1240	Fusion welding of FeMnAl alloys (J DuPont)	1300	Influence of chemistry and cleanliness on notch toughness of FeMnAl castings (L Bartlett)
1300	Varestraint and hot ductility characterization of FeMnAl (R Giorajo)	1320	Ballistic performance of FeMnAl (K Limmer)
1320	Welding FeMnAl with conventional armor filler materials (R Dull)	1340	FeMnAl composition evaluation for corrosion protection (L Blohm)
1340	Discussion	1400	Discussion
1400	Flattening and machining performance of FeMnAl steel (J Keogh)	1420	Closing remarks and open discussion
1420	Machining of FeMnAl steel (D Handayani)		
1440	Enhancing the strength and toughness of high strength steels via Equal Channel Angular Pressing (ECAP) (I Karaman)		
1500	Discussion		
1520	Day 1 closing remarks		

2. Briefing Abstracts

An abstract for each of the 17 briefings presented at the meeting has been included here in chronological order as outlined in Table 1. Each briefing slide deck has been included as a separate appendix as denoted after each abstract.

2.1 Day 1: 11 August 2021

2.1.1 A Review of the Army FeMnAl Program

Katherine Sebeck[1], Krista Limmer[2], Daniel Field[2], Katherine Vieau[1], Jennifer Lask[1], Daniel Wagner[1], and James Heading[1]

[1] *GVSC*
[2] *ARL*

The Army program for industrial-scale production and characterization of FeMnAl steels for potential armor applications started in FY16. Since then, a substantial amount of research has been conducted to better understand this class of lightweight steels. In addition to maturation of industrial steel-making practices, the FeMnAl project has covered characterization of survivability and integration requirements, as well as other performance parameters. Major milestones are reviewed, highlighting key results and lessons learned in these key areas. The limitations and successes of FeMnAl steel for Army applications are addressed at a high level, providing context for further talks over the course of this review meeting.

This briefing is included as Appendix A.

2.1.2 Powder Development of FeMnAl Steel for Additive Manufacturing

Sonia Zacher[1], Paul Meese[1], Christopher Eonta[1], and Katherine Sebeck[2]

[1] *MolyWorks Materials Corporation*
[2] *GVSC*

In a joint effort with the US Army DEVCOM GVSC, MolyWorks Materials Corporation developed a method to produce FeMnAl steel powder using a Greyhound system. At present, no commercial source of additive manufacturing (AM) powder exists for this alloy. The Greyhound is a horizontal free-fall gas atomizer, designed to recycle scrap metals into on-chemistry, spherical AM powder.

Powder was made using two feedstock sources: pre-alloyed wrought plate and elemental constituents alloyed directly before atomization. The powder resulting from these two production methods was evaluated on the basis of chemical

composition, particle size distribution, particle morphology, and technical and economic feasibility to determine the optimal manufacturing process for directed energy deposition (DED)–grade FeMnAl powder.

Technical feasibility was achieved with the production of 19.6 kg of 60- to 125-µm FeMnAl steel powder. Using pre-alloyed plate feedstock was found to be the more economically viable option for large-scale production due to the reduced production rate of powder from elemental feedstock.

This briefing is included as Appendix B.

2.1.3 Additive Manufacturing and Characterization of FeMnAlC Armor Steel

Ayman Salem[1], Daniel Satko[1], Austin Tiley[1], Pawan Vedanti[1], Katherine Vieau[2], Thomas Wagner[2], and Katherine Sebeck[2]

[1] *MRL (Materials Resources LLC)*
[2] *GVSC*

AM holds significant promise as a technique to repair armor systems. In particular, DED techniques using powder or wire could facilitate in situ repair of armor systems by building up damaged surfaces or repairing cracked plates to restore structural integrity and protection ability. In recent years, there has been significant interest in the application of lightweight high-strength alloys of the Fe-Mn-Al-C system for armor systems due to a unique combination of reduced density, low magnetism, and high-energy absorption capability leading to excellent ballistic performance.

In this work, MRL demonstrated successful production of powder feedstock, AM of test coupons, characterization of the microstructure and mechanical performance, and the effect of heat treatment. Laser powder bed fusion (PBF) was used in combination with MRL's Integrated Computational Adaptive Additive Manufacturing software for processing parameter optimization to minimize porosities and lack of fusion defects, which was confirmed by density measurement, metallographic inspection, and micro-computed tomography (CT) inspection.

This briefing is included as Appendix C.

2.1.4 Additive Manufacturing of AM-Grade FeMnAl Powder Feedstock Gas Atomized in a Mobile Foundry from Recycled Scrap

Andelle Kudzal[1], Marc Pepi[1], Chris Eonta[2], Andrew LaTour[2], and Matthew Charles[2]

[1] *ARL*
[2] *MolyWorks Materials Corporation*

ARL is researching technologies that will make it possible for the warfighter to manufacture and/or repair components at the point of need with scrap materials on-hand, thus increasing operational readiness while reducing the military logistics footprint. The objective of this project was to show proof-of-concept of AM of powder that was gas atomized in a MolyWorks Corp Mobile Foundry housed within a shipping container made from scrap FeMnAl steel. The powder feedstock was subjected to the laser PBF process to determine manufacturability. Cursory results show that while the FeMnAl powder processed through PBF was able to result in bulk parts, laser limitations and longer laser dwell times increased defect density, determined via micro-CT analysis, and made it impossible to manufacture this material in an ideal processing window.

This briefing is included as Appendix D.

2.1.5 Fusion Welding of FeMnAl Alloys

John DuPont and Rishi Kant

Lehigh University

The thermal cycles associated with fusion welding have a significant influence on the microstructure and properties of FeMnAl alloys. In addition, there is a need to identify optimum commercial filler metals for the various requirements of different applications. This presentation reviews recent work that demonstrates the influence of weld thermal cycles and post-weld heat treatment on the mechanical properties of FeMnAl alloys with the goal of optimizing welding procedures for mechanical properties. Recent work on selecting suiting commercial filler metals is also described.

This briefing is included as Appendix E.

2.1.6 Varestraint and Hot Ductility Characterization of FeMnAl

Rafael Giorjao[1], Kaue Riffel[1], Katherine Sebeck[2], and Antonio Ramirez[1]

[1] *Welding Engineering Program – Dept of Material Science and Eng, The Ohio State University*
[2] *GVSC*

The Welding Engineering Program at The Ohio State University worked with GVSC on developing and optimizing the FeMnAl armor steel plates, focusing on material weldability. As liquation cracking was reported on these alloys by several research groups, in this new effort, a combination of well-established Spot Varestraint and hot ductility tests, state-of-the-art modeling, and characterization were used to evaluate and quantify the liquation cracking susceptibility of four experimental hot-rolled FeMnAl alloys. The goal was to unveil the effects of small chemical, and potentially microstructural, differences on material weldability. The Spot Varestraint results revealed the weldability was directly related to the alloys' composition: higher Mn and C increased the alloys' liquation cracking susceptibility, while high Al resulted in lower liquation cracking susceptibility. Therefore, lower Mn and C and higher Al reduced segregation to the austenite grain boundaries within the heat-affected zone (HAZ) during welding and stabilized the second-phase ferrite, which seems to preclude high-temperature crack propagation. Hot ductility results revealed that all alloys presented similar high-temperature performance, with similar on-heating and on-cooling behavior. The combined results suggest the composition and phases play an important role in grain boundary liquation and crack propagation, which suggests better liquation cracking resistance on FeMnAl alloys with a duplex (ferrite–austenite) microstructure on a broader temperature range.

This briefing is included as Appendix F.

2.1.7 Welding FeMnAl with Conventional Armor Filler Materials

Randal Dull[1], Katherine Sebeck[2], Daniel Wagner[2], and Gary Thompson[1]

[1] *EWI*
[2] *GVSC*

EWI further evaluated the welding of wrought FeMnAl plate. Gas metal arc welds on FeMnAl were made in a previous project with good mechanical properties using a variety of conventional electrode types including austenitic stainless steel, and high chrome, high manganese. Base metal mechanical properties had a strong influence on weld and HAZ mechanical properties, with low toughness in the base metal an issue on a few welds. The weld HAZ was generally not the limiting factor in performance. Additional welds were made in a follow-on project using an

ER100S-1 carbon steel electrode. EWI welded one H-plate using an ER316L electrode. EWI also evaluated pressing plates to improve flatness.

This briefing is included as Appendix G.

2.1.8 Flattening and Machining Performance of FeMnAl Steel

John Keogh

American Lightweight Materials Manufacturing Innovation Institute (ALMII)

FeMnAl is a lightweight, wrought, high-manganese, high-aluminum steel under investigation for ground vehicle structure and armor applications when both weight and space are of significant concern. However, its successful application hinges on several key characteristics including manufacturability, formability, weldability, machinability, and performance. Rolled FeMnAl incurs significant distortion and work hardens rapidly, presenting myriad fabrication challenges. In this work, LIFT investigated plate flattening in relation to work hardening and the machinability of bulk FeMnAl. Results show that 1) a successful flattening procedure was developed for FeMnAl plate with a unidimensional bend, and work hardening (evaluated statistically via surface hardness) did not present as an issue, and 2) given correct tool selection, speeds, feeds, depth of cut, ramp rate, cooling, and other parameters, FeMnAl can be machined and processed via milling, drilling, tapping, waterjet and bandsaw cutting, and wire and sinker electrical discharge machining.

This briefing is included as Appendix H.

2.1.9 Machining of FeMnAl Steel

Dika Handayani[1], Victor Okhuysen[1], and Nicole Wagner[2]

[1] *Cal Poly Pomona*
[2] *Chapman University*

A series of FeMnAl steel turning experiments were conducted to assess the machinability of FeMnAl steel in the solution-annealed condition. Tool life, surface finish, and load percentage/spindle load are used as the machinability criteria. Results from the study point to the recommendations that negative rake angle on a stainless-steel-designated tool should be used to turn FeMnAl with a starting parameter of 0.008-inch/rev feed rate, 0.080-inch depth of cut, and 150-ft/min cutting speed. A modified Taylor Tool Life equation was also generated and can be used to determine starting parameters based on desired tool life. Work-hardening behavior of FeMnAl during machining was also examined. The initial result shows an increased hardness closer to the machined edge. The availability of this machining information is expected to reduce the machining cost and time, and

thus would encourage the application of this material in a more efficient and productive manner.

This briefing is included as Appendix I.

2.1.10 Enhancing the Strength and Toughness of High Strength Steels via Equal Channel Angular Pressing (ECAP)

Ibrahim Karaman, MW Vaughan, Sezar Picak, and C Acemi

Texas A&M University

This study is an ongoing work on strengthening and toughness enhancement for a variety of different high-strength steel alloys, documenting the effects of equal channel angular pressing on the mechanical properties of martensitic AF96, austenitic FeMnAl, and martensitic HY100 steels, in particular. Some of the highlights of these studies show that, given the appropriate processing parameters, remarkable strengthening above 2 GPa may be achieved for AF96 and HY100. In addition, toughness may be improved via ECAP for AF96, while it suffers for HY100 after ECAP. Alternatively, ECAP of the age-hardenable FeMnAl steel allows significant Hall–Petch strengthening, prior to any aging heat treatment, thereby enabling significant strengthening and high toughness simultaneously. Overall, these improvements are discussed in the context of microstructural evolution resulting from the imposed thermomechanical processing schemes for each unique alloy.

This briefing is included as Appendix J.

2.2 Day 2: 12 August 2021

2.2.1 Composition Dependent Aging Kinetics in FeMnAl

Krista Limmer, Daniel Buzminsky, and Daniel Field

ARL

A series of Fe-Mn-Al-C alloys were produced and evaluated to determine the effect of composition variation on the kinetics of κ-carbide formation. Whereas past studies examined the sensitivity of mechanical properties to changing a single element in the composition in these alloys, this study evaluated covariance of the major elements: Mn, Al, and C. Wrought plates were produced by two vendors according to a 2^3 factorial design of experiments that were all expected to be age hardenable through precipitation of κ-carbide. Johnson–Mehl–Avrami kinetics were determined for each alloy and the results are discussed in terms of composition and microstructure. Additional insights into the composition-dependent aging

mechanisms from high-resolution characterization including synchrotron X-ray diffraction and atom probe tomography are also discussed.

This briefing is included as Appendix K.

2.2.2 Grain Refinement and Mechanical Properties of FeMnAl Steels with Ni and Nb Additions

Michael Piston[1], Wint Watwood[1], Laura Bartlett[1], Ron O'Malley[1], Krista Limmer[2], Dan Field[2], and Katie Sebeck[3]

[1] *Missouri University of Science and Technology*
[2] *ARL*
[3] *GVSC*

Micro-alloy additions of niobium (Nb) up to 0.04 wt% in an Fe-28Mn-8Al-1C steel containing 0.5 wt% molybdenum (Mo) was shown to be effective at forming grain pinning niobium carbonitride (Nb(C,N)) precipitates during hot rolling and significantly reduce grain size and notch toughness. Additions of nickel (Ni) to these steels has also been shown to greatly increase strength and hardness by forming hard intermetallic B2 precipitates within the austenite matrix. Two hot rolling temperatures of 1200 and 1050 °C and additions of up to 8 wt% Ni and 0.4 wt% Nb were investigated in an Fe-20Mn-8Al-1C steel for dual precipitation of B2-NiAl and Nb(C,N) on grain refinement and mechanical properties.

This briefing is included as Appendix L.

2.2.3 Thermophysical Properties of Fe30Mn4Al0.9C: A Coupled Computational-Experimental Approach

Manuel E Umanzor, Matthew E Drew, and Alan P Druschitz

Department of Materials Science and Engineering, Virginia Tech

Due to their low density and high toughness, compared to traditional steels, high-manganese austenitic steels are outstanding candidates across several industries like defense and automotive for lightweight structural applications. Over the past few decades, modeling tools have found their way into foundries worldwide. Nonetheless, for these tools to provide trustworthy predictions, accurate input properties are required. For the composition studied (Fe30Mn4Al0.9C1Si0.5Mo), thermophysical properties are scarce in the literature. Hence, a coupled computational-experimental approach was used to determine the needed property data as a function of temperature. Key properties like phase transitions, enthalpy, density, fraction solid, specific heat capacity (C_P), latent heat, and viscosity were determined using a commercially available thermodynamics calculation package.

These properties were first calculated for known systems (304SS and A356), and the calculated results were compared to results from the literature. Thermophysical properties for the system of interest were then calculated. Validation for C_P and liquidus and solidus temperatures was performed via differential scanning calorimetry (DSC). Detection of solidus temperature via DSC proved to be challenging; hence, a discrete-derivative analysis was conducted to determine this parameter. Mold filling and solidification simulations were performed and compared with actual castings.

This briefing is included as Appendix M.

2.2.4 Phase-Field Modeling of κ-carbide in FeMnAl Alloy

Yijia Gu, Julia Medvedeva, and Kyaw Hla Sain Chak

Missouri University of Science and Technology

To investigate the evolution of κ-carbide in FeMnAl alloy, a phase-field model was proposed. In this presentation, we focus on the thermodynamics aspect of the model. In the model, the total free energy of the system (γ and κ) includes bulk energy, interfacial energy, and elastic energy. The interfacial energy and the elastic energy determine the morphology of κ-carbide and its orientation relationship with γ. The bulk energy has been modeled by several groups using the calculation of phase diagrams (CALPHAD) approach, which, however, are not able to predict the correct C concentration in κ-carbide phase due to the incomplete description of the octahedral interstitial sites (for C and vacancy). A 4-sublattice CALPHAD model is developed to describe the κ-carbide in FeMnAl alloy. The transformation from γ phase to κ-carbide can thus be considered as two consecutive ordering processes. The first one is the L_{12} ordering and the second is the ordering of C and vacancy.

This briefing is included as Appendix N.

2.2.5 Influence of Chemistry and Cleanliness on Notch Toughness of FeMnAl Castings

Laura Bartlett[1], Wint Watwood[1], Ron O'Malley[1], Krista Limmer[2], Dan Field[2], and Katie Sebeck[3]

[1] *Missouri University of Science and Technology*
[2] *ARL*
[3] *GVSC*

Lightweight FeMnAl castings have the potential to lower the density of critical components in ground vehicles without a sacrifice in performance. However, the chemistry and casting parameters must be strictly controlled to prevent a loss in

notch toughness. In the current study, the effects of Al, C, and Mn were studied to determine the effects on the microstructure and mechanical properties of FeMnAl castings. A novel mold design was developed to determine the effect of different gating systems on steel casting cleanliness and notch toughness. Results showed that increasing Al and decreasing C and Mn contributed to brittle ordered ferrite phases that greatly lowered toughness in both the solution-treated and aged conditions. Casting cleanliness also plays an important role on performance and castings with a higher percentage of oxide bi-films exhibited low notch toughness and premature fracture. Filters were shown to be more effective at removing solid oxide bi-films from the melt than naturally pressurized bottom fill gating systems.

This briefing is included as Appendix O.

2.2.6 Ballistic Performance of FeMnAl

Krista Limmer[1], Daniel Field[1], Katherine Sebeck[2], Katherine Vieau[2], and Alyssa Gafner[2]

[1] *ARL*
[2] *GVSC*

This briefing consists of three components. First, the ballistic performance of industrially produced FeMnAl plates from 0.5 to 2 inches in thickness against a range of armor-piercing (AP) and fragment-simulating projectiles (FSP) are discussed in terms of space and mass efficiency compared to Class 1 rolled homogeneous armor (RHA; MIL-DTL-12560K[4]). Second, AP and FSP performance of industrially produced and solution-treated FeMnAl plates that were aged in a laboratory setting to achieve a range of hardness–toughness combinations are discussed. Statistical analysis was used to correlate the aging process with the toughness, hardness, AP performance, and FSP performance. Third, the role of composition on performance is evaluated for a series of 0.5-inch-thick plates varying Mn, Al, and C targets.

This briefing is included as Appendix P.

2.2.7 FeMnAl Composition Evaluation for Corrosion Protection

Lindsey Blohm, Joseph Labukas, and Krista Limmer

ARL

FeMnAl, a ferrous alloy containing large amounts of Mn and Al, is under consideration for use in Army systems and is subsequently being investigated for corrosion performance. FeMnAl is being evaluated as an alternative for RHA. Work has been done to evaluate FeMnAl as a substrate in addition to having

pretreatments evaluated for flash rust resistance. Coating stack-ups, including pretreatments, were also evaluated and compared to RHA performance. There were no significant failures in any pretreatments or stack-ups considered in any initial testing.

An electrochemical investigation of 12 alternate FeMnAl compositions was performed in 0.1M H_2SO_4 electrolyte, showing only minor changes in the corrosion potential. Molybdenum was found to be the only alloying element to affect the corrosion potential. Mass loss testing in ASTM B117[5] was performed in addition to the electrochemical investigation along with an analysis of variance (ANOVA). In neutral sodium chloride solution, there was no major influence from individual elements. Additional work is ongoing to include primed FeMnAl and RHA samples with various pretreatments exposed to ASTM B117, exposed at Cape Canaveral Space Force Station, and ASTM GMW 14872.[6]

This briefing is CUI, and thus not included as a part of this report. Approved persons may review the detailed results in ARL-TR-9441.[7]

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Appendix A. A Review of the Army FeMnAl Program

This appendix appears as a PDF attached to the report.

Appendix B. Powder Development of FeMnAl Steel for Additive Manufacturing

This appendix appears as a PDF attached to the report.

Appendix C. Additive Manufacturing and Characterization of FeMnAlC Armor Steel

This appendix appears as a PDF attached to the report.

Appendix D. Additive Manufacturing (AM) of AM-Grade FeMnAl Powder Feedstock Gas Atomized in a Mobile Foundry from Recycled Scrap

This appendix appears as a PDF attached to the report.

Appendix E. Fusion Welding of FeMnAl Alloys

This appendix appears as a PDF attached to the report.

Appendix F. Varestraint and Hot Ductility Characterization of FeMnAl

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Appendix G. Welding FeMnAl with Conventional Armor Filler Materials

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Appendix H. Flattening and Machining Performance of FeMnAl Steel

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Appendix I. Machining of FeMnAl Steel

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Appendix J. Enhancing the Strength and Toughness of High-Strength Steels via Equal Channel Angular Pressing (ECAP)

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Appendix K. Composition Dependent Aging Kinetics in FeMnAl

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Appendix L. Grain Refinement and Mechanical Properties of FeMnAl Steels with Ni and Nb Additions

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Appendix M. Thermophysical Properties of Fe30Mn4Al0.9C: A Coupled Computational-Experimental Approach

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Appendix N. Phase-Field Modeling of κ-carbide in FeMnAl Alloy

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Appendix O. Influence of Chemistry and Cleanliness on Notch Toughness of FeMnAl Castings

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Appendix P. Ballistic Performance of FeMnAl

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List of Symbols, Abbreviations, and Acronyms

Al	aluminum
ALMII	American Lightweight Materials Manufacturing Innovation Institute
AM	additive manufacturing
ANOVA	analysis of variance
AP	armor piercing
ARL	Army Research Laboratory
AVPTA	Advanced Vehicle Power Technology Alliance
C	carbon
CALPHAD	calculation of phase diagrams
CT	computed tomography
DED	directed energy deposition
DEVCOM	US Army Combat Capabilities Development Command
DOD	Department of Defense
DOE	Department of Energy
DSC	differential scanning calorimetry
ECAP	equal channel angular processing
Fe	iron
FSP	fragment-simulating projectile
FeMnAl	high-Mn, high-Al, ferrous alloy
FY	fiscal year
GVSC	Ground Vehicle Systems Center
HAZ	heat-affected zone
LIFT	Lightweight Innovations for Tomorrow
Mn	manganese
Mo	molybdenum

MRL	Materials Resources LLC
Nb	niobium
Ni	nickel
PBF	powder bed fusion
RHA	rolled homogeneous armor

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