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**CRADA Final Report
for
CRADA Number ORNL 93-0202**

**USE OF Ni₃Al-BASED ALLOYS FOR
WALKING-BEAM FURNACES**

**V. K. Sikka
R. E. Dailey**

**Prepared by the Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831-6285
managed by**

**LOCKHEED MARTIN ENERGY SYSTEMS for the
U.S. DEPARTMENT OF ENERGY
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USE OF Ni_3Al -BASED ALLOYS FOR WALKING-BEAM FURNACES

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ABSTRACT

This report summarizes the joint work performed by the Oak Ridge National Laboratory (ORNL) and Rapid Technologies, Inc. (the CRADA partner) to determine the potential of Ni_3Al -based alloys for use in walking-beam furnace components. The report identifies tasks to be performed as part of the CRADA and the organization responsible for each task. The work required under each task was completed and is described. The CRADA accomplished the primary goal of utilizing cast Ni_3Al -based alloy as rails and other components for walking-beam furnaces manufactured by Rapid Technologies. Rapid Technologies, a small business, is implementing on a commercial basis a highly energy efficient rapid-heating technology for use in the metals manufacturing industry. The rapid heating process allows energy savings of up to 95%.

Although goals of all of the tasks of this CRADA were met, there is still a need for a material to work in the rapid heating furnaces at temperatures in the range of 1350 to 1400°C. Future effort should be focused in fulfilling this need.

PURPOSE AND BACKGROUND

The purpose of this Cooperative Research and Development Agreement (CRADA) between Lockheed Martin Energy Systems (LMES) [formerly Martin Marietta Energy Systems, Inc.] (contractor) and Rapid Technologies, Inc. is to further advance the Ni_3Al -based alloy technology in support of manufacturing walking-beam furnace components. The gas-fired walking-beam furnaces developed by Rapid Technologies need materials with: (1) a high melting point, (2) excellent oxidation resistance, (3) carburization resistance, (4) high-temperature strength, and (5) ease of castability. Initial trials with Ni_3Al -based alloys indicate that these alloys perform better than mechanically alloyed material that is currently in use. The Ni_3Al -based alloys also have the added advantage of being castable to net shape and are significantly lower in cost than the mechanically alloyed material. However, the application of Ni_3Al -based alloys on a commercial scale requires additional information in the areas relating to casting practices, chemical analysis, mechanical properties, machinability, and recyclability. The component design, field testing, and procurement of the material by Rapid Technologies and extensive background on Ni_3Al -based alloys at the Oak Ridge National Laboratory (ORNL) provided a unique collaborative opportunity for addressing the program objectives in a thorough and timely fashion. The work consisted of seven distinctive major activities with the following goals:

1. Identification of needs and development of component drawings to determine the casting process.
2. Identification of Ni_3Al -based alloy compositions to cast components of desired properties.
3. Casting of test components to obtain the operating experience.

4. Chemical analysis standards for being able to cast the parts reproducibly.
5. Weldability to develop steps for weld repairing of beam components.
6. Recyclability to determine if scrap can be used in commercial production to help reduce material cost.
7. Machinability to develop procedures for rapid machining under commercial manufacturing conditions.

SCOPE OF WORK

In order to achieve the goals listed above, work was carried out under seven tasks. Each of these tasks is described below with the specific work carried out and accomplishments.

TASK 1: IDENTIFY NEEDS AND DEVELOP COMPONENT DRAWINGS

This task was to be carried out by Rapid Technologies and included identifying the operating temperatures, furnace environments, and component drawings. The component design was to be used in identifying the casting, welding, and machining needs.

Consistent with the task requirements, Rapid Technologies identified that walking-beam furnaces operate with furnace internal parts operating at room temperature on the loading end to approximately 1500°C on the exit, also known as the burner end. In most cases, the furnace operates with air as the atmosphere. Some carburizing conditions may arise from the combustion products due to the use of natural gas as fuel.

Since the furnace temperature varied from room temperature to approximately 1500°C, materials need for furnace components also varied. The higher temperatures exceeding 1000°C existed for the 36 to 50 in. of the furnace on the exit or burner end. The high temperatures and the furnace environment, which is oxidizing or slightly carburizing, resulted in the following failure modes in walking-beam furnace components:

1. Melting of components located 8 to 12 in. from the burners,
2. Distortion of the components from lack of high-temperature strength and from thermal gradients,
3. Oxidation of components,
4. Carburization of components, and
5. Brittle failures in ceramic components that were tried for components close to the burners.

Figure 1 shows a typical walking-beam furnace. The burner end of the furnace and the heated parts are visible from the photograph. A close-up of the inside of the furnace is shown in Fig. 2, and the components needed from the nickel-aluminide alloy are shown in Fig. 3.

Fig. 1. Typical walking-beam furnace at Rapid Technologies, Inc. (Newnan, Georgia).

Fig. 2. Close-up of the inside of the walking-beam furnace at Rapid Technologies, Inc. (Newnan, Georgia).

Fig. 3. Components made from nickel aluminide, some of which were cast by Cast Masters (Bowling Green, Ohio).

The rapid-heating walking-beam furnace developed and marketed by Rapid Technologies uses convection heating, which minimizes the heat directed into the large furnace chambers and refractory walls. Rapid Technologies' rapid-heating furnace offers the following benefits:

1. High efficiency — up to 75% savings have been achieved;
2. Quick start-up — work piece is heated within minutes;
3. Flexibility — furnace can be turned off during nonproductive periods;
4. Improved working environment — this results in higher output;
5. Improved product quality — because of short heating times, scale formation and decarburization are minimal;
6. Consistent stock temperature — this is provided by controlling temperature of the part and not the furnace;
7. Reduced maintenance — costs for maintenance have proven to be lower;

8. Increased productivity — rapid heating is ideally suited for automation;
9. Lower capital costs — typically substantially less than electric systems; and
10. Environmentally clean — since less energy is released, the furnace provides environmentally friendly operation.

Rapid-heating technology is applicable in a number of industries including: forging, rolling, mining, automotive, spring manufacturing, agricultural, railway, and nonferrous extrusions.

The advantages of rapid heating can only be achieved if long life can be assured for furnace components (see Fig. 3) operating close to the burner end.

Rapid Technologies developed detailed drawings for components identified in Fig. 3. These drawings were used for the fabrication of the patterns used during the casting of components made from nickel aluminide. With the capability of being able to cast net shapes, only the cutting of runners and risers was required for most components. The pins were the only components that required machining the bar stock to the final dimensions.

The design of the furnace required no welding for components. However, some weld repair of the castings was identified for cosmetic reasons.

TASK 2: IDENTIFY THE Ni_3Al -BASED ALLOY COMPOSITIONS

This task was to be carried out at ORNL. The physical and mechanical properties of the Ni_3Al -based alloys were also to be provided by ORNL to Rapid Technologies and its casting vendor(s).

Based on the identification of issues with components in the walking-beam furnaces, nickel aluminides were suggested as the possible candidate materials. The composition of the candidate alloys are given in Table 1. Since most of the components for Rapid Technologies, Inc. were expected to be cast, the two castable compositions (IC-396M and IC-221M) were suggested. In addition to compositions, physical properties of Ni_3Al -based alloys were provided (see Tables 2 through 4). The comparative plot of thermal conductivity, oxidation, carburization, and mechanical properties of nickel-aluminide alloys were also prepared (see Figs. 4 through 11). These figures clearly demonstrate the superior oxidation resistance and high-temperature strength of Ni_3Al -based alloys. The same or similar data were also shared with the casting vendor(s) as required.

TASK 3: CASTING AND TESTING OF BEAM COMPONENTS

This task was to be carried out by both Rapid Technologies and ORNL. ORNL was to identify foundries for casting of components, train foundry employees on casting of Ni_3Al -based alloys, help prepare a list of recommendations for commercial manufacturing, and evaluate components for quality. Rapid Technologies was to place purchase orders with the foundries, pay for all of the components, and test components in their furnaces operating in the field. The operating data were to be shared with ORNL along with the receipt of some exposed components for post-service examination.

Table 1. The Ni₃Al-based alloy compositions selected for commercial applications

Element	Alloy (wt %)			
	IC-50 ^a	IC-218LZr ^b	IC-396M ^c	IC-221M ^d
Al	11.3	8.7	7.98	8.0
Cr	--	8.1	7.72	7.7
Mo	--	--	3.02	1.43
Zr	0.6	0.2	0.85	1.7
B	0.02	0.02	0.005	0.008
Ni	88.08	83.1	80.42	81.1

^aCold workable.

^bHot and cold workable.

^cCastable alloy for static applications (some microporosity).

^dCastable alloy for dynamic applications (no harmful microporosity).

Four foundries were identified to cast the components for Rapid Technologies. The casters identified and the outcome from each of the collaborations are described below:

1. Cast Masters, Bowling Green, Ohio

This is a small casting foundry located in Bowling Green, Ohio. They were identified as the possible source because they were the company licensed by ORNL for nickel-aluminide castings. Immediately after introduction of Cast Masters, Rapid Technologies provided the drawings of their components to be cast and placed purchase orders. Cast Masters did prepare some prototypes but could not produce parts on time without slag entrapment. Some of the prototype castings prepared by Cast Masters are shown in Fig. 3.

2. Alloy Engineering & Casting Company, Champaign, Illinois

Alloy Engineering & Casting was the next casting foundry recommended to Rapid Technologies because of the experience they had gained through the casting of prototype nickel-aluminide components for General Motors-Saginaw Division. Rapid Technologies visited Alloy Engineering, but no business relations developed because of quoted prices and delivery times.

Table 2. Smoothed physical property values for Ni-24 and 25 at. % Al

Temperature (K)	Ni _{0.75} Al _{0.25}				Ni _{0.76} Al _{0.24}			
	Electrical resistivity (10 ⁻⁸ Ωm)	Thermal conductivity (W/m•K)	Absolute Seebeck coefficient (μV/K)	Thermal expansion coefficient ^a (10 ⁻⁶ K ⁻¹)	Electrical resistivity (10 ⁻⁸ Ωm)	Thermal conductivity (W/m•K)	Absolute Seebeck coefficient (μV/K)	Thermal expansion coefficient ^a (10 ⁻⁶ K ⁻¹)
4.2	1.54	---	---	---	9.05	---	---	---
300	32.59	28.85	+5.4	12.5	51.3	21.37	+9.9	12.5
400	39.00	33.72	+4.1	13.0	58.89	24.21	+10.8	13.2
500	44.75	35.13	+1.8	13.5	64.17	26.35	+7.9	13.8
600	50.13	36.18	-0.4	14.0	68.60	28.30	+5.1	14.3
700	55.27	37.07	-2.4	14.6	72.60	30.14	+2.3	14.8
800	60.54	37.27	-4.3	15.2	76.52	31.82	-0.4	15.4
900	66.50	36.86	-5.5	16.0	80.41	33.13	-2.8	16.1
1000	73.02	36.12	-6.3	16.8	84.24	32.70	-4.8	16.8

^a(1/L₃₀₀)dL/dT.

Table 3. Mean coefficient of expansion of nickel aluminide (ppm/°C)

Temperature (°C)	IC-221M
100	12.77
200	13.08
300	13.40
400	13.72
500	14.01
600	14.33
700	14.72
800	15.17
900	15.78
1000	16.57

Table 4. Young's modulus data for Ni₃Al-based nickel-aluminide alloys

Temperature (°C)	Young's modulus, E (GPa)		
	Alloy		
	IC-50	IC-218LZr	IC-221M
20	203.5	225.0	200.0
150	198.0	223.0	195.0
300	---	218.0	184.0
500	178.0	206.5	163.0
700	162.5	193.5	157.0
900	136.0	---	139.0
1100	127.0	170.0	114.0

Fig. 4. Comparison of thermal expansion of castable Ni_3Al alloy IC-221M with austable nickel-based alloy IN-713C.

Fig. 5. Comparison of oxidation resistance of Ni_3Al -based alloys with Alloy 800. All three IC alloys fall in the same line. (Data were developed at The International Nickel Company, New York, New York.)

Fig. 6. Comparison of carburization resistance of Ni₃Al-based alloys with Alloy 800 in a reducing environment. (Data were developed at The International Nickel Company, New York, New York.)

Fig. 7. Comparison of carburization resistance of Ni₃Al-based alloys with Alloy 800 in an oxidizing environment. (Data were developed at The International Nickel Company, New York, New York.)

Fig. 8. Comparison of 0.2% yield strength of cast Ni₃Al-based alloys with cast HU alloy.

Fig. 9. Comparison of ultimate tensile strength of cast Ni₃Al-based alloys with cast HU alloy.

Fig. 10. Comparison of total elongation of cast Ni₃Al-based alloys with cast HU alloy.

Fig. 11. Comparison of creep rupture strength of cast Ni₃Al-based alloys with commercially used HU materials.

3. The BIMAC Corporation, Dayton, Ohio

The BIMAC Corporation was the next foundry introduced to Rapid Technologies because of their previous experience in casting of nickel aluminides. BIMAC was visited jointly by personnel from ORNL and Rapid Technologies. They agreed to make the castings, and both price and deliveries were reasonable considering the quantities requested. BIMAC produced several parts for use in walking-beam furnaces by Rapid Technologies.

ORNL trained BIMAC with the newly developed and highly economical melting process for nickel aluminides known as the Exo-Melt™ process. The Exo-Melt™ process offers several advantages over the conventional melting process (see Table 5). The letter acknowledging the benefits of the Exo-Melt™ process by BIMAC is shown in Fig. 12. An example of a walking-beam furnace rail cast by BIMAC is shown in Fig. 13.

4. United Defense, Anniston, Alabama

In an effort to expand the suppliers and create competitive pricing, United Defense is the latest foundry introduced by ORNL to Rapid Technologies. United Defense has already demonstrated the capability of melting and casting components needed for Rapid Technologies. Some of the components cast at United Defense for Rapid Technologies are shown in Fig. 14. Initial information suggests that United Defense's pricing for nickel aluminide will be reasonable. Rapid Technologies currently has a purchase order with United Defense for a variety of different parts.

United Defense is also currently negotiating with ORNL for a license to melt and cast nickel aluminides for Rapid Technologies and others. They will be the first foundry to have a direct license from ORNL to produce cast components of nickel aluminides.

TASK 4: CHEMICAL ANALYSIS STANDARDS FOR BEING ABLE TO CAST THE PARTS REPRODUCIBLY

This task was carried out by ORNL. In order to assure the castings of high-quality and reproducible composition, it was necessary to assist the casting foundry with developing chemical analysis standards. Aluminum and zirconium were considered the key elements that needed control, and for which the BIMAC foundry had no standards. Five 1-lb alloy heats made up of the compositions in Table 6 were made by the nonconsumable-arc process and sent to BIMAC. A sample of IC-396M cast by Cast Masters and its complete chemical analysis (see Table 7) were also sent to BIMAC. The availability of standards and complete analysis helped BIMAC check the analysis of each heat prior to its pouring.

TASK 5: WELDABILITY TO DEVELOP STEPS FOR WELD REPAIR OF BEAM COMPONENTS

This task was carried out jointly by ORNL and Rapid Technologies. Mr. Dennis Swaney and Dr. Michael Santella of ORNL's welding group went to Rapid Technologies on February 15, 1995, to train their welders on welding and weld repair of castings. As part of the training visit, ORNL provided the 1/16-in.-diam weld wire of alloy IC-221LA, which was purchased from Ametek. Rapid Technologies' welders were trained in gas tungsten arc welding of nickel-aluminide rails. Typical weld repair was for cracks that resulted from shrinkage during solidification. Although all of the rails that required

Table 5. Advantages of the Exo-Melt™ process over the conventional and modified conventional melting processes

Features	Process		
	Conventional	Modified conventional	Exo-Melt™
Practical aspects	Bath temperature is overshoot from the exothermic reaction when aluminum is added to molten nickel alloy. Temperature increase/ overshoot oxidizes alloying elements, affects crucible life, and delays the overall process because the melt has to set and cool.	Large difference in melting point of aluminum and nickel. The aluminum is expected to melt very early in the process and may seep through the cracks to the furnace coil and cause damage.	A very practical method. Easy to load the furnace with all elements. The exotherm generates the maximum heat, which is shared with the solid and, thus, the heat is used for increasing the solid temperature. No temperature overshoot occurs, and melting takes place in a much shorter time.
Time to melt	Unit time	Three-fourths to seven-eighths of conventional time	One-half of conventional unit time
Power	Unit power (5.5 kW h)	Three-fourths to seven-eighths of conventional time	One-half to two-thirds of conventional power requirement (2.92 kW h)
Safety	Temperature overshooting causes erosion of ceramic crucible, and can cause unexpected attack on induction coils by seeping through eroded area.	Melting point difference can cause aluminum seeping through furnace refractory cracks and attack the induction coil with potentially explosive results.	Avoids any potential safety issues

Table 5. Continued

Features	Process		
	Conventional	Modified conventional	Exo-Melt™
Cost	Melting cost is high because the exotherm is not used effectively. The oxidation of alloying elements can require either adding more of them or a large rejection rate resulting from poor repeatability.	The exotherm is not used effectively. Random loading will result in poor reproducibility of chemistry.	Effective use of exotherm and chemistry control result in saving nearly one-half the cost of the conventional method.
	Unit cost	Three-fourths to seven-eighths the cost of the conventional method	One-half the cost of the conventional method
Composition control	Addition of aluminum to molten nickel causes the bath temperature to increase by 500 to 700°C. Such a temperature rise oxidizes the important elements such as boron, zirconium, chromium, and aluminum. Bath chemistry is missed, and oxide inclusions are mixed in with the alloy.	Random loading may cause pockets of exotherm and oxidize some of the alloying element. Final results are not always reproducible.	Effective use of the exotherm prevents overheating and, thus, chemistry is reproducible every time.
	Poor	Slightly better chance than the conventional method	Excellent

Table 5. Continued

Features	Process		
	Conventional	Modified conventional	Exo-Melt™
Oxide inclusion formation	Overheating of bath causes excessive inclusion formation.	Pockets of overheating causes inclusion formation but slightly less than conventional method.	No excessive heating. Much less oxidation than conventional method.
Bath temperature control	No control	Random control	Real control
Crucible life	The temperature overshoot by 500 to 700°C above the melting point of nickel causes excessive erosion of the crucible.	Random overshoot causes excessive wear.	Uniform wear
	Excessive wear	Nonreproducible wear	Normal wear
Vacuum melting	Difficult to add aluminum	Possible with random output	Possible with reproducible results
Commercial	Because of poor results, commercial melters are not interested.	Potential seeping of aluminum makes commercial melters reluctant.	Many commercial vendors can easily use the process.

THE **BIMAC** CORPORATION, 3034 Dryden Rd., Dayton, Ohio 45439-1697
513-299-7333 FAX: 513-299-7367
PRECISION CASTINGS
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February 2, 1995

Vinod K Sikka, Ph.D.
Martin Marietta Energy Systems, Inc.
P.O. Box 2008, Bldg. 4508
Oak Ridge, Tn. 37831-6083

Dear Dr. Sikka:

Bimac has been using your exomelt process for approximately 12 months in the melting of nickel aluminide. The process allows us to load the aluminum up front and as a result we have experienced dramatic improvements in controlling material chemistries and casting integrity. The process has proven to prevent problems that we previously experienced in melting this alloy.

We appreciate your direct assistance in improving our melting practice and the sharing of the exothermic effect technology.

We look forward to working with you on future projects and technology advancements.

Respectfully,

Roger D. Reedy
President

Fig. 12. Benefits of the Exo-Melt™ process for melting and casting the Ni₃Al-based alloy acknowledged by The BIMAC Corporation (Dayton, Ohio).

Fig. 13. Walking-beam furnace rails of Ni_3Al -based IC-221M alloy cast by The BIMAC Corporation (Dayton, Ohio). The front portions are IC-221M, and the small attached segments are Fe_3Al -based alloy FA-129.

Fig. 14. Walking-beam furnace parts of Ni_3Al -based IC-221M alloy cast for Rapid Technologies Inc. by United Defense (Anniston, Alabama).

Table 6. Composition of alloys prepared by nonconsumable-arc melting for developing chemistry standards at BIMAC for Rapid Technologies

Element	Heat (wt %)					
	15648	15649	15650	15651	15652	15653
Ni	82.095	81.095	80.095	87.94	80.895	80.695
Al	7	8	9	11.45	8	8
Cr	7.7	7.7	7.7	--	7.7	7.7
Mo	3	3	3	--	3	3
Zr	0.2	0.2	0.2	0.6	0.4	0.6
B	0.005	0.005	0.005	0.02	0.005	0.005

Table 7. Detailed chemical analysis of a sample taken from IC-396M heat made by Cast Masters for Rapid Technologies^a

Analysis		
Element	Target	Check
B	0.005	--
C	--	0.024
S	--	0.001
Si	--	0.08
Ni	80.42	79.5
Cr	7.72	7.80
Mo	3.02	2.82
V	--	<0.01
Cb	--	<0.01
Ti	--	0.02
Co	--	0.01
Al	7.98	8.11
Zr	0.85	0.65
Fe	--	0.61
N ₂	--	0.069
O ₂	--	0.12

^aThis analysis was also used in support of developing chemical standards for use at BIMAC.

repair were repaired, the recommendation was made that the alloy for rails be changed from IC-396M to IC-221M for improved weld repairability and welding. The recent rails cast by United Defense have been from alloy IC-221M. They did not require any weld repair, however, if they did, it would be easier to do it.

TASK 6: RECYCLABILITY TO DETERMINE IF SCRAP CAN BE USED IN COMMERCIAL PRODUCTION TO HELP REDUCE MATERIAL COST

This task was to be carried out by ORNL. It involved addressing the issues of: (1) Can the runners, risers, and other scrap from the manufacturing processes be used as remelt stock?; (2) Can service-exposed components be used as remelt stock?; and (3) Can the scrap of another commercially available nickel-base alloy be used as melt stock? The answer of yes to all of the above issues will result in lowering the cost of the Ni₃Al-based alloy for commercial applications.

The first issue of the possibility of being able to use runners and risers was demonstrated by melts made at United Defense. The demonstration process consisted of melting two 1500-lb heats by air-induction melting. In both of the heats, two-thirds of the melting stock consisted of runners, risers, and castings that for one reason or another were rejected. The remaining one-third of the melt stock was virgin material. The melt step consisted of loading nearly half of the runner and riser melt stock at the furnace bottom, and the virgin stock was stacked on top to use the features of the Exo-Melt™ process. At the start of formation of the molten metal, the remainder of the melt stock was added in steps to avoid the complete chilling of the molten metal. After all of the remelt stock dissolved in the molten metal, the furnace temperature was brought to the desired pouring temperature and several cast shapes were poured. The chemical analysis of the heats in Table 8 show that remelting of runners and risers is quite acceptable.

In order to address the issue of recycling service-exposed components, one of the rails from a walking-beam furnace was utilized. The rail was sand blasted to remove any loose debris and cut up into pieces for remelting in the 15-lb furnace at ORNL. One heat was prepared by remelting 100% of the rail, while the second heat was prepared using half of the rail and half of the virgin stock to utilize the Exo-Melt™ process. Both melts were cast into 1-in.-thick plates, and the samples were checked for chemical analysis (see Table 9). Data in Table 9 show that even when recycled, the oxygen and nitrogen content of the nickel aluminide is very low. However, elements that go into the alloy at the start of the melt are still retained. These include elements such as iron and copper. The use of remelted parts, when mixed with the virgin stock, can result in dilution of such elements (see Table 9).

TASK 7: MACHINABILITY TO DEVELOP PROCEDURES FOR RAPID MACHINING UNDER COMMERCIAL MANUFACTURING CONDITIONS

This task was to be carried out primarily by ORNL and the results to be confirmed by Rapid Technologies. In most of the cases, Rapid Technologies' applications of Ni₃Al-based alloys required only the cast net-shape components. The only machining required during the production of net-shape castings was the cutting of runners and risers and the preparation of areas that may require weld repair. Abrasive cutting was clearly the method confirmed for cutting the runners and risers. Grinding was the operation recommended for the preparation of areas for the weld repair.

Table 8. Chemical analysis of nickel-aluminide alloy heats prepared by using remelt stock from runners and risers^a

Element	Weight percent	
	Remelt No. 1 (Heat 18751-P)	Remelt No. 2 (Heat 18752-P)
C	0.013	0.014
S	0.001	0.001
Si	0.04	0.06
Ni	<i>b</i>	<i>b</i>
Cr	7.53	7.23
Mo	1.40	1.29
V	<0.01	<0.01
Cb	<0.01	<0.01
Ti	<0.01	<0.01
Co	<0.01	<0.01
Al	7.81	7.04
B	0.009	0.009
Zr	1.49	1.49
Fe	0.20	0.21
N ₂	0.008	0.011
O ₂	0.002	0.001

^aHeats were melted at United Defense in Anniston, Alabama.

^bBalance.

Regarding machining, Y-12 Plant in Oak Ridge, Tennessee, conducted several trials of cutting speeds, depth of cut, and cutting tool, and concluded that Ni₃Al-based alloys are hard to machine. However, the machining can be accomplished by using small depths of cut and slow speeds. The cutting tool varied from tungsten carbide to toughened ceramic. Machining is an area that needs additional work. However, for the Rapid Technologies CRADA, there was neither sufficient funding to pursue the work nor a strong need.

FUTURE PLANS

Rapid Technologies continues to have a very strong interest in expanding the applications of Ni₃Al-based alloys in a broad range of furnace applications. In order to meet their need for obtaining the castings, United Defense, a casting house, has been licensed from ORNL to cast their required components. Rapid Technologies still has a need for a material that would perform in the walking-beam furnace at surface temperature exceeding 1350 to 1400°C. This use temperature exceeds by at least 200°C, the upper use temperature possible with Ni₃Al-based alloys. A new CRADA or other working arrangement needs to be developed in order to address the materials issues related to the higher temperature need.

Table 9. Chemical analysis of nickel aluminide melted and cast by using used furnace rail and rail material mixed with virgin stock

Element	Weight percent	
	Remelt of used rail ^a	Remelt of used rail with 50% virgin stock ^b
C	0.031	0.019
Mn	0.14	0.07
S	0.039	0.020
Si	0.23	0.11
Ni	^c	^c
Cr	7.60	7.60
Mo	3.17	1.50
V	<0.01	<0.01
Cb	<0.01	<0.01
Ti	0.10	0.05
Co	0.02	0.01
Cu	1.49	0.72
Al	6.92	7.46
B	0.005	0.008
Zr	0.60	1.32
Fe	2.27	1.08
N ₂	0.010	0.011
O ₂	0.002	0.004

^aThe starting rail was IC-396M composition.

^bThe rail of IC-396M was mixed with virgin stock to reach a target composition of IC-221M.

^cBalance.

CONCLUSIONS

This CRADA accomplished the primary goal of utilizing cast Ni₃Al-based alloys as rails and other components for walking-beam furnaces manufactured by Rapid Technologies. The goals of all seven tasks were met. Rapid Technologies contributed in-kind support beyond the requirements of this CRADA. The use of Ni₃Al-based alloys helped Rapid Technologies, a small business, in the following areas:

1. A highly energy efficient rapid heating technology was implemented to the metals manufacturing industry. The rapid heating process allows energy savings up to 95%.

2. Beyond energy savings, the implementation of rapid heating furnaces also provide other benefits including: (a) quick start-ups, (b) flexibility - furnace can be turned off during nonproductive periods, (c) improved working environment, (d) improved product quality through reduced scale formation, (e) consistent stock temperature through controlling temperature of each part, (f) reduced maintenance, (g) lower capital costs, and (h) cleaner environment since less energy is used.
3. The CRADA has also illustrated a way to make heat-treating companies in the United States more competitive in the World market through the use of rapid heating furnaces.
4. The industrial partner was satisfied with the outcome of the CRADA and is willing to develop similar fixture programs for further improvements in material performance at temperatures in the range of 1350 to 1400°C.

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