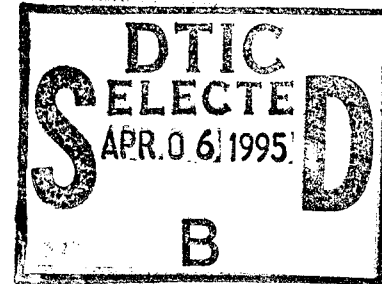


# AOARD REPORT

Materials and Processing Research Center, NKK Research and Development Division, Kawasaki, 11 May 94

May 11, 1994  
P. McQuay  
AOARD



This report summarizes a recent trip to NKK's Materials and Processing Research Center in Kawasaki, Japan, in order to discuss their activities in R&D of advanced materials. Emphasis was placed on three general areas: SP-700, a promising new superplastically formable Ti alloy with an attractive balance of properties and formability; a new titanium aluminide alloy for aerospace and automotive applications with a dramatically improved balance of room temperature strength and ductility, and process/product development efforts for automotive applications; process development and production of a magnetic steel sheet alloy, with 6.5% Si, a dramatic increase in Si over conventional Si sheet alloys, which in turn leads to improved electromagnetic properties. The high Si sheet steel is produced using a novel CVD reaction and diffusion process on a commercial scale.

DISTRIBUTION STATEMENT A:

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED.

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

ASIAN OFFICE OF AEROSPACE RESEARCH AND DEVELOPMENT

TOKYO, JAPAN  
UNIT 45002  
APO AP 96337-0007  
DSN: (315)229-3212  
Comm: 81-3-5410-4409

19950322 113

27 July 1994

AOARD Trip Report

FROM: Capt Paul McQuay  
 AFOSR/AOARD  
 US Address: Unit 45002, APO AP 96337-0007  
 Int'l Address: 7-23-17 Roppongi, Minato-ku, Tokyo 106, Japan  
 Tel/Fax: +81 (3) 5410-4409/4407  
 email: mcquayp@emh.yokota.af.mil

SUBJECT: Trip Report - Materials and Processing Research Center, NKK Research and Development Division, Kawasaki, 11 May 94

1. ABSTRACT

This report summarizes a recent trip to NKK's Materials and Processing Research Center in Kawasaki, Japan, in order to discuss their activities in R&D of advanced materials. Emphasis was placed on three general areas: SP-700, a promising new superplastically formable Ti alloy with an attractive balance of properties and formability; a new titanium aluminide alloy for aerospace and automotive applications with a dramatically improved balance of room temperature strength and ductility, and process/product development efforts for automotive applications; process development and production of a magnetic steel sheet alloy, with 6.5% Si, a dramatic increase in Si over conventional Si sheet alloys, which in turn leads to improved electromagnetic properties. The high Si sheet steel is produced using a novel CVD reaction and diffusion process on a commercial scale.

2. OVERVIEW AND BACKGROUND

NKK is the second largest steel producer in Japan, behind Nippon Steel (see TR-94-16). NKK's gross sales are approximately 80% from its primary steel business, and approximately 20% from industrial machinery and engineering services. Like other major steel producers, NKK also is actively moving into new diversified markets such as Ti and Al alloys, semiconductor materials and devices, and resort parks, although these other activities are still a small fraction of corporate sales.

NKK boasts one of the most efficient and modern steel making works in the world, the Keihin Works. The iron and steel making facilities were recently built or relocated to a 1,360 acre manmade island, Ohgishima, between Tokyo and Yokohama in Tokyo Bay.

Like many Japanese industries in the 1990's, NKK is feeling the combined fiscal pinch of a global recession and strengthening yen. Additionally, NKK invested heavily in facilities, equipment, and island building in the late 70's and 80's, and now is overcapitalized and has a reportedly high debt load. Because of these fiscal pressures, NKK has had several years of downsizing and reorganization, which has produced a large reduction in R&D and capital investments, which has not occurred for many decades.

As of July 1992, the R&D Division employed approximately 1,400 people, approximately half of which are scientists and engineers. Like many Japanese companies, the ratio of PhD's to BS and MS degree holders is very small.

The Research and Development Division of NKK includes four research centers, Applied Technology, Materials and Processing, Engineering, and Electronics Research Centers.

Availability Codes	
Dist	Avail and/or Special
A-1	

The remainder of this report summarizes a visit by Dr. Shiro Fujishiro, Director of AOARD, and myself to the Materials Processing and Research Center.

### 3. MATERIALS PROCESSING AND RESEARCH CENTER, KAWASAKI, 11 MAY 94

This visit was arranged as a follow up visit following the Titanium Assessment Activity carried out in Dec 93 (see AOARD TR-94-15). My primary hosts at the laboratory were: Mr. Atsushi Ogawa, Metallurgist, and:

Dr. Chiaki Ouchi, General Manager  
Materials and Processing Research Center  
Materials Research Dept.  
NKK Corp.  
1-1, Minamiwatarida-cho  
Kawasaki-ku, Kawasaki 210  
Japan  
Tel: +81 (44) 322-6047; Fax: +81 (44) 322-6514

The morning discussions centered around research and development activities of gamma titanium aluminide (TiAl) alloys. The effort at NKK, due to cutbacks in research is now limited to around one person year of effort. Most of the effort is now carried on by Mr. Shinichi Takagi, a metallurgist in the Al and Ti Lab.

Similar to other research conducted at NKK on Ti alloys, the thrust of the TiAl research appears to be on alloy and process development. In particular, NKK has been interested in finding a ternary alloying element which would concomitantly improve both room temperature strength and ductility. As with almost all metallurgical systems, effective solid solution or interstitial strengthening elements almost always lead to a decrease in the tensile ductility, which to date has been the case with gamma TiAl.

NKK reported that they had discovered a ternary transition metal addition which dramatically improves the strength and ductility at room temperature of a moderate grained cast duplex microstructure. In order to protect their discovery, NKK has reportedly filed for a patent. The room temperature tensile properties for this new alloy are in the range of 75 ksi yield strength, and plastic strain at failure above 4%. This is a rather dramatic improvement in tensile properties for a cast gamma alloy.

In general, most of the work over the last several years on TiAl has been several processing and demonstration studies for cast automotive applications. One program was to produce cast TiAl turbocharger rotors, for a US superalloy turbocharger producer. Another program was to produce cast automotive exhaust valves for one of Japanese large automotive corporations.

Both programs were reportedly a technical success, producing good parts with more than acceptable properties. Reportedly, the turbocharger application is unlikely, not because the gamma parts are inferior to the ceramic parts, or that they are more expensive, but because the capital investment and commitment which has already been made by several Japanese corporations on the monolithic ceramic silicon nitride rotors. The application of gamma valves continues to be stalled by a lack of a strong technology driver (i.e. more stringent fuel economy standards or requirements) and cost. Dr. Ouchi explained that the cost issues with gamma valves are not raw material costs, but processing costs (i.e., process efficiency, machinability, etc.).

In the afternoon we were given a tour of their new processing line for 6.5% Si steel sheet for electromagnetic applications, called by its trade name of NK Super E Core. The primary application of the sheet is for high-frequency transformers, where it offers higher efficiency, smaller size and weight, and reduced noise. The project was scaled up from a laboratory process no more than two years ago, and is now in production as a commercial product, with a current production capacity for 100 metric tons/month of 0.1-0.3 mm gage sheet, of 400 - 600 mm in width. The final coil size is approximately 2.5 metric tons per coil. The factory was planned and built to accommodate an additional processing line, if the market warrants it.

The engineering feat in the production of the NK Super E Core sheet is the use of CVD processing on a commercial scale. Increasing the Si content of steel sheet above the industry standard of 3% Si has always been limited by the brittleness of higher Si alloys, which has not allowed for the production of sheet economically.

The process begins with standard 3% Si steel sheet (Atch 1), already rolled to a thickness of 0.1 - 0.3 mm. Using a shear and welder at the beginning of the production line, the sheet production is a quasi-continuous process. The sheet comes off of the roll, is cleaned, heated in an inert nitrogen furnace, and then proceeds directly into the CVD furnace, where the sheet is reacted with a partial pressure of  $\text{SiCl}_4$  gas at between 700 and 800°C (Atch 2). The reaction products of the process are a surface layer of  $\text{Fe}_3\text{Si}$  on the sheet, and gaseous  $\text{FeCl}_2$ . The sheet is then passes directly into an annealing furnace, where the Si from the surface layer of  $\text{Fe}_3\text{Si}$  diffuses into the sheet until a uniform 6.5% Si sheet is produced (Atch 3). The surface of the finished sheet requires no additional machining - only a ceramic coating which is commonly used on Si steel sheet alloys is applied. The magnetic properties of the sheet steel are summarized in attachment 4.

Finally, a brief review was given of NKK's new superplastically formable alpha-beta alloys, SP 700. The alloy has superior superplastic behavior at temperatures as low as 775°C, which is more than 100°C lower than for the industry standard, Ti-6Al-4V. SP 700 is also superior in its cold and warm workability compared to conventional Ti alloys in such metal working operations as drawing, stamping and forging. The NKK alloy also has better hardenability characteristics, compared with Ti-6Al-4V. A paper summarizing the mechanical and processing behavior of the alloy is given in attachment 5.

NKK has succeeded in marketing the alloy for several non-aerospace applications, such as watch cases, sporting equipment, and hand tools. The formability of the alloy, and its good combination of mechanical properties should also make it a good candidate for future aerospace applications. NKK has reportedly been making material available to several US Aerospace companies for testing and evaluation.

#### 4. SUMMARY AND COMMENTS

Like other major Japanese Steel producers, NKK is attempting to diversify its products beyond conventional steel production. Of the three materials or products reviewed, the 6.5% Si sheet alloy is definitely the most mature and successful. NKK's production of high Si steel sheet is not only important in and of itself, but offers a unique and innovative process for producing normally brittle materials into sheet products, at an efficient, affordable commercial scale.

SP 700 shows excellent prospects as a lower cost, more workable Ti alloy, with a good balance of properties. However, it must overcome a very conservative aerospace community, which apparently has a very low tolerance for new alloys .

NKK's research on gamma TiAl alloys has been somewhat successful in their casting development for automotive parts, and in identifying an alloy with improved strength and ductility. However, a clear market driver for these new materials in the automotive industry has yet to emerge, due to their higher cost compared with conventional materials, such as steel.