Marine Aluminum Plate - ASTM Standard Specification B 928 And The Events Leading To Its Adoption.

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ABSTRACT

During the winter of 2001-2 over 200 aluminum vessels, ranging from four to forty four meters in length were diagnosed as having been built with 5083-H321 temper aluminum plate that was susceptible to intergranular corrosion. This resulted both severe pitting and extensive stress corrosion cracking. Many of the vessels involved will require new hulls and superstructures. This paper traces the discovery of the problem, the forensic process, and the short term aluminum purchase specifications used during the start of the repairs. It also introduces the new ASTM B 928 Standard Specification for High Magnesium Marine Aluminum Alloy Sheet and Plate for Marine Service and discusses the ramifications for the shipbuilding industry.

Harold Bushfield is the current chair of the ASTM B07.03 committee that wrote the new B 928 standard. Marc Cruder and Rendall Farley, P.E. represented the USCG at the national and local levels. Jim Towers, P.E. represented Elliott Bay Design Group who was retained by the Nichols Bros. Boat Builders and Kvichak Marine Industries to provide forensic engineering.

NOMENCLATURE
EBDG – Elliott Bay Design Group
USCG – United States Coast Guard
MSO – Marine Safety Office
ABS – American Bureau of Shipping
ASTM – American Society of Testing and Materials
NVIC – Navigation and Vessel Inspection Circular
DNV – Det Norske Ventas

This paper traces the history of a saga that originated with one or more decisions taken by the staff of an aluminum rolling mill during the late 1990's. The exact details of that decision may never become public. The resulting metallurgical conditions were not detected until the summer of 2001. They were not correctly identified until December 2001.

The first part of this paper traces the history of the discovery of the sensitized metal and provides a basic primer of high magnesium aluminum plate metallurgy. It then recounts the ongoing industry remediation. The later sections discuss the impact to the aluminum shipbuilding industry, generation of the new ASTM B 928 standard, and a prognosis for the future of aluminum plate for marine use.

The authors have included a number of technical definitions. Some terminology has differing meanings between the aluminum and shipbuilding industries.

(1) Plate – Throughout the paper, the term refers to all rolled, flat goods unless of gauge thickness. This is common practice in shipbuilding. The aluminum industry refers to material 0.250" and thicker as plate, less than 0.250" as sheet.

(2) Sensitization – A condition that occurs in aluminum alloys with high magnesium content (greater than 3%), in which the grain boundaries become outlined with an aluminum magnesium precipitate. This condition leads to susceptibility to intergranular types of corrosion.

(3) Intergranular corrosion (I.G.) – Preferential corrosion at or adjacent to the grain boundaries of a metal or alloy [1]. The corrosion of sensitized plate described in this paper all originates as intergranular corrosion though it show different characteristics depending on location and local conditions. The ASTM G 67 (NAMLT) Test [3] is used to determine an alloy's susceptibility to intergranular corrosion.

(4) Stress corrosion cracking (S.C.C.) – A cracking process that requires the simultaneous action of a corrodent and sustained tensile stress [1]. Stress corrosion cracking described in this paper is initiated by salt water (the corrodent) acting on sensitized plate that is susceptible to intergranular corrosion, in areas of higher tensile stress.

(5) Exfoliation – Corrosion that proceeds laterally from the sites of initiation, along planes parallel to the surface, generally at grain boundaries, forming corrosion products that force metal away from the body of the material, giving rise to a layered appearance [1]. The ASTM G 66 (ASSET) Test [2] is used to provide visual assessment of exfoliation corrosion susceptibility.

(6) Pitting – Corrosion of a metal surface, confined to a point or small area that takes the form of a cavity [1]. The pitting described in this paper followed a predominately intergranular path.

(7) Aluminum Nomenclature – In order to correctly identify an aluminum product both the four digit alloy number and the temper must be specified, along with a manufacturing specification.

IDENTIFICATION OF THE PROBLEM

The Initial Discovery

M/V *JET CAT EXPRESS*

Nichols Bros. Boat Builders Inc. launched the M/V *JET CAT EXPRESS* in late April 2001. This aluminum catamaran is 42 meters length overall, with a capacity of 420 passengers designed by Incat Designs of Sydney, Australia for service between Catalina Island and Long Beach, CA. The M/V *JET CAT EXPRESS* is typical of the larger passenger ferries for which Nichols Bros. is well known. While very similar in many respects to the earlier 44 meter M/V *CATALINA JET*, the new boat features a modified ride control system utilizing interceptors instead of trim tabs at the stern in conjunction with the usual T foil forward. Sea trials progressed uneventfully with the exception of severe vibration originating from the torsionally soft couplings between the main engines and the reduction gear boxes. Temporary repairs reduced the vibration problems to acceptable levels and the vessel departed Puget Sound for Southern California. By arrival in San Pedro the vibration had returned with a vengeance and the couplings had started to disintegrate. The couplings were replaced with a different model and the M/V *JET CAT EXPRESS* entered passenger service in early June 2001.

Within a month, the crew was reporting salt water seeping from behind the structural fire protection insulation on the inboard side of both engine rooms. Removal of the insulation revealed small semicircular cracks. These started about 1/4" to 3/8" into the plating from the end of the intermittent fillet welds between the longitudinals and the shell plating on the inboard side of the engine room. Figure 2 illustrates the cracking that quickly became referred to as "smiley face cracks." The inboard side shell plating of the demihulls above the waterline was unpainted, a practice not atypical for this type of vessel. Inspection of the inboard side of the hulls indicated numerous cracks, almost all located above the waterline and between the engine room forward and aft bulkheads. The cracks were attributed to the high vibration levels experienced during the coupling failures.

The Catalina Island tourist season extends from late May until September. After consultation with the USCG, it was decided to effect a temporary repair. External doubler plates were added in way of the inboard side of the engine rooms, so that the vessel could complete the high revenue season. The M/V *JET CAT EXPRESS* would then return to the builder's yard for permanent repairs in the fall. The doubler plates were prepared so that the slot welds between the doubler and the original hull plating would coincide exactly with the existing intermittent welding between the frames and longitudinals and the shell plating. The temporary repairs were completed, the vessel sea trialed and returned to service. In November the M/V *JET CAT EXPRESS* was returned to Nichols Bros. yard on Whidbey Island, Washington.

After hauling out at the yard, it was noted that the same "smiley face cracks" had appeared in the doubler plating as had been found in the original shell plating. This raised an unexpected question. Why was the doubler exhibiting what appeared to be stress related cracking when the vessels vibration signature had indicated very low amplitudes after the replacement of the torsionally soft couplings? The doubler plating was removed, and the forensic process commenced. While the doublers were being removed, a list of possible causes was compiled:

- Incorrect plating or structural members installed by the yard
- Natural frequencies of panels close to the frequencies experienced during the coupling problems
- Incorrect weld design or execution
- Unexpected loads from the ride control system which was reported to elicit faster response than the trim tabs used for previous catamaran ride control systems
- Incorrect scantling design
- Global structural problems

Sensitized materials were not even considered initially. One by one, items were struck from the list. However, once a possible cause had been identified, the yard had to provide conclusive evidence to the attending USCG inspector before elimination from the list. This resulted in a finite element model of the hull being developed by Incat, and the vessel being instrumented during the February post repair sea trials and redelivery voyage to Long Beach. Both the yard and the designer reviewed scantlings and weld design. Mathematical analysis was conducted to model the ride control responses and the resulting structural loads. Material problems had still not been investigated up to this time.

As the doublers were removed, the crack locations were mapped. In addition to the cracks illustrated in Fig. 5, vertical cracks were found in the plating immediately below the deck edge. These did not originate near the heat affected zone of the welds but instead ran vertically from approximately one inch below the deck edge. These cracks were around four inches long and ran parallel to each other spaced between two and four inches apart. Further cracking was found in the inboard plating of the water jet room. The crack maps however were starting to illustrate a trend. The cracks mapped to date were all in 5mm plating. Additionally, Mel Helley (Nichols Bros. welding foreman) noticed that there was a subtle difference in the surface color of the 5mm plate when compared to the surrounding 4mm and 8mm plates. Cracks were mapped both from the interior and exterior of the hull.

Another trend was noted. The interior and exterior crack maps did not always compare. Sections taken through the plating in way of the cracks showed that the cracks often did not penetrate the plate but ran parallel to the surface and, in some cases, even started to return to the originating surface (see Fig. 7).

Samples of the plate were removed and sent to a metallurgical laboratory for testing. The next day the metallurgist's preliminary report indicated that the plate was sensitized and suffering from intergranular corrosion. The following day the yard received the mass loss results of the ASTM G 67 test for intergranular corrosion [3]. The mass losses were 220mg/in^2 and 387mg/in^2. Mass loss of less than 100mg/in^2 passes the ASTM G 67 test and that of 160mg/in^2 or over is deemed to have failed. Mass loss between 100 and 160 mg/in^2 falls into a transitional range where the pass/fail criteria are determined by examination of the metal structure under the microscope after the ASTM G 67 testing. Mill certificates for the plate were retrieved from the archives. All the 5mm plate for that hull had been supplied from a single mill. Conclusion: we must have received a single batch of sensitized plate. How wrong we all were!!!

Now that the problem had been defined in our minds, the solution was relatively easy; crop the sensitized 5mm plate and insert with alloy that was not susceptible to intergranular corrosion. All of the side shell plate in the engine room, the jet room and extending into the void forward of the engine room had to be replaced. The Incat designed catamarans feature a floating deckhouse supported on rubber isolation mounts. The foredeck and a single transverse girder aft connect the two demihulls. In order to reduce the weight on the demihulls during the repairs, the yard elected to lift the deck house and support it independently on wooden cribbing. As the superstructure isolation mounts were unbolted, small pieces of aluminum, approximately the size of a new U.S. dollar coin and between 1/16" and 1/8" thick, were noted lying on the deck of the demihulls. These had fallen out of the spray deflector; a non-structural member running the length of the superstructure immediately above the inboard isolation mounts. Inspection of the spray deflector revealed, in addition to the numerous "missing" pieces, extensive local pitting (see Fig. 4). Also noted were a number of fractures. The spray deflector presented completely different symptoms of corrosion.

Metal samples were sent to the laboratory for analysis and again the results indicated sensitization and intergranular corrosion. While the metal had originated from the same mill, the plate thickness differed from the engine room side shell plating. Pitting was also noticed in the 4mm deck plating where it was exposed to the salt spray. The 1/8" plate that had been used for the engine room air intakes also showed both the stress corrosion cracking and pitting. The only common factor now was that all the plate was relatively thin (¼" thick or less) and had been supplied from a single mill. The focus now was to track down all the plate from this manufacturer. Every single plate tested from that mill used in the M/V *JET CAT EXPRESS* failed ASTM G 67 and most exhibited one or more of the characteristics of intergranular corrosion.

Fig. 1 M/V *JET CAT EXPRESS* under repair with the superstructure raised.

The M/V *JET CAT EXPRESS* turned into a major plate replacement effort with the final costs exceeding $1 million. Eleven weeks after arrival at Nichol's Bros., the vessel was instrumented, tested and returned to service. Sea trials proved that the hull loads from the interceptor operation were considerably lower than predicted by the analysis. Sea loads were also lower than predicted, though they reinforced the importance of considering the hull resonant frequency.

The highest stresses amidships were actually recorded when obliquely transiting a container ship's stern waves on a perfectly calm Puget Sound. However, the M/V *JET CAT EXPRESS* showed lower stresses at the same locations on the coastal voyage to Long Beach, despite having to reduce speed twice due to heavy sea conditions. The container ship stern wave frequency matched the hull natural frequency almost exactly.

It has since been determined that three more Nichols Bros. boats were built with the sensitized aluminum in addition to one major conversion and one repair project. Remediation is underway at the time of writing with new hulls and house under construction for M/V *MENDOCINO* and the M/V *PERALTA* scheduled for later this fall.

M/V *HULA KAI*

The M/V *HULA KAI* was the second catamaran built by Kvichak Marine Industries of Seattle, Washington. She was designed by Crowther Multihulls of Sydney, Australia and was launched in October 1999. The M/V *HULA KAI* is a 64' catamaran with a capacity for 100 passengers. The vessel was designed for passenger excursions in the waters of Hawaii. The M/V *HULA KAI* was operated between December 1999 and December 2001 without structural problems.

The vessel was sold to the Waterways Corporation in December 2001. The change in ownership also entailed a new route, and a USCG inspection was scheduled for December 20, 2001. Extensive cracks were noted in the both port and starboard outboard side shells. These were similar in appearance to the "smiley face cracks" that had been discovered in the M/V *JET CAT EXPRESS* although at this juncture no connection had been identified between the two vessels. Typically the M/V *HULA KAI*'s cracks occurred in the shell plating, starting approximately 1/8" to 3/8" from the end of an intermittent weld and radiating out in an approximately 180° arc either above or below the weld. The cracking was isolated to the engine room and lazarettes. After conferring with the USCG MSO Honolulu, the Certificate of Inspection was withdrawn, and the vessel prohibited from further passenger operations until repairs were completed. This also effectively put the sale of the vessel on hold.

Kvichak was notified and with the assistance of an outside consultant, inspected the vessel in Honolulu December 27, 2001. Cracks were discovered in the 3/16" plate from just below the main deck to the top of the radiused chine on both outer side shells. The cracks appeared to be concentrated fore and aft from about the

Fig. 2 M/V *HULA KAI* - Stress corrosion cracking often referred to as "Smiley face cracks"

Fig. 3 M/V *JET CAT EXPRESS* - Deck plating showing a section about to pop out

Fig. 4 M/V *JET CAT EXPRESS* - Pitting in a section of spray rail. This plate was in service for less than eight months

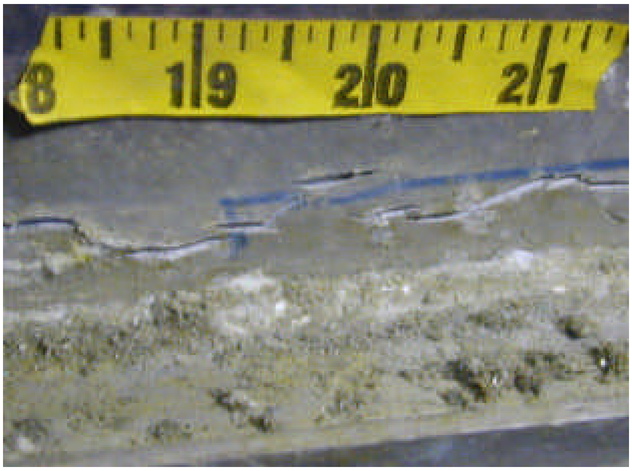


Fig. 5 M/V *JET CAT EXPRESS* - Shell plating illustrating both stress corrosion cracking and pitting

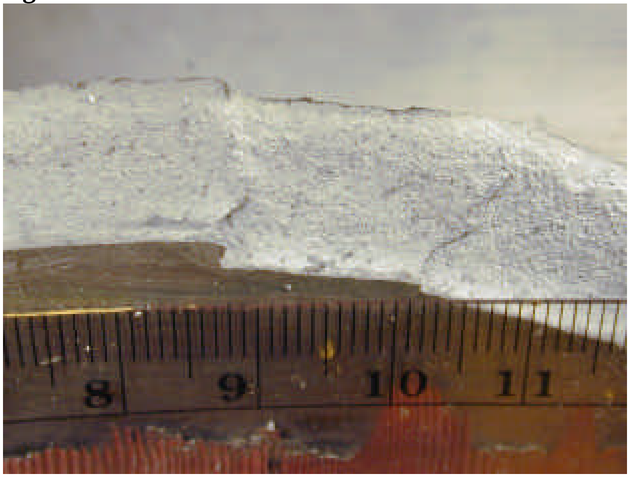


Fig. 6 M/V *JET CAT EXPRESS* – Note multiple fatigue fracture initiation sites

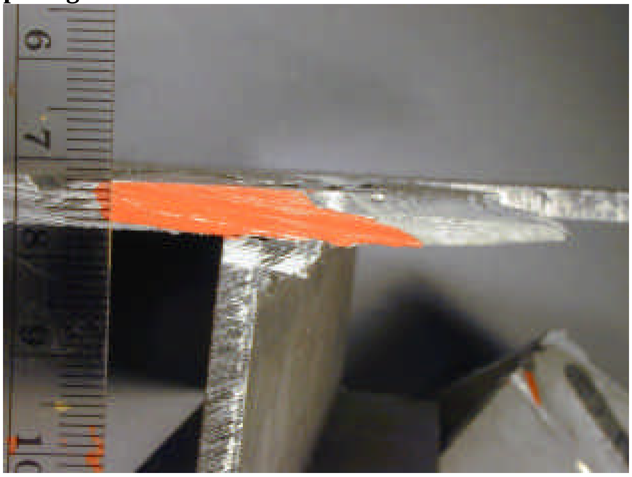


Fig. 7 M/V *JET CAT EXPRESS* – Fracture in Fig. 6 viewed from the side

middle of the engine rooms, extending forward to the engine room bulkhead and aft past the aft engine room bulkhead, through the lazarettes, to the transoms. Numerous cracks were noted in both hulls. On December 28, 2001, the M/V *HULA KAI* was hauled in Honolulu and plans were made to replace the cracked side shell. As in the case of the M/V *JET CAT EXPRESS* there was a great deal of speculation as to the cause of the cracking including:

- Incorrect weld design or execution
- Incorrect scantling design.
- Incorrect exhaust support attachment to the hull
- Global structural problems

December and January are prime tourist season in Hawaii so repairs needed to be made quickly. On January 8, 2002, a Kvichak Marine crew arrived in Honolulu to start the repairs. Replacement plate and tools had been flown from Seattle. Lacking a definitive cause of the problem, with agreement of USCG MSO Honolulu, it was decided to replace the failed 3/16" plate with 1/4". Midway through repairs to M/V *HULA KAI*, Kvichak Marine received a phone call from CWO4 Steve Peters of USCG MSO Puget Sound in Seattle, WA. Mr. Peters was working with Nichols Bros. Boat Builders Inc. to identify and resolve the M/V *JET CAT EXPRESS* problems. The M/V *HULA KAI* had been inspected during construction by the MSO Puget Sound Staff. MSO Honolulu had contacted their counterparts in Seattle to discuss the M/V *HULA KAI*. MSO Puget Sound considered the possibility that the two cases were in some way connected. Mr. Peters commented that the similar problems developing with vessels from two well established marine aluminum construction yards at the same time was more than coincidence. He advised Kvichak of the Nichol Bros. experience and asked if Kvichak Marine would research the plate purchases for the M/V *HULA KAI*. He also requested that they work with Nichols and the USCG to investigate if there were any common elements to the plate purchases and certifications. Kvichak Marine's purchasing and engineering staff went to work matching invoices and certifications to the plate nesting records. The cracked shell plate had been furnished by the same distributor and had originated from the same mill.

Meanwhile back in Hawaii, repairs continued apace to the M/V *HULA KAI*. The side shell repairs were done in approximately ten foot sections to maintain the shape of the vessel. As plate was removed, sections were sent to Seattle for testing. The aluminum fitting and welding was completed January 26, 2002, and the painters started work that evening. On the way back to the hotel that night, the repair crew was advised that the plate utilized for construction had been identified as the cause of the problem. ASTM G 67 test results had determined that the plate had been sensitized during manufacture and was susceptible to intergranular corrosion. The real irony was that the ¼" plate used in the repair had been manufactured by the same mill as the replaced metal. On January 22, 2002, the manufacturer had written to MSO Puget Sound to advise that they did not guarantee the use of their 5083-H321 aluminum plate in marine applications, as it was susceptible to corrosion! Testing confirmed that the repair plate also failed ASTM G 67.

Fig. 8 M/V *HULA KAI* under repair

Needless to say, the perspective purchaser promptly returned the M/V *HULA KAI* to her original owner for a full refund. As industry knowledge of the failure modes of the sensitized aluminum improved, the M/V *HULA KAI* was allowed to return to service although with a strict inspection program to monitor the sensitized plate deterioration.

As the vessel replacement program was developed later in 2002, the need arose for a relief boat and Kvichak purchased the M/V *HULA KAI* back from its original owners. Once it had been determined that a vessel had sufficient quantities of sensitized aluminum that its replacement was the only economic remediation, Kvichak would build a new hull. As the aluminum fabrication was nearing completion, the original boat would be withdrawn from service and returned to Seattle so that engines, water jets, windows, outfit items etc. could be transferred to the new hull. Meanwhile, the M/V *HULA KAI* maintained the operator's service to minimize disruption.

In January 2002, Nichols Bros., while a prolific builder of aluminum vessels, was starting construction of a 360' cruise ship with a steel hull and had no aluminum new construction in hand. Kvichak, however, specializes in aluminum craft, and had six vessels in various stages of construction at this time. The company was faced with two issues. Firstly, they had to address the partial or complete reconstruction of a number of completed vessels that were already in service. Also, they had to plan the disposition of the current new construction. On January 25, 2002, Kvichak had six hulls under construction; two fisheries patrol catamarans for the State of California, a 72' pilot boat for the Sabine Pilots, a 55' survey vessel for the U.S. Army Corps of Engineers and two 36' fire boats for the City of Los Angeles. The two fisheries patrol boats were the most complete. One had been accepted by the owners and was waiting to depart Seattle; the second was 95% complete. Both had extensive quantities of sensitized aluminum and they were subsequently replaced. The pilot boat and survey vessel also had sufficient sensitized plate making it uneconomic to replace, and both hulls were cut up for scrap. The two fire boats were in the early stage of erection. The sensitized aluminum parts, mostly bulkheads, were identified and replaced.

Throughout the first two months of 2002, Kvichak tested a representative sample of each plate heat number that had been used in the construction of these vessels. Initially the focus was on the 5mm plate from a single mill. As the repair to the M/V *JET CAT EXPRESS* progressed this focus widened to include all of the thinner plates (¼" and below) from this company. However, accelerated pitting was noted in plate from another source and the test program was again expanded to include other manufacturers. Some plate from a second manufacturer failed the ASTM G 67 tests. No longer was the problem a single source.

The shipyards, again, expanded the test program to include the 5083-H116 plate, a few samples of which also failed G 67. All results were in the transitional zone with weight loss between 100mg/in² and 160mg/in², requiring metallographic examination. It should be noted that while some -H116 plates have exhibited pitting in service, no stress corrosion cracking has been reported. Although the symptoms were minor compared to those encountered with 5083-H321; 5083-H116 that had not passed G 67 testing, was no longer acceptable to the shipyards as replacement plate.

Neither 5083-H321 or H116 could be relied upon not to be susceptible to intergranular corrosion. Both manufacturers stated that their product was in full compliance with the current ASTM B 209 Standard. Close examination of the physical and chemical test results confirmed this statement. Not only was there a corrosion problem with some of the aluminum that was being used in the shipbuilding industry, there was apparently no standard that could be used to assure that the plate supplied was resistant to intergranular corrosion in marine service. The owners of Kvichak faced an unpalatable decision. On January 28, 2002, they furloughed almost their entire shop crew while management completed their investigation as to the extent of the crisis and formulated plans for recovery.

At this juncture it is appropriate to review basic aluminum metallurgy, manufacturing processes and the applicable quality assurance programs.

METALLURGY

The alloys discussed in this section are 5083, 5086 and 5456 in the -H116 and -H321 tempers, with emphasis placed on -H321. 5083-H321 represents the majority of the materials involved in the events that occurred in the Pacific Northwest over the last two years, and was the only material to display stress corrosion cracking in service.

TABLE 1 – Chemical Composition Limits %*

Alloy		5083	5086	5456
Silicon		0.40	0.40	0.25
Iron		0.40	0.50	0.40
Copper		0.10	0.10	0.10
Manganese		0.40-1.0	0.20-07	0.50-1.0
Magnesium		4.0-4.9	3.5-4.5	4.7-5.5
Chromium		0.05-0.25	0.05-0.25	0.05-0.20
Zinc		0.25	0.25	0.25
Titanium		0.15	0.15	0.20
Other Elements	Each	0.05	0.05	0.05
	Total	0.15	0.15	0.15
Aluminum		Remainder	Remainder	Remainder

**Maximum unless a range is shown.*

Table 1 lists the chemical composition of the alloys. While there is nominally 93% aluminum in these alloys, there are other elements present as well, that improve strength. Depending on the history (processing) of the material, some of these other elements may be completely dissolved in the aluminum, like sugar in coffee, or they may be in various stages of precipitating out of solid solution. The area of particular interest in this study involves the magnesium element precipitating out of solution and solidifying at the product's grain boundaries on the molecular level. Metallurgists call this magnesium rich precipitate Beta phase.

For example, samples of these alloys that are quenched in water from 400°C will show no signs of Beta phase (Photomicrograph Fig. 9A), while this same material when quenched from 400°C and aged 4 days at 100°C will show solid lines of Beta defining the grain boundaries (Photomicrograph Fig.9B). These solid lines of Beta at the grain boundaries are sensitive to intergranular corrosion.

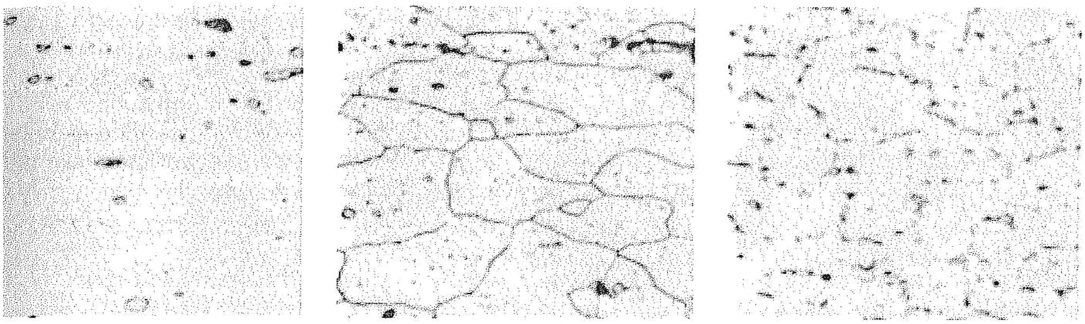


Figure 9, Photomicrographs of 5083-type Al-Mg sheet. *Magnification 130x ratio*

If the same material is aged at 300°C after quench, the precipitate at the grain boundaries will break from the solid lines and coarsen into spheres, which resemble a string of pearls around the grain (Photomicrograph Fig. 9C). This "string of pearls" structure is resistant to intergranular corrosion.

Intergranular Corrosion

The high magnesium constituent (Beta Phase) in Photomicrograph B is attacked by seawater at the grain boundaries and it continues the attack along those continuous grain boundaries until the grain is separated and falls away. By making the grain boundary semi continuous as is shown in Photograph Fig. 9C, the attack is stopped at the point where no high magnesium constituent (Beta Phase) is present.

The Photomicrograph in Figure 10 shows an example of intergranular attack. Note how the grain boundaries have been corroded away.

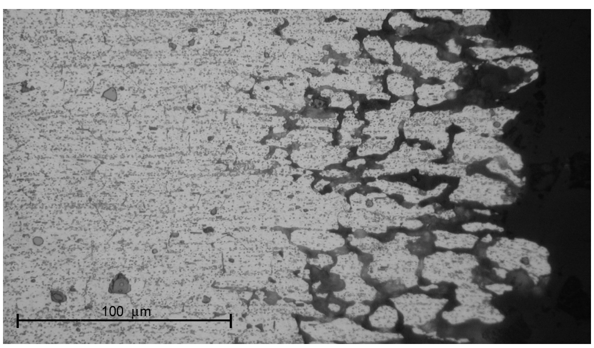


Figure 10, Example of G 67 Corroded Test Coupon Microstructures with Susceptibility to Intergranular Corrosion. *Photograph is an example of an intergranular attack. Taken after testing to ASTM G 67 and etching with modified Keller's reagent (HF, HCL, HNO_3 and H_2O).*

From the metallurgist's perspective, once a desired microstructure's appearance is known, work may commence on developing a process to produce the given microstructure.

Manufacturing Process

In the cast house, an aluminum sow is charged into a furnace along with certain alloying ingredients that are called out on the charge sheet (recipe) for the particular alloy under production. After the charge materials are melted, stirred, and analyzed, the resulting molten metal is cast into molds in which the bottom is continuously dropping out, resulting in a rolling ingot typically some 16" thick and 200" long. After these ingots are scalped and preheated they are sent to the rolling mill where they are rolled down to final thickness in a series of steps called passes.

The pass schedule, which varies from mill to mill, is made up of several passes through the hot mill. Each pass is chosen carefully to reduce the thickness of the work piece from the ingot thickness down to that of required sheet or plate. By controlling the number of passes, the reduction thickness, and the temperature of the metal at each pass, the microstructure is controlled such that the resulting sheet or plate has the desired microstructure. Deviation from any of the pass schedule parameters can result in reduced corrosion resistance.

The Viet Nam Experience

The manufacturing techniques and the resulting pass schedules were developed in the 1970's after exfoliation corrosion had occurred in U.S. Navy vessels operating in Viet Nam. The North American aluminum industry responded with the development of the -H116 temper that had a pass schedule and a microstructure that resisted both exfoliation and intergranular corrosion. Concurrently the ASTM G 66 (ASSET) test for exfoliation corrosion resistance and the ASTM G 67 (NAMLT) test for intergranular corrosion resistance were developed.

In the early 1980's, high speed aluminum passenger vessels started to gain acceptance in the U.S. Both the European and the Australian yards had been developing this type of craft for a number of years and the North

American builders, naturally enough, turned to the overseas naval architects for their designs. While the -H116 temper had been intended to replace the -H321 metal for marine application in the United States, in Europe and Australia both tempers were used interchangeably. The foreign suppliers regarded both as marine tempers and the naval architects, as often as not, specified 5083-H116 or -H321 aluminum for their designs. Through the 1980's and early to mid-1990's, many North American yards also used the tempers interchangeably, with no known or reported corrosion problems of significance. It is only in this recent instance that a percentage of -H321 temper material has been noticed to exhibit susceptibility to extreme intergranular corrosion.

Keep in mind that it is quite possible to purchase 5083-H321 manufactured in North America that passes ASTM G 66 and ASTM G 67 standards. The true extent of the confusion is best illustrated in a brochure, written by a European service center, extolling the use of -H321 for boat builders. It states that -H116 is so unacceptable that it requires additional testing to assure its suitability. Of course, the opposite is true. Clearly, more consistent standards and perceptions are needed, as aluminum vessels today operate in a global environment where they are often built, operated and repaired in various countries around the world during their life.

THE MANUFACTURER'S RESPONSE

Once the cause of the cracking had been identified through robust laboratory testing, the shipyards contacted the material manufacturer. A metallurgist visited both Nichols Bros. Boat Builders and the Kvichak Marine Industries yards and viewed the M/V *JET CAT EXPRESS* and the material that had been taken from the M/V *HULA KAI*. Approximately a week later the yards received the first response from the mill. The metal was indeed 5083-H321 and had been manufactured by their plant. The mill further concluded that the material met all the requirements of the ASTM B 209 standard. They regretted that the material was not satisfactory for marine service but stressed that the ASTM G 67 test for intergranular corrosion was not a requirement to comply with the ASTM B 209 Standard for either 5083-H321 or -H116. This was followed by a letter which stated that the material was not guaranteed for marine use; this was initially interpreted as applying only to seawater, but was subsequently broadened to include brackish and fresh waters.

5083-H321 had been used as a marine alloy-temper since the 1970's in Australia. Nichols Bros. Boat Builders had used either 5083-H321 or -H116 since 1987 and until this time had experienced no material related failures. Their high-speed catamaran designers, Incat Designs of Sydney, had specified either 5083-H321 or -H116 throughout this time as was common practice for both Australian and European designers. The M/V *HULA KAI* had been designed by Crowther, also an Australian company. The design documents again specified 5083-H321 or -H116. The two yards reviewed the ASTM B 209 Standards and confirmed that there was no testing required for intergranular corrosion for either temper. There was also no exfoliation test required for the -H321 temper. Exfoliation had been a major problem for marine alloys in the Viet Nam war era. The -H116 temper was required to be tested for exfoliation and to pass the ASTM G 66 test, but was not subjected to ASTM G 67. Both tempers could be in full compliance with the North American manufacturing standards and still be susceptible to intergranular corrosion. Three major classification societies confirmed that they also did not require testing for intergranular corrosion.

This left the shipyards with a new dilemma. Some 5083-H321 aluminum plate being manufactured in North America in early 2002 was definitely not suitable for marine service. The 5083-H116 temper, that had been developed especially for the shipbuilding industry, also included a few plates that marginally failed the G 67 test and exhibited pitting in service. Two mills produced plate that had been used by Nichols Bros. or Kvichak and failed the ASTM G 67 test. The plate from one mill exhibited mass loss that ranged from below 100mg/in² to over 280 mg/in² when tested for intergranular corrosion. All of the second mill's samples failed the ASTM G 67 test. Material that passed the ASTM G 66 test for exfoliation did not necessarily pass the ASTM G 67 test for intergranular corrosion. ASTM B 209 was obviously not sufficient to ensure production of suitable high magnesium aluminum alloys for the shipbuilding industry. 5083-H321 plate that fully complied with the ASTM B 209 standard exhibited visible pitting after as little as four hours in saltwater and showed advanced stress corrosion cracking after less than two months in service. No current North American standards were available that would guarantee acceptable plate.

TEMPORARY TEST PURCHASE SPECIFICATIONS

Both Nichols Bros. and Kvichak urgently needed to start purchasing plate again. The M/V *JET CAT EXPRESS* had large sections of plate cropped from both sides of the engine rooms. It was time to replace plate before any more could be removed. Kvichak on the other hand had completely ceased production and furloughed almost their entire production crew. Two Kvichak vessels had such extensive quantities of plate failing ASTM G 67 that the only economic solution was to scrap the almost completed hulls. The structure of the Sabine Pilot boat was completely fit up and 95% welded when production was halted. It took three days for a crew to reduce it to small sections in the scrap bin. Kvichak now claims that they can scrap a hull in 6% of the time that it takes to build it!

The shipyards decided to generate a temporary purchase specification so that the yards could continue repair and restart new construction. In addition to requiring material produced to the ASTM B 209 standard, Kvichak specified that the material pass both the ASTM G 66 and G 67 tests. The pass criteria for the ASTM G 66 test was modified to require that the alloy pass with pitting not exceeding PA (i.e. PB and PC would both be regarded as failing) (Appendix 1).

Initially this standard got a mixed reception from the local distributors. In some instances the distributors agreed to test before delivery. Others insisted that the yards take delivery of the material, with no right of return, and test at their own risk. However, the temporary purchase standard served the purpose of providing a basis to restart production. The temporary purchase specification, which was generated in a single afternoon, is included in Appendix 1.

SOLUTIONS TEAM AND REMEDIES

The Regulatory Framework

As the first two vessels identified with the aluminum materials problem were USCG inspected small passenger vessels certified under 46 CFR subchapters T and K, it is helpful to review regulatory requirements. For vessels under 100 gross tons, regulatory requirements for structural materials for inspected vessels are minimal. While international Classification Society standards for construction and materials are recognized as acceptable for USCG inspected vessels, they are not required since most domestic passenger vessels are not classed.

There is an existing guidance document published by the USCG, Navigation and Vessel Inspection Circular (NVIC) 11-80, titled "Structural Plan Review Guidelines for Aluminum Small Passenger Vessels"[5]. This document provides a scantling calculation methodology suitable for field use on deep-vee monohull forms from 60' to 135', typical of those used as crew boats in the offshore industry with a service speed of about 24 knots. The NVIC refers to alloys 5086, 5083, 5456 and 6061 as suitable for hull structure. As this is a guidance document, the alloy is not mandated, much less the temper designation.

Aluminum Boat Solutions Team and the Repair Process

In addition to the investigative work by both Nichols Bros. and Kvichak, parallel efforts were made to determine appropriate repair strategies. Since the first impacted craft were under the regulatory control of the USCG, direct intervention and oversight was required before these vessels could resume passenger carrying service. The technical research indicated sensitized condition in the metal, with full replacement of the affected material as the only acceptable repair solution. Normal USCG interaction in the design and construction process had taken place, including a review of scantling calculations, construction plans, as well as on-scene oversight of construction and welding, at both yards. Furthermore, the design sources and construction history for both shipyards were reputable.

The repair situation alone would normally be handled at the field level by a single USCG MSO. However, due to the fact that two vessels operating in different geographic locations were identified, the Quality Assurance and Traveling Inspection Staff at USCG Headquarters were contacted. The function of this staff of experienced senior marine inspectors is to support the field offices nationally and internationally. This ensures consistency in the administration of the marine inspection program, particularly when the issue involves several marine inspection zones or is otherwise more than just a local problem. When the USCG Traveling Inspection Staff was first advised, the connection between the two vessels was not obvious, as the visual indicators were not identical. When the ongoing materials research connected the two vessels, central coordination became essential.

Material problems with aluminum vessels are relatively rare – these cases were obviously abnormal. The M/V *JET CAT EXPRESS* reported over 800 fractures after only five months in service. The fractures on M/V *HULA KAI* were less extensive, but over 60 were reported after approximately two years. The aluminum distributor reacted publicly by issuing a notice to its customers on February 7, 2002, advising that the alloy was not guaranteed for marine use and was susceptible to corrosion. This prompted MSO Puget Sound to issue an Officer in Charge, Marine Inspection Advisory on February 11, 2002, establishing interim measures for coating requirements, inspection protocols, etc., in order to continue the use of 5083-H321 in new construction and the repair of existing vessels.

Both Nichols Bros. and Kvichak commenced work on plans to define the extent of the problem and start repair or replacement of vessels, not knowing the true extent of their potential financial commitment. As the shipyards brought outside engineering and legal resources to bear on the investigative process, they opened dialogue with representatives in the manufacturing chain. In short order, the shipyards put forward their case for assistance from the aluminum industry which included the following points:

- The supplied material was obviously not suitable for marine construction although it technically met the existing ASTM B 209 standards.
- There was no doubt that the material was to be used in marine construction. Neither yard manufactures products for use outside of the marine industry as evidenced by their corporate names. There could be no confusion as to the end use of the aluminum plate.
- If the situation was not quickly and effectively resolved there were substantial safety concerns.
- The magnitude of the problem was far beyond the financial capability of the shipbuilders.

This effort succeeded in convincing the distributor and manufacturer to closely review the production and distribution processes, in order to determine what had changed the product's performance.

When it was determined that a change to the manufacturing process had taken place in the production of the material in question, a team was formed by the aluminum industry, known as the Aluminum Boat Solutions Team (ABST). It included representatives from:

- The plate manufacturer
- The distributor
- The distributors' parent company, itself an aluminum manufacturer
- A corrosion expert retired from the U.S. Navel Labs
- Case Western Reserve University (expertise in corrosion and structural engineering), and
- The Glosten Associates (a Seattle based naval architecture and engineering firm.)

The Solutions Team visited USCG Headquarters in April 2002 and presented a multi-faceted strategy to remedy the situation. They would identify the vessels, plan and finance remediation, provide engineering to define the failure mechanism and evaluate its impact. Their multi-pronged strategy included:

- Ascertaining the distribution of the suspect material;
- Identifying other factors that contributed to or accelerated the intergranular corrosion and, cognizant of these factors, schedule remediation based on each particular vessel's needs;
- Locating and contacting builders to determine which vessels and/or other components, such as fuel tanks, may have been constructed with the problem aluminum plate;
- Developing a reliable method of identifying the suspect material insitu on the vessels;
- Negotiating repair, remediation, replacement, substitution strategies with builders, owners and the USCG (for inspected vessels) on a case by case basis, including temporary repairs, if necessary, while new hulls or components were constructed;
- Initiating research to validate the initial assessment that the fracture mechanism would not lead to catastrophic hull failure; and
- Researching existing standards for marine aluminum manufacture and ways to improve them.

The Extent of the Problem

What started with two USCG inspected vessels from separate builders quickly expanded into a complicated and far-reaching project. Many other boat builders, as well as equipment manufacturers in the recreational and uninspected segments of the marine construction industry, were identified. The USCG inspected vessels, by nature of their regulatory oversight, were well documented. As of this writing, 16 commercial passenger carrying vessels, operating from Southern California to Southeast Alaska and Hawaii, have been identified and are being actively tracked. The more daunting task was clearly the uninspected fleet and associated equipment issues, such as fuel tanks. As of this writing, that number is approximately 280 small vessels and approximately 90 fuel tanks, with 75% being diesel and 25% gasoline applications. This uninspected fleet includes a number of public vessels built for local municipalities and a small number of non-standard "off the shelf" commercial boats purchased by the USCG for its expanding role in Homeland Security. USCG Headquarters coordinated with other internal entities, such as the USCG Office of Boating Safety, to determine if conditions existed to initiate a product recall of recreational vessels or equipment. The Offices of Naval Engineering and Boat Forces addressed affected assets in the USCG's operating fleet. All the subsequent builders and end users identified were also in the same geographic Pacific Northwest location. Challenges to identifying end users included:

- Builders' attitudes of denial and associated lack of cooperation
- The Aluminum Boat Solution Team's lack of exposure to the marine industry, domestic boat builders and their market issues
- Verifying the accuracy of smaller shipbuilders' plate usage records

The USCG's Oversight Role

The USCG has a regulatory mandate to oversee the inspected domestic fleet, and to ensure satisfactory public safety levels related to the marine industry. Following the attacks of September 11, 2001, the USCG bore significant additional workloads and priorities related to homeland security issues. Resultant resource challenges made the USCG very receptive when representatives from the aluminum industry stepped forward to not only manage and finance the remediation effort, but to initiate standards that would reduce or eliminate the chance of a recurrence.

The Aluminum Boat Solutions Team's well structured approach was accepted by the USCG and a partnership quickly formed. Combining the resources and perspectives proved more productive than working separately. The Solutions Team was committed from the start and showed itself to be flexible in its decision making, as it became more familiar with the marine industry. Its own engineering tests and analysis quickly expanded the database of affected vessels and appropriate remediation procedures. This proactive approach led to the conclusion to completely remediate unsuitable material wherever found, regardless of vessel service.

From the long-term perspective, it also became clear that material specifications and Class society rules were not sufficient to prevent a recurrence of this problem, as there were no mandatory requirements for intergranular corrosion testing. In retrospect, it seems likely that many similar material problems may have occurred in the past, unbeknownst to individual builders or the USCG, due to a smaller magnitude and inability to connect individual cases with the larger, long-term issues. In an attempt to initiate long-term solutions, the USCG MSO Puget Sound provided a written brief and requested The Aluminum Association, Inc. to review and assess the situation. The Aluminum Association Inc. responded by forming the Task Force on Marine Alloys under The Technical Committee for Products Standards. The task group's mission was to create a draft document that would expedite the development of a new ASTM material specification for marine grade aluminum.

It was agreed that the USCG Headquarters-based Quality Assurance and Traveling Inspection Staff would be the single USCG point of contact for the Aluminum Boat Solutions Team activities. The following fundamental operating procedures were agreed upon:

- Local assessment surveys by the Solutions Team's designated contractor would be performed with the coordination and attendance of a marine inspector from the local USCG MSO for inspected vessels
- Vessel conditions determined to permit anything short of full remediation would mandate USCG Traveling Inspection Staff review and approval
- All gasoline fuel tanks found would be replaced; diesel fuel tanks would be identified and monitored to determine further action
- USCG would provide guidance to the Solutions Team regarding the economics and operation of the marine industry
- USCG position in oversight would provide a venue for the impacted vessel owners to offer feedback on the progress and interaction with the Solutions Team
- The USCG and the Solutions Team would jointly work to approve creative arrangements to get vessels repaired within the shipyard's schedule constraints, while keeping the vessel owners operating safely.

The Aluminum Boat Solutions Team has aggressively pursued commercial settlement with the boat building industry, still ongoing as of this writing. These negotiations have proved as diverse as the number of affected vessels. While it may be a relatively simple decision to identify and replace discrete plating in a larger vessel, such as a 350-passenger ferry, the most economical solution for a 26' private vessel may be destruction and transfer of custody to the aluminum supplier, followed by monetary settlement with the builder and/or owner for a replacement hull. Although a large percentage of end users have been identified, it is anticipated that a small percentage will never be contacted. While this effort continues, the Solutions Team expects substantial closure of the settlement process by the end of 2003.

The performance of aluminum plate in the commercial marine industry has historically been relatively trouble-free. Problems with aluminum have typically related to quality of design, construction and welding details – not materials. To date, there have been no reports of sensitized material originating from outside the geographic area of the builders already identified. There have also been no reports of problems along the U.S. Gulf Coast, where by far the largest percentage of aluminum construction occurs for both the world-wide and domestic US market. As a result, there was little justification to allocate USCG resources toward a broad national search for other data points. USCG Headquarters and the USCG Marine Safety Center, where new vessel and major modification plan review takes place, found no reports of failing aluminum materials elsewhere in the country. A briefing was prepared for USCG units at the annual Chief of Inspection Seminar held in September of 2002. Frequently Asked Questions were collated and posted on USCG MSO Puget Sound's Website together with answers [4]. Further information was disseminated through the Passenger Vessel Owners Association whose members included most of the inspected vessels.

The challenge for the Coast Guard will be determining the future applicability of the new ASTM B 928 in the context of vessel plan review and field inspection policy. While a regulatory project to incorporate the new specification into the existing regulations by reference is a possibility, other avenues likely to be considered include reference to the lessons learned from this experience in a revision of NVIC 11-80 "Structural Plan Review Guidelines for Aluminum Small Passenger Vessel" which, as previously mentioned, is a current guidance document used by the field Marine Safety Offices and their inspectors.

The new ASTM Specification B 928 has already impacted some Class Societies. The American Bureau of Shipping (ABS) is already specifying the ASTM B 928 required G 66 and G 67 corrosion testing for new aluminum alloy approvals. Once the specification is published, ABS intends to revise their rules to formally incorporate ASTM B 928 as part of their aluminum alloy approval process.

ASTM B 928 may have additional impact in that, in its current form and because of the additional testing required by conformance with ASTM G 66 and G 67, it goes beyond current marine classification society standards for aluminum corrosion testing. The intent of the new specification is not to undermine classification society standards, but to ensure improvement in the corrosion resistance of the relevant aluminum alloys. Major classification societies that participated in the ASTM process were not unaware of the finer points of properly producing high magnesium content aluminum alloys. In fact, the International Association of Classification Societies (IACS) has this topic on their current work program to consider a revision to IACS Unified Requirement (UR) 25, "Aluminum Alloys for Hull Construction and Marine Structure." While there is no direct connection between the two documents, ASTM B 928 may be used as a basis in the near future for the ongoing revision of IACS UR W25.

ASTM STANDARD DEVELOPMENT

On April 19, 2002, Captain M. R. Moore, the USCG Officer in Charge, Marine Inspection MSO Puget Sound, sent a letter to Mr. Michael Skillingberg asking that The Aluminum Association Inc. help in "finding effective long term solutions that clearly identify proper aluminum applications in marine vessel repairs and new construction." As a result, a task group was formed comprising of representatives of the major aluminum marine plate producers on both sides of the Atlantic.

The first task of the group was to redefine both the -H116 and the -H321 as marine plate tempers and assign both exfoliation and intergranular corrosion resistance criteria as appropriate. Once the new temper definitions were agreed, a start was made writing a new ASTM specification which was given the working title ASTM B ZZZ, High Magnesium Aluminum-Alloy Sheet and Plate for Marine Service. After several iterations, the Aluminum Association Task Group completed a preliminary draft and forwarded it to the ASTM Subcommittee B07.03, on Aluminum Alloy Wrought Products. The B07.03 subcommittee then organized yet another task group and invited all interested parties to participate. Det Norske Ventas provided substantial input.

In the fall of 2002, a copy of the August 28, 2002, draft specification and an invitation to attend the first ASTM Task Group on Marine Plate meeting in Miami on November 4, 2002, were sent out by email to the classification societies and other interested parties. This August 28, 2002 draft was also sent out for ballot to the B07.03 subcommittee. Unfortunately, while there were some email responses to this draft from outside the B07.03 membership, only Dr. Gopal Magadi of ABS represented the shipbuilding industry at the meeting. Nonetheless, that meeting was pivotal in deciding that the -H321 temper was to be redefined as a marine temper. New tempers would be registered for non-marine -H321 applications. The August 28, 2002, B ZZZ draft was discussed and the three negative votes it had received from the B07.03 membership were reviewed. Mr. Harold Bushfield, the chair of B07.03, was tasked with producing a second draft.

The December 9, 2002, draft was balloted during Dec/Jan 2003, formally by the ASTM and informally by the Coast Guard and the Classification Societies. Comments from both the B07.03 committee and the Classification Societies were then used to write the third and final draft, which went to ballot in February 2003.

The third draft received one negative vote from a producer who contended that there was insufficient test data to conclude that ASTM G 67 testing would predict the metal's corrosion resistance. At the May ASTM B07.03 and Marine Task Group meetings, there was much debate regarding the "less than optimum" amount of data, correlating ASTM G 67 test results with field performance. This data is especially "less than optimum" at low ASTM G 67 (NAMLT) mass loss values. The final decision was that sufficient data was available to determine acceptable pass criteria. The need for further research is addressed later in this paper.

The shipbuilding industry was represented at this crucial meeting by a single consulting engineer, retained by a group of five shipyards, all active in aluminum construction. The American Bureau of Shipping was the only attendee from amongst the classification societies. It is doubtful if the ASTM B 928 Standard would have been adopted without the aggressive position taken by these two spokespersons for the marine industry. This standard is a prime example of the necessity for the shipbuilding industry to remain active in the generation of quality assurance standards for the materials that they use. In this case the failure of the existing standard to keep unsuitable aluminum plate out of the supply chain will result in costly remediation.

Corrosion Testing

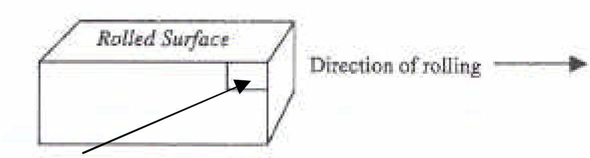
Corrosion quality control test programs for aluminum plate fall into three categories. Process Qualification testing is conducted when a mill starts to produce an alloy or if the production technique is altered. This is the most rigorous test program. Surveillance testing is a periodic program to ensure continued compliance. Lot release testing for corrosion consists of a metallographic examination of a specimen and comparison to a photomicrograph prepared from a sample that successfully passes the process qualification testing. The photomicrograph produced at process qualification is used as a comparison for all future production samples. This procedure allows the mill to check production with minimal time delays (Results from both the ASTM G 66 AND G 67 tests take in excess of 24 hours).

ASTM B 209

Both the ASTM B 209 Standard Specification for Aluminum Sheet and Plate and the ASTM B 928 Standard Specification for High Magnesium Alloy Sheet and Plate for Marine Service require that the alloy meet the chemical analysis, physical properties and product dimensional tolerances. The difference is apparent when one examines the corrosion testing requirements. B 209 specifies no additional testing is required for 5083-H321 although 5083-H116 is required to pass the ASTM G 66 Test for Exfoliation. This test is conducted when the manufacturing process is first qualified. At original qualification the mill produces a photomicrograph of the metal sample that passes the G 66 test. No test procedures are necessary for intergranular corrosion for either alloy or temper. Once the process is qualified no further checks are required unless the manufacturing process is modified. 5083-H116 was subjected to micrographic examination for lot release to ensure compliance with G 66.

ASTM B 928

The new B 928 standard has considerably stricter process qualification requirements. All high magnesium marine alloys must pass both the ASTM G 66 and G 67 tests. The G 66 test specimen must not only pass the G 66 with no signs of exfoliation, it must also exhibit a pitting rating of PB or better. This results in an alloy that is less susceptible to pit blistering. Previously the exfoliation criteria alone determined the pass/fail criteria while the pitting result was noted but did not contribute to the pass/fail determination. The qualification test specimen must pass G 67. This was not a requirement of B 209. The new standard includes instructions for the location of the metallographic examination (See Fig. 11).



Area and Face to be Metallographically Examined

Fig. 11 Location for Metallographic Examination

These were added as many marine construction details leave the end grain of the metal exposed (see Fig. 12), whereas previously the examination site was left to the individual metallurgist's discretion. Better results are usually exhibited at the rolled surface, as opposed to the plate end. If the alloy temper passes these tests, a photomicrograph is taken that is used as the comparison for metallographic examination for lot release.

ASTM B 209 requires surveillance testing only for 5XXX-H116 for exfoliation, once the process has been qualified. B 928 requires that G 66 and G 67 surveillance testing be conducted each quarter that the mill manufactures the alloy. This ensures that minor modifications to production techniques do not cumulatively over time decrease the corrosion resistant properties of the alloy.

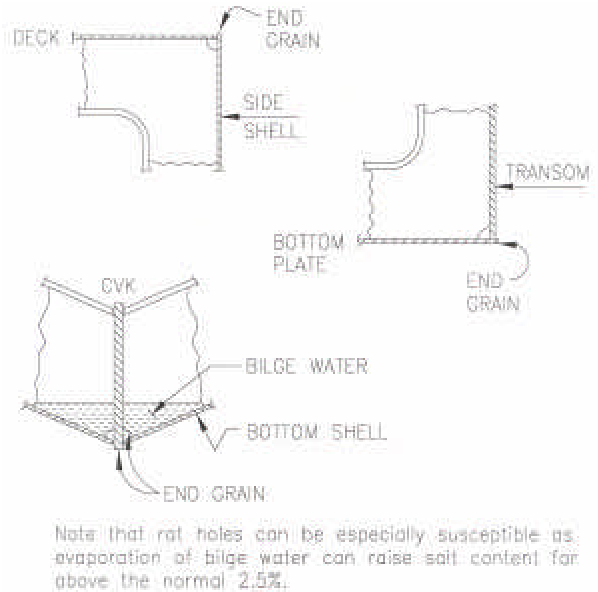


Fig. 12 Typical Marine Construction Details

Marking

The last highlight of the new standard is the mandatory marking requirement. While ASTM B 209 and ASTM B 209M require marking only when so specified on the purchase order, the new ASTM B 928 specification requires marking per ASTM B 666/B 666M on each and every plate or coil. B 928 requires marking to ASTM B 666/ B 666M both at the mill and, in situations where a marked coil is cut to length at the distributor, each plate or sheet must be marked by the distributor. Typical marking schemes are shown in Appendix 2.

Coiled sheet is spot marked in one or more rows near the outside end as shown in figure. Two marking schemes are used for aluminum plate or sheet depending on size and thickness of the product.

ASTM STANDARD IMPACT ON INDUSTRY AND THE FUTURE

The Future for ASTM B 928/B 928M

The new ASTM Standard B 928/B 928M will be published fall of 2003 and the manufacturers can start producing metal to the new standard immediately. The standard will remain a work in progress. It is expected that it will be revised this fall to include 5383-H116, -H321 and also 5059-H116 and -H321. Non marine alloys will continue to be specified by ASTM B 209 (and B 209M) which will be revised to remove the marine tempers. However, the ASTM B 209 revision will not occur immediately. In the interim, manufacturers will still be able to produce 5083-H116 and -H321 to the existing ASTM B 209 standard.

Shipyards will need to clearly specify on purchase orders that they are ordering B 928 material in order to be certain of receiving metal that will perform in marine service. It is important that purchase orders read, "this material shall meet the requirements of ASTM B 928/ B 928M." It is also important the yard check that the plate is appropriately marked upon receipt and that the mill and class certificates also reference ASTM B 928/ B 928M. Failure to follow these procedures may well result in repetition of the recent problems until existing inventories have been completely exhausted. It is possible that non marine plate may appear on the secondary market for a number of years.

The authors strongly encourage builders to specify the new standard on purchase orders immediately after its publication, as speedy acceptance of the new standard will, in all likelihood be customer driven.

Technical changes to the specification are also under consideration. It is planned to register both longitudinal and transverse tensile properties in the future. This change will better mirror some current classification society requirements and will give more reliable design data for naval architects. Primary stresses often occur in the long transverse direction, depending on vessel design and plate orientation, so plate performance in both directions is important.

After revision, ASTM B 209 will no longer specify the two, now exclusively, marine tempers (-H116 and -H321). The non marine material will be re-designated as 5083-H32 and 5456-H32. These will have the same tensile properties as the respective -H321 material but will not be required to be tested for corrosion resistance. The Aluminum Association Technical Committee on Product Standards intends to replace 5052-H321 with the designation H322, thus making the -H321 an exclusive marine temper. 5052 is not a high magnesium alloy and as such is not addressed by the new standard.

Future Testing and Research

As mentioned earlier the negative votes during the balloting of ASTM B 928 were based on the limited amount of data correlating between the ASTM G 67 test results and the samples' field performance in marine service. Much further testing is needed in this area. ASTM B 928 was based on the results available during mid 2003. It may need refinement in the future as the gaps in our knowledge are filled. There are currently two task group planning programs that will add credibility to the new ASTM B 928, both should commence work before the end of 2003. The first is a round robin study in which participating laboratories will compare G 67 results obtained to those from other laboratories and also to the microstructure of the specimen. Results are expected by Spring 2004. The second task group is testing the correlation between G 66 and G 67 results and samples exposed to salt water. This testing is scheduled to start by year end, but results are not expected for up to five years.

Conclusions

- Material specification ASTM B 209 is inadequate to ensure customers will receive aluminum alloys suitable for marine applications.
- To ensure satisfactory marine performance, material must pass both G 66 and G 67 test (as modified).
- ASTM B 928 provides the industry with an effective standard to ensure that intergranular corrosion is effectively eliminated from marine aluminum plate. The authors recommend that yards adopt the new standard as soon as possible and make personnel aware of the new documentation and marking.
- Until all existing stocks are used there may be some confusion. Buyers and materials departments need to be extra vigilant to avoid receiving unsuitable material.
- Builders need to press for classification societies beyond ABS to either endorse or assist with improvement of the new standard.
- The Solutions Team, with oversight and co-operation from the USCG, has effectively kept the affected vessels in service with minimal lost time and no compromise of passenger or cargo safety. They are well on the way to completing successful remediation. The process is an excellent case study in industry and government collaboration to solve complex, far-reaching problems.
- Aluminum designers, classification societies and ship builders must engage in the ongoing development of the new ASTM B 928 Standard. Aluminum plate manufacturing, like shipbuilding, is an ever evolving process and changes will occur in the future. Standards development must be a team effort between the producers and the shipbuilding industry. This recent incident involves multi-million dollar remediation. Similar material problems have occurred in the past. Are we willing to risk another event of this magnitude – or worse?

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2. American Society for Testing and Materials, "Designation: G 66, Standard Test Method for Visual Assessment of Exfoliation Corrosion Susceptibility of 5XXX Series Aluminum Alloys (ASSET Test)[1]," 1995 Annual Book of ASTM Standards – Metals Test Methods and Analytical Procedures, Philadelphia, Pennsylvania, 1995.

3. American Society for Testing and Materials, "Designation G 67, Standard Test Method for Determining the Susceptibility to Intergranular Corrosion of 5XXX Series Aluminum Alloys by Mass Loss After Exposure to Nitric Acid (NAMLT Test)[1]," 1995 Annual Book of ASTM Standards – Metals Test Methods and Analytical Procedures, Philadelphia, Pennsylvania, 1995.

4. USCG MSO Puget Sound, "Frequently Asked Questions," website http://www.uscg.mil/d13/units/msopuget/al_fracturing.htm

5. USCG, Navigation and Inspection Circular (NVIC) 11-80, "Structural Plan Review Guidelines for Aluminum Small Passenger Vessels," http://www.uscg.mil/hq/g-m/nvic/index.htm.

APPENDIX 1 – TEMPORARY PURCHASE SPECIFICATION

KVICHAK MARINE INDUSTRIES, INC. 469 NW Bowdin Place, Seattle WA USA
(206) 545-8485 (206) 545-3504

MATERIAL QUALITY AND DOCUMENTATION NOTICE

Applicability:	Aluminum plate, 5086 and 5083 alloys, all tempers
Issue Date:	2-21-02
From:	David C. Weed, VP Product Development, KMI
Internal release:	Corporate, Engineering, Estimating, Purchasing, MBB, Sales
External release:	All suppliers of aluminum plate
Implementation:	Immediate

1] Effective 2-21-03, Kvichak Marine Industries Inc. will require that the following tests be conducted and documented for all 5086 and 5083 aluminum plate prior to delivery to KMI.

2] All 5086 and 5083 plate of the –H32 and –H321 tempers will be tested per ASTM G66-99 for exfoliation corrosion. Complete and traceable documentation shall be provided indicating that all material delivered to KMI, or to a designated KMI subcontractor, exhibits no greater degradation that the PA (Code: pitting, Classification: A) rating of this test.

3] All 5086 and 5083 plate, in all tempers, will be tested per ASTM G-67-99 for intergranular corrosion. Complete and traceable documentation shall be provided indicating that all material delivered to KMI, or to a designated KMI subcontractor, has been so tested, and the test results shall be presented.

> **3A]** For all plate where testing causes a loss of less than 100mg/in² of mass, no further documentation is required.
>
> **3B]** For plate that loses over 100 mg/in² but less than 160mg/in², a sample of that plate shall be microscopically inspected by Northwest Laboratories of Seattle to establish whether or not the mass loss is the result of intergranular attack. Complete and traceable documentation of this inspection shall be provided prior to delivery.
>
> **3C]** Any plate that loses over 160mg/in² will not be accepted.

4] All testing referenced above shall be conducted by individuals and/or laboratories recognized by an accepted industry authority, such as USCG, ABS, DNV, LRS, or the American Association for Laboratory Testing Accreditation. Documentation from suppliers and/or manufacturing mills for specific lots or plate batches will be acceptable as long as a clearly traceable record, positively identifying each plate, is provided. Material will not be accepted without complete and traceable documentation.

-End-

APPENDIX 2 - ALUMINUM COIL AND PLATE MARKING

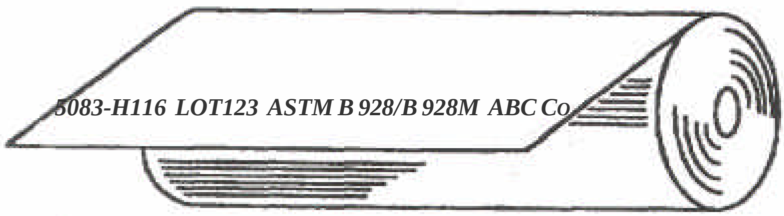

Fig. 1 Spot marking for coil sheet

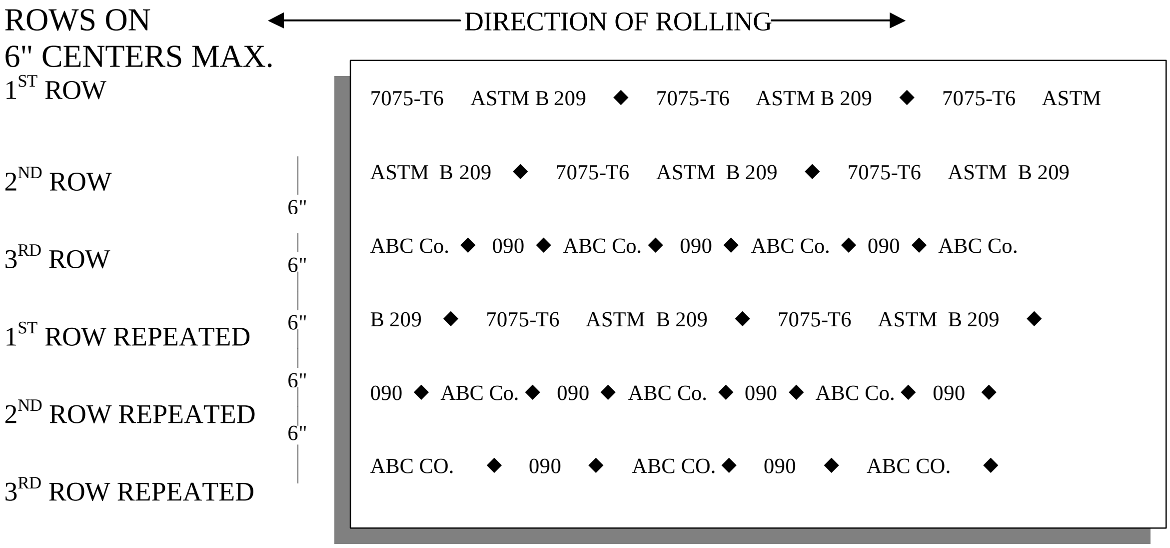

Fig. 2 Continuous marking for plate through 0.375" and flat sheet 0.012" and over (for O temper, 0.020" and over) in thickness, 6" through 60" in width, and through 200" in length

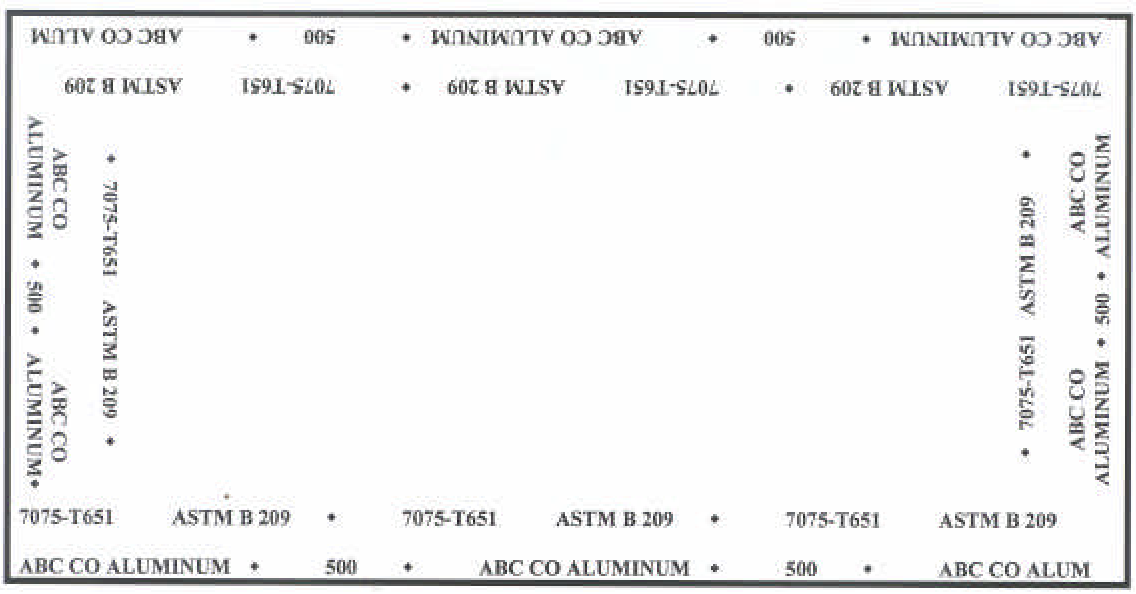

Fig. 3 Perimeter marking for plate over 0.375" thickness, flat sheet and plate over 60" in width or over 200" in length