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Mechanical buckling collapse testing on aluminum stiffened plate structures for marine applications

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SYNOPSIS

This paper summarizes the objectives and some progress of an on-going research project related to mechanical buckling collapse testing on aluminum stiffened plate structures, sponsored by Alcan Marine, France and Ship Structure Committee, USA. Unlike steel structures, the experimental test data on buckling collapse of aluminum stiffened plate structures is very lacking. Existing test data has mostly been obtained for plate-stiffener combination models or column type models rather than single or multi-bay stiffened panel models, with the focus on some specific types of collapse modes. No specific information regarding the fabrication related initial imperfections and softening in the heat affected zone (HAZ) due to welding is found in the literature. To address these issues, a research project, which involves an extensive test program, is on-going under the responsibility of the first author. Design of the test structures and the methods for measuring fabrication related initial imperfections are addressed in the present paper. Some preliminary results are presented, although the test program is on-going and the detailed test results will be reported separately in near future.
Note: The opinions expressed herein are the views of the authors and should not be interpreted as the views of the Naval Surface Warfare Center or the Department of the Navy, USA.

INTRODUCTION

The use of high strength aluminum alloys in shipbuilding provides many benefits but also many challenges. The benefits of using aluminum versus steel include lighter weight, which helps increase cargo capacity and/or reduce power requirements, excellent corrosion resistance and low maintenance. Challenges include reduced stiffness causing greater sensitivity to deformation, buckling, and plastic collapse, more susceptible to fatigue cracking, different welding practices and different health and safety concerns.

[1]The benefits noted above are well recognized for design and building of war ships, littoral surface crafts and littoral combat ships as well as fast passenger ships. The size of such ships is increasing, causing various design challenges compared to vessels with shorter length. In addition to aluminum alloys being less stiff than mild steel, no refined ultimate limit state (ULS) design methods involving local and overall ULS assessment exist unlike steel structures where plenty of related information exists. Lack of information on fabrication-related initial imperfections, including softening in the heat affected zone due to welding, can also make the design process uncertain. Theoretical and numerical methodologies for ULS design must of course be validated prior to their applications by comparisons with an experimental

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Authors' Biographies

Dr. Jeom Kee Paik is Professor of Ship Structural Mechanics, Department of Naval Architecture and Ocean Engineering, Pusan National University since 1989. Currently, Prof. Paik chairs the ISSC (International Ship and Offshore Structures Congress) Committee on Condition Assessment of Aged Ships, and the ISO (International Organization for Standardization) TC8/SC8 Working Group on Strength Assessment of Ship Structures with focus on limit states. Prof. Paik is Editor-in-Chief of Ships and Offshore Structures (An International Journal), and he is the author of the textbook titled 'Ultimate Limit State Design of Steel-Plated Structures', published by John Wiley & Sons (2003). Prof. Paik is now in the middle of writing another book titled 'Advanced Engineering for Ship-Shaped Offshore Installations' to be published by Cambridge University Press (2006). **Dr. Jae Myung Lee** is Assistant Professor of the same Department to Prof. Paik. **Mr. Jung Yong Ryu** and **Mr. Jun Ho Jang** are graduate students under the supervision of Prof. Paik. **Dr. Celine Renaud** graduated from the French Institute of Advanced Mechanics in 1999 and received her PhD in Reliability, Structure and Engineering at the University Blaise Pascal (France, 63) in 2002. Then she was a Lecturer and Researcher at 'Laboratory of Mechanics of Naval and Offshore Structures' in Brest, France, an Engineer School and Lab with strong marine competencies. She directed several R&D projects related to marine structures. Now, she works in the Alcan's T&I Marine team as a Marine Market Development Manager, and is situated at Alcan's Issoire Plant, France. **Dr. Paul E. HESS III** is a naval architect at the Naval Surface Warfare Center, Carderock Division where he began his career in 1989. Dr. Hess earned his B.S. and M.S. in Aerospace and Ocean Engineering at the Virginia Polytechnic Institute and State University, and completed his Ph.D. in Reliability Engineering at the University of Maryland. Dr. Hess has experience in surface ship structural analysis, design applications and structural reliability. Most recently, Dr. Hess has been heavily involved in conducting reliability and risk studies for the US Navy. His areas of expertise include structural reliability analysis and tool/process development (metallic and composite); development of reliability-based design criteria; probabilistic and statistical data analysis; and ship structural failure analysis.

database.

Hopperstad et al [1,2], Matsuoka et al [3] and Zha & Moan [4] carried out mechanical collapse testing on aluminum structures. Almost all existing test data are of plate-stiffener combination models in small scale, except for those by Matsuoka et al [3] which were multi-bay stiffened panel models with the focus on flexural-torsional buckling (or tripping). All existing test data are on limited / specific collapse mode(s), e.g., beam-column type collapse or tripping. No test data representing systematic characterization of various collapse modes possible for aluminum stiffened plate structures is found in the literature. It is recognized that possible collapse modes can be categorized into six types, namely overall collapse (Mode I), biaxial compressive collapse (Mode II), beam-column type collapse (Mode III), local buckling of stiffener web (Mode IV), lateral-torsional buckling of stiffeners (Mode V) and gross yielding (Mode VI) similar to those of steel plated structures [5].

An extensive test program under the responsibility of the first author was then initiated by the sponsorship of Alcan Marine, France and Ship Structure Committee, USA. Hanjin Heavy Industries and Construction Co., Korea is also involved as the fabricator of the test structures. Multi-bay, full scale stiffened panels representative of structure found in 80m long fast ships are tested under axial compressive loads until and after the ULS is reached. A total of 78 test structures are considered with varying parameters for design and building including material types (5083, Sealium, 6082), stiffener types (flat, built-up Tee, extruded Tee), plate thickness (5mm~8mm), stiffener web thickness (4mm~8mm), stiffener web height (40mm~140mm) and test structure size. There are no replicates being tested for any particular combination of parameters.

The objective of the present test program is to obtain a systematic test database on full scale aluminum stiffened plate structures in terms of buckling collapse patterns and fabrication related initial imperfections. The test results will be very useful for better understanding the buckling collapse characteristics of aluminum stiffened plate structures. They will be used for a validation basis of theoretical and numerical ULS assessment methods. Relevant tolerance of fabrication related initial imperfections can also be identified. This paper focuses on the design of test plate structures and the techniques for measuring fabrication related initial imperfections.

ALUMINUM ALLOY

Table 1 compares the properties between aluminum alloy and steel. The density of aluminum alloy is one thirds that of steel, while the elastic modulus of aluminum alloy is one thirds that of steel. This is a unique feature of aluminum alloy that provides benefits and challenges. Table 2 indicates designation of aluminum alloy groups. 5xxx and 6xxx series whose yield strength is in the range of 200~350MPa comparable to the strength of mild steel are usually employed for marine applications.

The temper is a significant aspect in terms of the nonlinear structural behavior of aluminum structures. The basic temper designations consist of letters and numerals followed by the letter. Three types of the letter are usually relevant, namely

- F – as fabricated with no special control related to thermal or strain-hardening treatments,
- O – fully annealed to obtain the target strength conditions,
- H – strain-hardened to improve the strength, with or without thermal treatments,
- T – thermally treated to produce stable tempers other than F, O or H.

H or T tempers are typically adopted for aluminum alloys of marine applications. The H is always followed by two or more digits. The first digit representing the alloy production method is usually given as 1 – strain-hardened only, 2 – strain-hardened and then partially annealed, and 3 – strain-hardened and then thermally stabilized. The second digit representing the degree of strain-hardening in the final temper state is given by a numeral with 1 – eighth hard, 2 – quarter hard, 4 – half hard, 6 – three quarter hard, 8 – hard and 9 – extra hard. A third digit may be considered to indicate a specific condition of the basic two tempers resulting in a significance difference in mechanical properties.

The T is always followed by one or two digits. The first digit represents the degree of heat or ageing treatments with 1 – cooled from an elevated temperature shaping process (extrusion), 3 – heat-treated, cold-worked and the naturally aged, 4 – heat-treated and naturally aged, 5 – cooled from an elevated temperature shaping process and then artificially aged, 6 – heat-treated and then artificially aged, 8 – heat-treated, cold-worked and then artificially aged, and 9 – heat-treated, artificially aged and then cold-worked. Additional digits may be added to represent the different temper conditions resulting in significant differences in the alloy properties.

Table 1 Comparison of the properties between aluminum alloy and steel

Property	*Density (kg/m^3)*	*Electrical conductivity (%)*	*Thermal conductivity (W/m^oC)*	*Thermal expansion ($10^{-6}/^oC$)*	*Specific heat (J/kg^oC)*	*Melting point (^oC)*	*Elastic modulus (N/mm^2)*
Aluminum	2,700	62	222	23.6	940	660	70,000
Steel	7,850	10	46	12.6	496	1,350	207,000

One typical standard material type for plating has been 5083, while that for stiffeners is 6082, where H116 tempers are typically applied for plating, and T6 tempers are taken for stiffeners. It is however interesting to note that 5083 was not developed originally for marine applications, but was developed for applications to land-based structures and other types. By considering that the operational environments of marine structures, e.g., exposed to acid attack or corrosion, are different from those of land-based structures, a new material, 5383 sold by Alcan, France under the brand name 'Sealium' is an advanced alloy that has been optimized to be suitable under marine environments. The mechanical properties of Sealium are slightly better than 5083 as indicated in Table 3. For Sealium (5383), H116 temper is usually taken for sheets and plating, while H112 temper is taken for extruded stiffeners.

Table 2 Classification of aluminum alloy

Alloy	*Major alloying element*	*Alloy number*
Pure aluminum		1xxx
Aluminum alloy	Copper	2xxx
	Manganese	3xxx
	Silicon	4xxx
	Magnesium	5xxx
	Magnesium and silicon	6xxx
	Zinc	7xxx
	Other elements	8xxx
Experimental alloy		9xxx

Table 3 Mechanical properties of typical aluminum alloys for marine applications [6,9]

Alloy and temper	*Yield strength of base metal (MPa)*	*Yield strength of welded metal (MPa)*	*Tensile strength of base metal (MPa)*	*Elongation of base metal (%)*
5083-H116	215	144	305	10~12
5383-H116	220	154	305	10
6082-T6	260	138	310	8~10

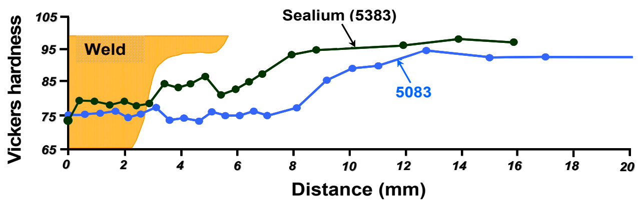


Fig 1 Comparison of hardness at weld and base metal for 5083 and Sealium (5383)

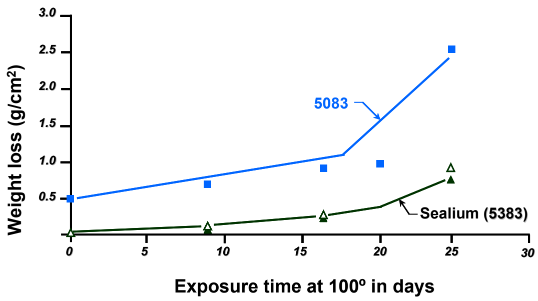


Fig 2 Comparison of resistance against acid attack for 5083 and Sealium (5383)

Figure 1 compares the hardness at welds and base metal for 5083 and Sealium [7]. Figure 2 compares the resistance against acid attack such as corrosion for 5083 and Sealium [7]. It is evident from Figs. 1 and 2 that Sealium is more appropriate for marine applications than 5083.

DESIGN OF TEST STRUCTURES

The configuration of aluminum stiffened plate structures is similar to that of steel stiffened plate structures as illustrated in Fig.3. Test structures are designed in terms of single and multi-bay stiffened panels in full scale equivalent to those found in 80m long, aluminum, fast ship structures. To cover various collapse mode patterns possible for aluminum stiffened plate structures, the range of design variables considered are as follows:

- Panel breadth: B = 1000 mm
- Stiffener spacing: b = 300 mm (with stiffeners on free edges as shown in Fig 4)
- Panel length: 1000 mm (one bay), 1200 mm (one bay), 3000 mm (three bays of 1000 mm length)
- Material types: plate – 5083-H116, Sealium (5383-H116), stiffeners – 5083-H116, Sealium (5383-H112 or 5383-H116), 6082-T6
- Thickness: plate – 5 mm, 6 mm, 8 mm, stiffeners – 4 mm, 5 mm, 6 mm, 8 mm
- Stiffener types: flat, built-up Tee, extruded Tee
- Stiffener web height: 60 mm, 70 mm, 80 mm, 90 mm, 100 mm, 120 mm, 140 mm

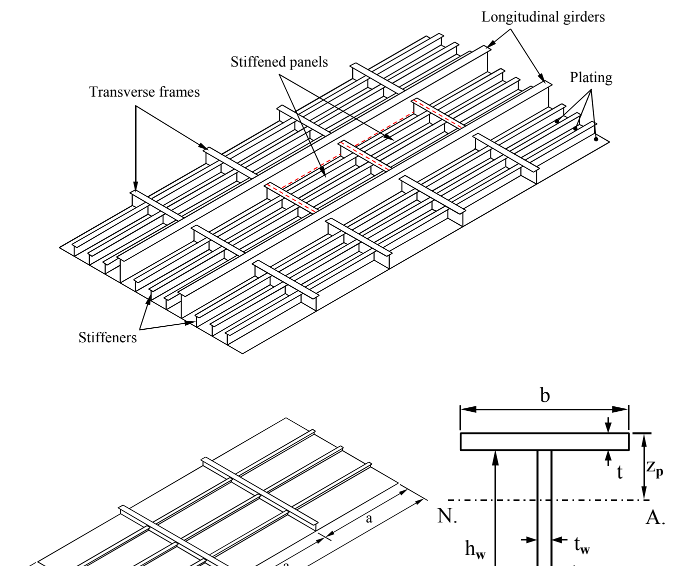
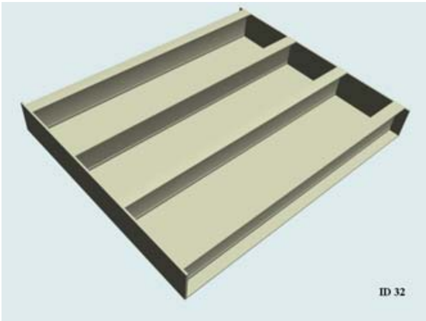


Fig 3 Typical configuration of aluminum stiffened plate structures and its nomenclature (N.A. = neutral axis)



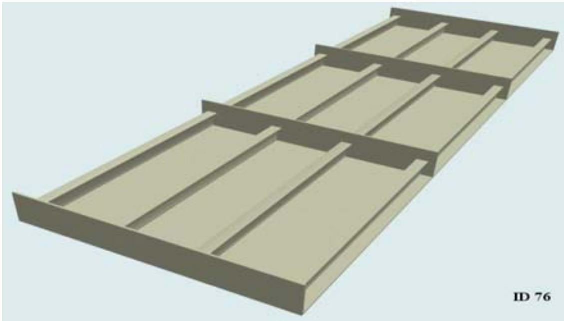


Fig 4 One bay (left) and three bay (right) test structures

It is recognized that rotational restraints along transverse frames in a continuous stiffened plate structure can play a role in the panel collapse behavior. In this regard, three bay test structures as shown in Fig.4 are considered while most of the test program are considered to one bay test structures. Table 4 indicates the list of test structures including a total of 75 one bay structures and a total of 3 three bay structures.

Table 4 List of test structures

One bay test plate structures (1200 mm × 1000 mm) with no replications:

ID	*Plate*		*Stiffener*					
	t(mm)	*Alloy and temper*	*Type*	*h_w(mm)*	*t_w(mm)*	*b_f(mm)*	*t_f(mm)*	*Alloy and temper*
1	5	5083-H116	Extruded Tee	55.7	3.7	40	(6.7)	5383-H112
2	5	5083-H116	Extruded Tee	66.1	4	40	(5.7)	5383-H112
3	5	5083-H116	Extruded Tee	76.8	4	45	(5.6)	5383-H112
4	5	5083-H116	Extruded Tee	135	6	55	(8.2)	5383-H112
5	6	5083-H116	Extruded Tee	55.7	3.7	40	(6.7)	5383-H112
6	6	5083-H116	Extruded Tee	66.1	4	40	(5.7)	5383-H112
7	6	5083-H116	Extruded Tee	76.8	4	45	(5.6)	5383-H112
8	6	5083-H116	Extruded Tee	135	6	55	(8.2)	5383-H112
9	8	5083-H116	Extruded Tee	55.7	3.7	40	(6.7)	5383-H112
10	8	5083-H116	Extruded Tee	66.1	4	40	(5.7)	5383-H112
11	8	5083-H116	Extruded Tee	76.8	4	45	(5.6)	5383-H112
12	8	5083-H116	Extruded Tee	135	6	55	(8.2)	5383-H112
13	5	5083-H116	Extruded Tee	55.7	3.7	40	(6.7)	6082-T6
14	5	5083-H116	Extruded Tee	66.1	4	40	(5.7)	6082-T6
15	5	5083-H116	Extruded Tee	76.8	4	45	(5.6)	6082-T6
16	5	5083-H116	Extruded Tee	135	6	55	(8.2)	6082-T6
17	6	5083-H116	Extruded Tee	55.7	3.7	40	(6.7)	6082-T6

18	6	5083-H116	Extruded Tee	66.1	4	40	(5.7)	6082-T6
19	6	5083-H116	Extruded Tee	76.8	4	45	(5.6)	6082-T6
20	6	5083-H116	Extruded Tee	135	6	55	(8.2)	6082-T6
21	8	5083-H116	Extruded Tee	55.7	3.7	40	(6.7)	6082-T6
22	8	5083-H116	Extruded Tee	66.1	4	40	(5.7)	6082-T6
23	8	5083-H116	Extruded Tee	76.8	4	45	(5.6)	6082-T6
24	8	5083-H116	Extruded Tee	135	6	55	(8.2)	6082-T6
25	5	5383-H116	Extruded Tee	55.7	3.7	40	(6.7)	5383-H112
26	5	5383-H116	Extruded Tee	66.1	4	40	(5.7)	5383-H112
27	5	5383-H116	Extruded Tee	76.8	4	45	(5.6)	5383-H112
28	5	5383-H116	Extruded Tee	135	6	55	(8.2)	5383-H112
29	6	5383-H116	Extruded Tee	55.7	3.7	40	(6.7)	5383-H112
30	6	5383-H116	Extruded Tee	66.1	4	40	(5.7)	5383-H112
31	6	5383-H116	Extruded Tee	76.8	4	45	(5.6)	5383-H112
32	6	5383-H116	Extruded Tee	135	6	55	(8.2)	5383-H112
33	8	5383-H116	Extruded Tee	55.7	3.7	40	(6.7)	5383-H112
34	8	5383-H116	Extruded Tee	66.1	4	40	(5.7)	5383-H112
35	8	5383-H116	Extruded Tee	76.8	4	45	(5.6)	5383-H112
36	8	5383-H116	Extruded Tee	135	6	55	(8.2)	5383-H112
37	5	5083-H116	Flat	60	5	-	-	5083-H116
38	5	5083-H116	Flat	90	5	-	-	5083-H116
39	5	5083-H116	Flat	120	5	-	-	5083-H116
40	6	5083-H116	Flat	60	6	-	-	5083-H116
41	6	5083-H116	Flat	90	6	-	-	5083-H116
42	6	5083-H116	Flat	120	6	-	-	5083-H116
43	8	5083-H116	Flat	60	8	-	-	5083-H116
44	8	5083-H116	Flat	90	8	-	-	5083-H116
45	8	5083-H116	Flat	120	8	-	-	5083-H116
46	5	5083-H116	Flat	60	5	-	-	5383-H116
47	5	5083-H116	Flat	90	5	-	-	5383-H116
48	5	5083-H116	Flat	120	5	-	-	5383-H116
49	6	5083-H116	Flat	60	6	-	-	5383-H116
50	6	5083-H116	Flat	90	6	-	-	5383-H116
51	6	5083-H116	Flat	120	6	-	-	5383-H116

52	8	5083-H116	Flat	60	8	-	-	5383-H116
53	8	5083-H116	Flat	90	8	-	-	5383-H116
54	8	5083-H116	Flat	120	8	-	-	5383-H116
55	5	5383-H116	Flat	60	5	-	-	5383-H116
56	5	5383-H116	Flat	90	5	-	-	5383-H116
57	5	5383-H116	Flat	120	5	-	-	5383-H116
58	6	5383-H116	Flat	60	6	-	-	5383-H116
59	6	5383-H116	Flat	90	6	-	-	5383-H116
60	6	5383-H116	Flat	120	6	-	-	5383-H116
61	8	5383-H116	Flat	60	8	-	-	5383-H116
62	8	5383-H116	Flat	90	8	-	-	5383-H116
63	8	5383-H116	Flat	120	8	-	-	5383-H116
64	5	5083-H116	Built-up Tee	100	5	60	5	5083-H116
65	6	5083-H116	Built-up Tee	60	5	60	5	5083-H116
66	8	5083-H116	Built-up Tee	100	5	60	5	5083-H116
67	5	5083-H116	Built-up Tee	80	5	60	5	5383-H116
68	6	5083-H116	Built-up Tee	60	5	60	5	5383-H116
69	8	5083-H116	Built-up Tee	100	5	60	5	5383-H116
70	5	5383-H116	Built-up Tee	80	5	60	5	5383-H116
71	6	5383-H116	Built-up Tee	60	5	60	5	5383-H116
72	8	5383-H116	Built-up Tee	100	5	60	5	5383-H116

One bay test plate structures (1000 mm × 1000 mm):

ID	*Plate*		*Stiffener*					
	t(mm)	*Alloy and temper*	*Type*	*h_w(mm)*	*t_w(mm)*	*b_f(mm)*	*t_f(mm)*	*Alloy and temper*
73	6	5083	Extruded Tee	76.8	4	45	(5.6)	6082-T6
74	8	5083	Extruded Tee	135	6	55	(8.2)	6082-T6
75	8	5383	Extruded Tee	135	6	55	(8.2)	5383-H112

Three bay test plate structures (3000 mm × 1000 mm):

ID	*Plate*		*Stiffener*					
	t(mm)	*Alloy and temper*	*Type*	*h_w(mm)*	*t_w(mm)*	*b_f(mm)*	*t_f(mm)*	*Alloy and temper*
76	6	5083-H116	Extruded Tee	76.8	4	45	(5.6)	6082-T6
77	8	5083-H116	Extruded Tee	135	6	55	(8.2)	6082-T6
78	8	5383-H116	Extruded Tee	135	6	55	(8.2)	5383-H112

Notes: t = plate thickness, h_w = web height (excluding flange thickness), t_w = web thickness, b_f = flange breadth, t_f = flange thickness,

t_f in bracket indicates the value equivalent to the usual built-up Tee section with the same moment of inertia as a single plate-stiffener combination.

FABRICATIONS OF TEST STRUCTURES

All aluminum alloy sheets and extrusions have been shipped by containers from Alcan Marine, France to Pusan National University, Korea. Virgin aluminum alloy sheets were cut by laser cutting machine in Korea. Tensile coupon testing was undertaken to investigate the mechanical properties (e.g., elastic moduus, yield stress, ultimate tensile stress, fracture strain) of each type of material sheets. While various methods for fabricating aluminum ship structures are relevant, namely metal inert gas (MIG) welding, tungsten inert gas (TIG) welding, laser welding and friction stir welding (FSW), the present test program adopts MIG welding technique with 5183 filler metal alloy, which is now one of the most popular methods. Test structures have been fabricated by Hanjin Heavy Industries & Construction Co., Ltd. in Korea. Figure 5 shows a typical order of welding where most welding is performed by a welding robot, while manual welding is minimized by applying to keep stiffeners in the upright position.

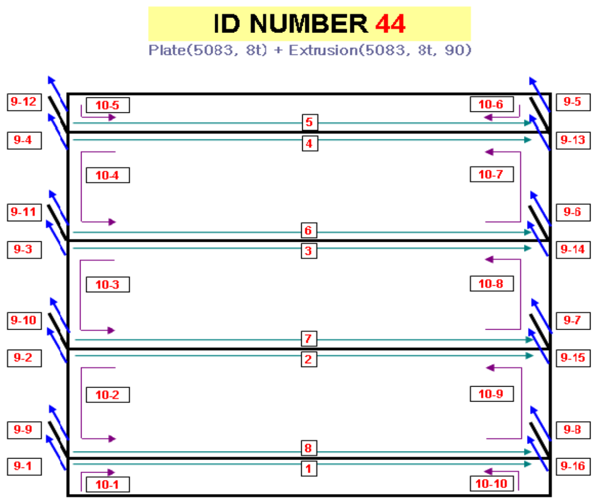


Fig 5 Welding process upon the fabrication of test structures

FABRICATION RELATED INITIAL IMPERFECTIONS

Due to cutting and welding, fabrication related initial imperfections are essentially developed in the structures and they play a significant role in the buckling collapse behavior. The following types of fabrication related initial imperfections must be considered for aluminum structures, namely

- Initial distortions and their shapes: plate initial deflection, column type initial deflection of stiffeners, sideways initial deflection of stiffeners (Fig 6)
- Residual stresses: residual stress in plating between stiffeners, residual stress in stiffener web (Fig 7)
- Softening in the heat affected zone (Fig 8)

Some useful estimates of fabrication related initial imperfections for welded steel structures have been developed based on measurements of steel ship structures and are as follows [5,8]

$$w_o = C_1 \beta^2 t, \; w_{oc} = C_2 a, \; \sigma_{rc} = -C_3 \sigma_Y, \; \beta = b/t\left(\sqrt{\sigma_Y / E}\right)$$

where w_o = maximum amplitude of plate initial deflection, w_{oc} = maximum amplitude of column type initial deflection of stiffeners, σ_{rc} = compressive residual stress, b = plate breadth, t = plate thickness, E = elastic modulus, σ_Y = yield strength, a = plate length, C_1 = plate initial deflection constant (0.025 for slight level, 0.1 for average level, 0.3 for severe level), C_2 = column type initial deflection constant (0.0015 for average level), C_3 = welding residual stress constant (0.05 for slight level, 0.15 for average level, 0.3 for severe level).

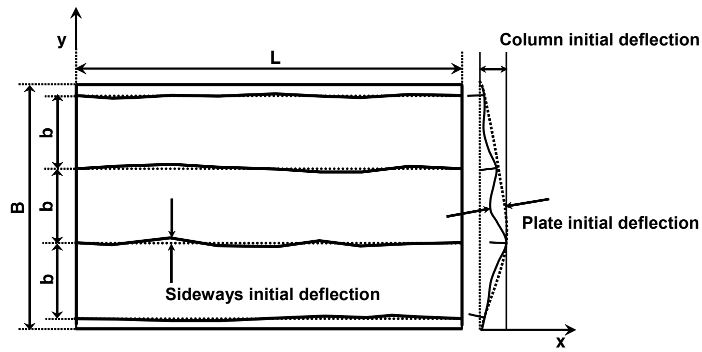


Fig 6 Configuration of fabrication related initial distortions

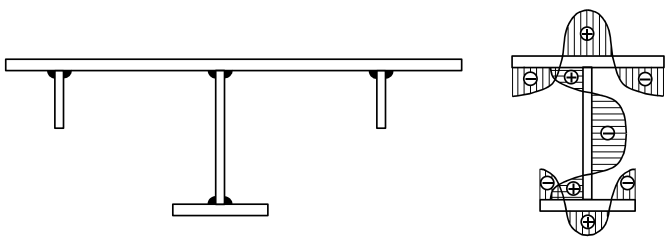


Fig 7 Configuration of fabrication related residual stresses

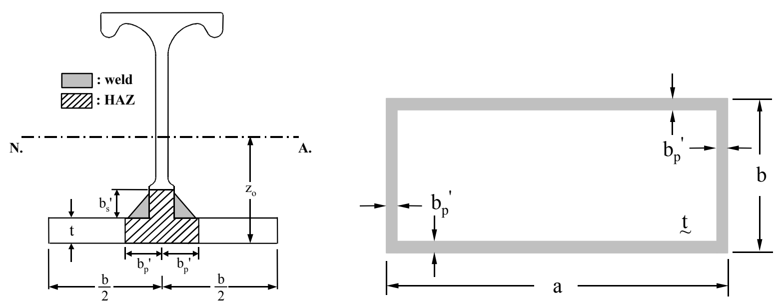


Fig 8 Softening areas in the heat affected zone

In contrast to steel structures, there is no refined guidance to identify the level of fabrication related initial imperfections for aluminum structures. This study will then develop similar expressions of fabrication related initial imperfections based on measurements of aluminum stiffened plate structures.

Furthermore, softening phenomenon occurs in the heat affected zone of welded aluminum structures as illustrated in Fig.8. The reduction ratio of yield strength at the welds or softening area is known to be over 30~50% compared to the yield strength of base metal, as indicated in Table 3 [9]. Because of softening in the heat affected zone, the ultimate strength of stiffened panel can be reduced by over 15% depending on panel geometries [10]. In addition to the yield strength reduction itself in the heat affected zone, the breadth of softening areas as illustrated in Fig.8 also plays an important role. Typically, the so-called 1-in rule (25 mm) or 3t rule (3 times plate thickness) is often adopted to define the breadth of the softening areas [11]. However, since this factor significantly affects the panel plastic collapse behavior, some experimental verification is required. The present test program will also develop the guidance to identify the characteristics of the heat affected zone including softening.

In the present test program, the characteristics of all fabrication related initial imperfections for aluminum plated structures are identified by direct measurements. Dial gauges are used for measuring the initial distortions and their shapes. Figure 9 shows a typical example of initial deflections measured for one bay test structures.

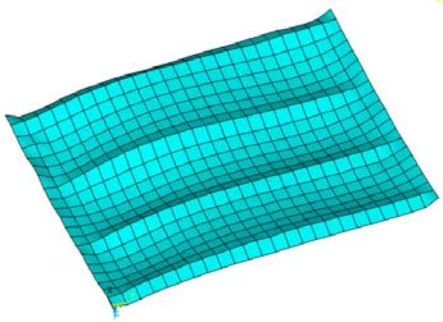


Fig 9 Typical example of fabrication related initial deflection measurements

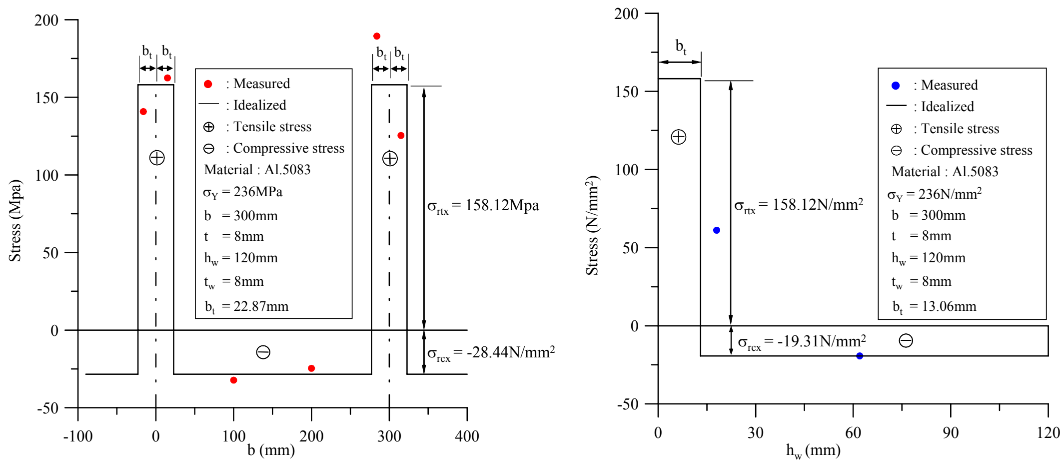


Fig 10 Typical example of fabrication related residual stress measurements together with softening in the heat affected zone

Welding induced residual stresses are measured by the technique of a drilled hole where the release of strain components in three principal directions is detected by strain gauges after drilling a hole close to each strain gauge. Once three principal strain components are measured, the residual stress components can be theoretically obtained from the relationship between stress and strain.

Statistical analysis of the measurements will be performed to identify the level of fabrication related initial imperfections with mean and standard deviation. Figure 10 shows a typical example of welding residual stresses in plating and stiffener web together with the breadth of the heat affected zone equivalent to the breadth of softening area.

SHAKE-DOWN TEST OF WELDING RESIDUAL STRESSES

It has been said that welding induced residual stresses may be released to some extent after cyclic loading of the structures while in service [11]. To examine this phenomenon quantitatively, some physical model tests are performed in the present test program. Butt-welded aluminum plate strips as shown in Fig.10, one for 5083 and the other for Sealium are tested. The test strip was also fabricated by the same welding machine of Hanjin Heavy Industries & Construction, Co., Ltd. Filler wire for welding is 5183 aluminum alloy. A 3-point cyclic bending test is undertaken; a line load at the plate strip center is cyclically applied to generate sagging and hogging in the plate strip, as shown in Fig.11. The magnitude of cyclic loads is two types, namely extreme or high cycle load. The former type of load is considered for plastic collapse aspect, while the latter is important for fatigue and fracture issue at welds. Welding residual stresses are measured before and after the load cycle. While the testing is still on-going, some 30% of welding residual stresses have been released by the extreme type of load cycles.

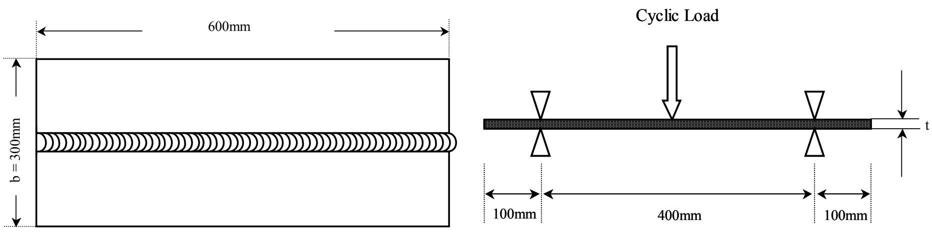


Fig 11 Test set-up for shake-down simulations of welding residual stresses

BUCKLING COLLAPSE TEST SET-UP

Large test frame, 9.2 m (test bed length) × 2.4 m (test bed breadth) × 4.42 m (frame height), of Pusan National University is used for the testing. Figure 12 shows an overview of the test set-up. A 2000 kN actuator controlled by the hydraulic system is used to apply the axial compressive loads. The loaded edges are set to be simply supported keeping them straight.

The loads are applied at the line of the elastic neutral axis of the stiffened panel cross-section so that no eccentricity is developed before the elastic limit is reached. The unloaded edges are set by jigs to be simply supported and straight. The loads are applied until and after the test structures reach the ultimate limit state. The loads and axial shortening during the testing are automatically detected by data acquisition systems.

Figure 13 shows typical collapse patterns observed from the testing with varying the dimensions and geometry of the structures. It is evident that aluminum stiffened plate structures collapse by beam-column type collapse mode, local buckling of stiffened web or lateral-torsional buckling of stiffeners.

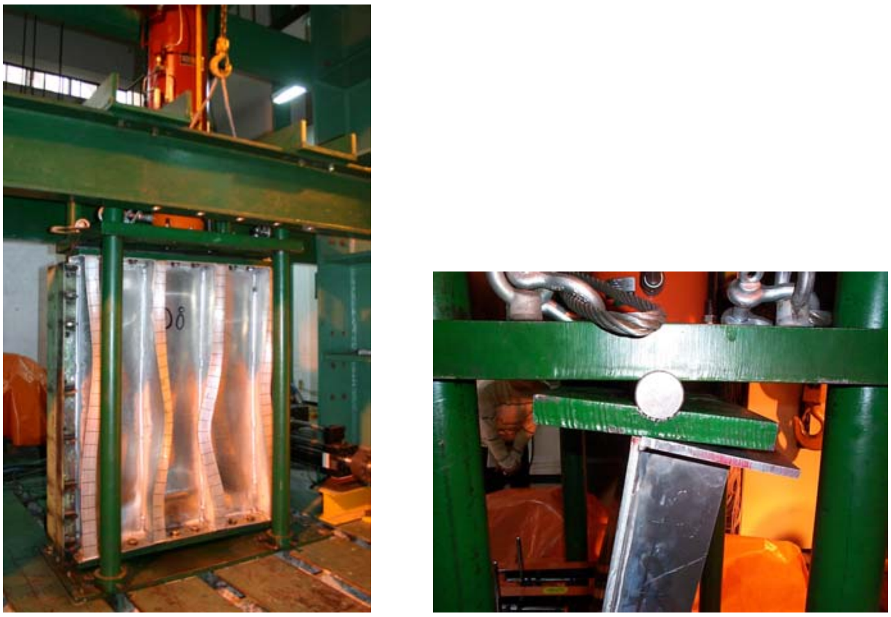


Fig 12 An overview of the buckling collapse test set-up after testing

Fig 13 Typical collapse modes observed during the buckling collapse testing on aluminum plated structures

CONCLUDING REMARKS

Although some mechanical collapse tests on aluminum structures have been previously performed in the literature, it is recognized that there is a need for more exhaustive parametric mechanical collapse testing, especially as concerns of more realistic geometries and properties. An extensive test program started in this regard and the present paper outlines the objectives and adequacy of the test program with some preliminary test results, while the detailed test results will be reported in near future. It is our belief that the insights to be developed from the test program will contribute to a large extent to the advancement of core technologies for ultimate limit state design and strength assessment of large aluminum fast ship structures.

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