Technology for a Sustainable World

GTT Inside

The GTT newsletter - April 2021 - n° 21

Message from Jean-Baptiste Boutillier, Innovation VP of GTT

GTT is very proud to propose to its clients innovative solutions. This issue of GTT Inside will highlight four of these latest important innovations, some of which have required several years of work to our teams.

Since the last issue, and the issuance of the first AIP, GTT has built, in our premises, a mock up for the NO96 SUPER+ to validate the assembly. Shipyards can now propose to their clients a LNG containment system with a double metallic barrier and with a Boil of Rate of 0,085% (for the current standard size design of LNG Carrier of 174.000 m^3).

Our long lasting expertise in metallic materials enabled us to develop with APERAM a new alloy: CRYOSTAL®, which associates the advantages of INVAR® and stainless steel. CRYOSTAL® combines advantageous features: limited thermal contraction, corrosion resistance, good weldability, and a competitive cost. We outline this new alloy, which is compliant with the *"Guidelines for the Acceptance of Alternative Metallic Materials for Cryogenic service in ships carrying liquefied gases in bulks and ships using gases or other low flashpoints fuel" (*MSC.1/Circ1622 ; 2nd December 2020), and thus applicable to LNG applications.

To encourage flexibility, GTT has worked with ABS on the notation *"LNG Cargo ready"* to enable Ethane carriers to be available to carry LNG. We therefore support the flexibility requested by the market.

GTT is at the forefront of innovation by designing the LNG tank for the world first and largest LNG fuel retrofit. GTT has developed several solutions to enable such LNG retrofits, but also provides to its clients several support services to ensure success in operation.

Have a good and interesting read.

Jean-Baptiste BOUTILLIER

INNOVATION

CRYOSTAL® - A new corrosion resistant cryogenic alloy for GTT membrane technologies

For GTT membrane technologies, austenitic stainless steels and Fe-36%Ni alloys, typically INVAR®, have been successfully employed as they ensure the required strength, toughness and structural stability at cryogenic temperatures. These two metallic solutions may have reached their limits in an increasingly technologically challenging era for the LNG market.

In 2014, GTT and APERAM Alloys decided to launch a development of a new metallic alloy to be incorporated into GTT membrane technologies.

The Metallic Material & Welding Department of GTT and APERAM Alloys Research Center jointly led this project.

The main objective was to propose a new breakthrough material for the enhancement of existing system competitiveness by providing the best compromise between different properties:

- Enhanced mechanical properties and good toughness at cryogenic temperatures;
- Limited thermal contraction;

- Good formability;
- Corrosion resistance;
- Good weldability;
- Competitive cost.

Alloy development phase

Laboratory screening

An intensive bibliographic study has been carried out on a large number of academic articles, patents and industrial data. Based on this overview, a laboratory screening has been launched over 12 chemical compositions split into four families, proposed by GTT and APERAM Alloys metallurgists.

Twelve lab castings have been produced and hot rolled to 4 - 5mm thick slabs at the Research Center of APERAM Alloys Imphy.

The hot rolled slabs have been sampled and characterized in order to evaluate the mechanical and thermal properties, toughness and weldability of the produced steels.

Based on this first screening, a promising chemical composition has been identified for the next milestone of the project: the semi-industrial trial.

A new alloy was born; CRYOSTAL®. It is a mixture composed of a significant amount of Manganese, with a Chromium content close to that of a stainless steel as well as a small percentage of Nickel and Nitrogen.

This new metallic solution is not a conventional high-manganese steel but a high-manganese austenitic alloy: even though there is a large manganese content, other alloying elements were also added.

This new alloy meets the technical requirements in term of mechanical properties, ductility at cryogenic temperatures as well as corrosion resistance.

Moreover, impurities such as Sulphur and Phosphorus were limited to improve weldability.

Semi-industrial trial

Two semi-industrial casts of 50kg each have been then produced and cold rolled to a thickness of 1.0mm. Examples of the produced material are shown in Figure 1.

Figure 1: High Manganese 1mm thick sheets – semi-industrial trial

This step was crucial since as it permitted the verification of the feasibility of the chosen chemical composition and the optimisation of some process parameters before the industrial stage.

Different characterization tests have been carried out in order to evaluate the thermal and mechanical properties, corrosion and weldability behaviour of the elaborated material. The results obtained were very promising and the materials produced showed very interesting properties compared to usual cryogenic metallic materials such as 304L stainless steel and Fe-36%Ni alloy.

The cast is characterized by a high toughness at cryogenic temperature and a lower thermal expansion coefficient compared to stainless steels. In addition, the enhanced mechanical strength and the structural stability at low temperatures and after welding have been highlighted. The weldability of the semi-industrial product has been successfully assessed using Varestraint and Cross-Bead tests.

Moreover, impurities such as Sulphur and Phosphorus were limited to improve weldability.

Industrial Product

Based on these encouraging results obtained on the semi-industrial cast, an industrial trial (cast of 120 tons) has been launched in 2019 at APERAM Group industrial facilities. The main objective of this step was to identify potential issues and risks during the casting and the processing of this new material and any corresponding improvements.

The process route used for the production of this new material was similar to other stainless steel products using an electric arc furnace and a continuous casting process. Special management of different parameters was necessary in order to avoid and/or reduce some issues related to the specific chemical composition.

This industrial trial has been a success and two thicknesses have been produced: 0.7mm and 1.0mm.

Results & advantages of CRYOSTAL®

A new international standard

As mentioned above, this alloy is a new metallic material and it was essential that its chemical composition be recognized in an international standard.

GTT has been working together with APERAM Alloys to register this new material. This work has successfully led to the proposal and the approval of the international standard ISO 23430 dealing with the specification of high manganese austenitic steel thin strips used for LNG tanks on board ships.

C	Mn	P	S	Al	Si	Ni	Cr	N
0.05 max	24.0 to 34.0	0.020 max	0.010 max	0.10 max	0.35 max	0.50 to 3.50	7.50 to 12.50	0.05 to 0.25

Table 1: Chemical composition of high manganese austenitic alloy (%wt)

Mechanical characteristics

A testing campaign has been carried out in order to characterize the properties of the High Manganese alloy for both 0.7mm and 1.0mm thicknesses.

Figure 2 compares the mechanical properties obtained of our metallic alloy CRYOSTAL® with 304L stainless steel and Fe-36%Ni alloy; both used in GTT technologies.

Our high-manganese alloy CRYOSTAL® shows an enhanced mechanical strength at both ambient and cryogenic temperatures. The relatively lower thermal expansion coefficient allows a non-negligible reduction of the thermal stresses induced by temperature gradient compared to stainless steel.

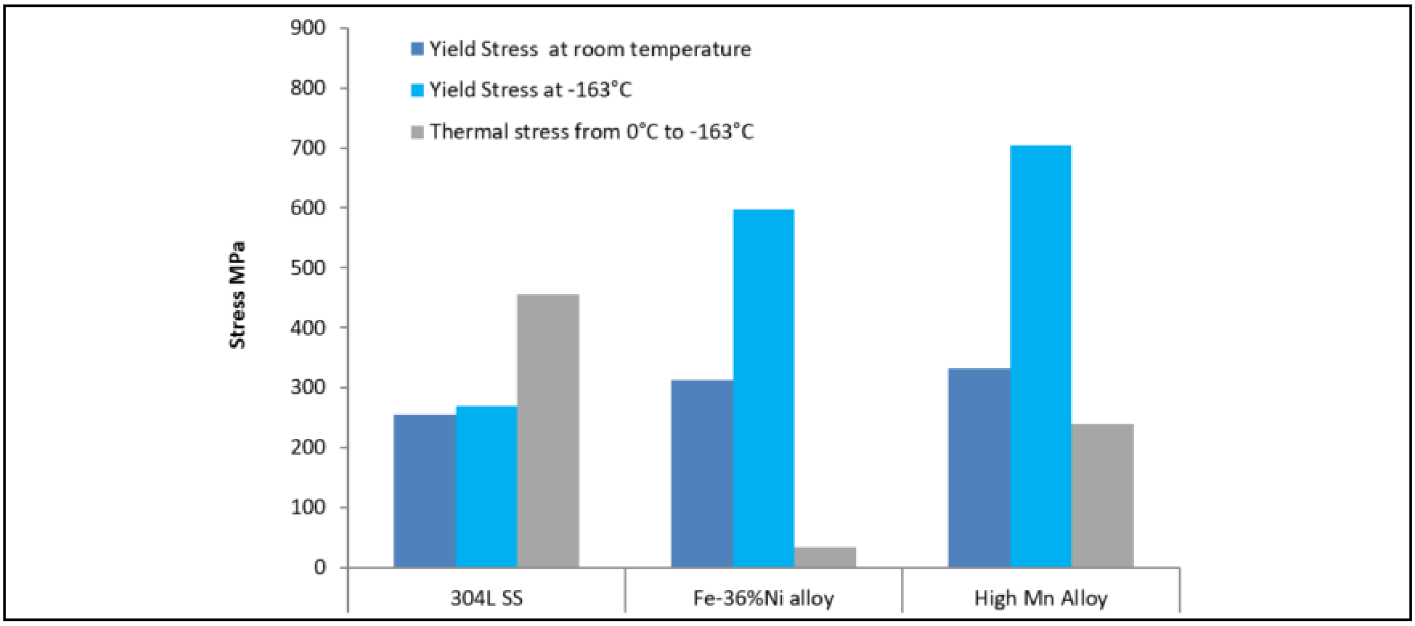


Figure 2: Mechanical and thermal properties of our high-manganese alloy compared to 304L stainless steel and Fe-36%Ni alloy

The fatigue test results on raw material are very satisfactory. Indeed, the results at -163°C are better than the results of both Invar® and 304L.

Corrosion resistance

Conventional high-manganese steels are susceptible to corrosion. Our objective was to develop a new alloy which has a better resistance to general and pitting corrosion than carbon steel, high-manganese steel and Fe-36%Ni.

The measurement of potentio-dynamic polarization curves showed that this new metallic alloy CRYOSTAL® meets this requirement.

For instance, after 1000 h at 55°C and 95% Relative Humidity, no corrosion has been observed.

Weldability

Weldability is a key parameter for the applicability of the material in GTT membrane technologies.

From the early stages of this project, the weldability of CRYOSTAL® has been investigated using Varestraint and Cross-Bead tests. Furthermore, the weldability of the industrial sheets has been verified using different welding processes usually used in GTT technologies such as TIG, PAW and seam welding processes. Figure 3 illustrates some welded CRYOSTAL® samples using different tests and welding processes.

The weldability of our high-manganese alloy CRYOSTAL® has been assessed and no metallurgical issues have been encountered in both homogeneous configuration and heterogeneous assemblies (with 304L stainless steel and Fe-36%Ni alloy). Moreover, the mechanical strength under tensile loads is high.

The fatigue behaviour of the welded specimen is still to be determined.

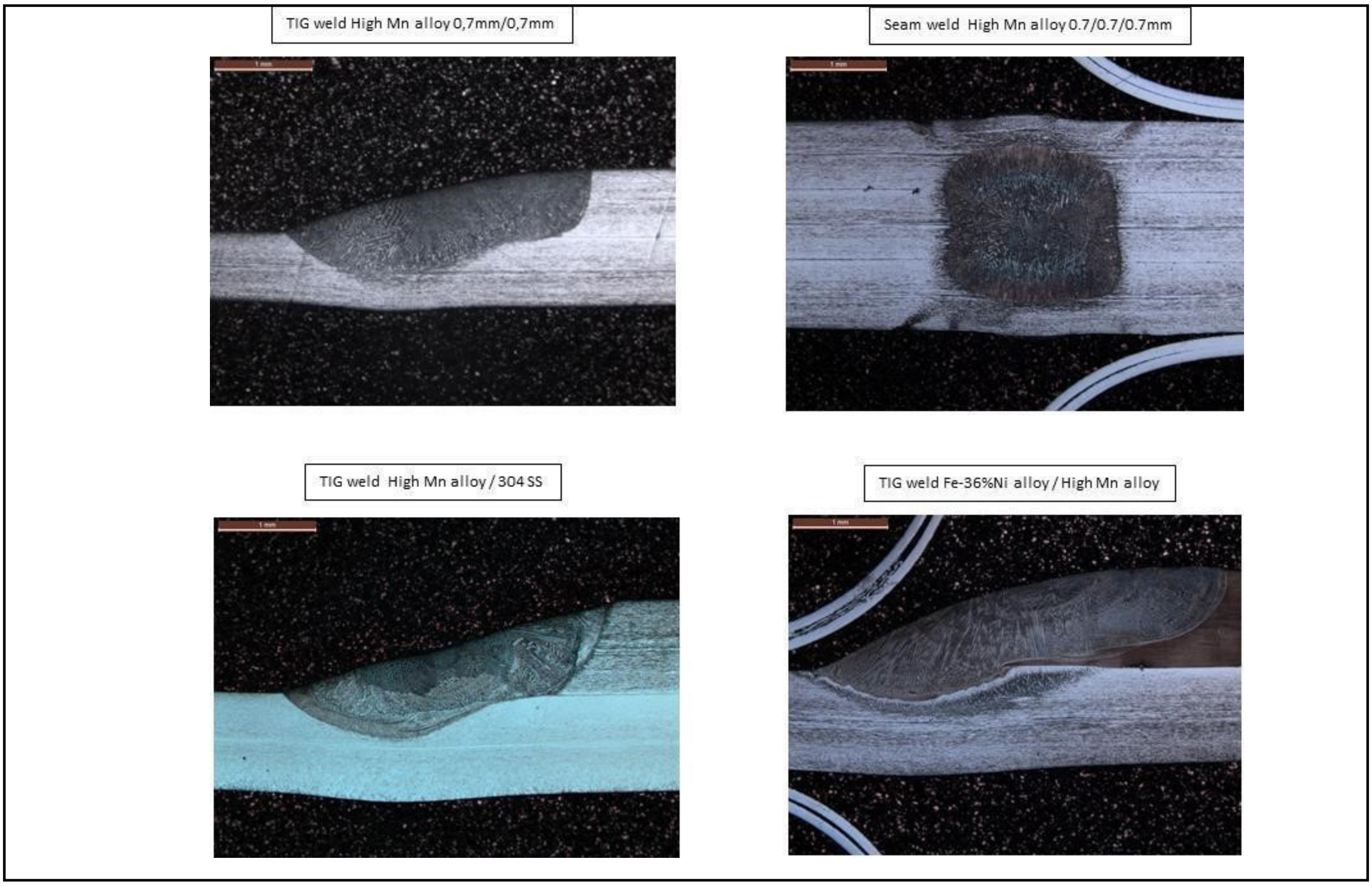


Figure 3: Illustration of welded samples with High Manganese Alloy

Formability

The forming limit diagram (FLD) of CRYOSTAL® has been determined by means of Nakazima tests in order to evaluate the formability of the material. The obtained FLD is presented in figure 4 and compared to those of 304L stainless steel and Fe-36%Ni alloy.

It can be shown that the workability of the new High Manganese alloy is better than Fe-36%Ni alloy and comparable to 304L stainless steel.

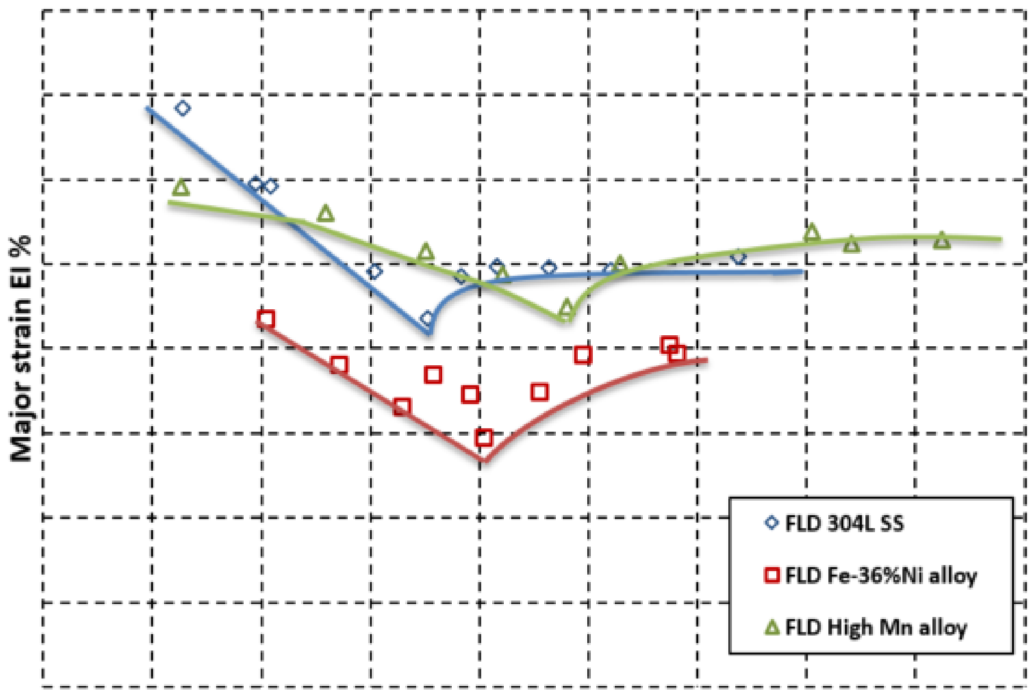


Figure 4: Forming limit diagram

Moreover, in order to investigate the possibility of using the new High Manganese alloy in a corrugated form (corrugated membrane), 0.7mm thick samples have been shaped using forming tools developed by GTT and already validated for Fe-36%Ni alloy.

The shaping of High Manganese alloy sheets did not show any particular difficulties; which is a promising point for the application of this new material in GTT systems. Figure 5 illustrates the obtained shaped specimens for both high manganese alloy and Fe-36%Ni alloy (for comparison).

High Mn alloy specimen

Fe-36%Ni alloy specimen

Figure 5: High Manganese alloy and Fe-36%Ni alloy corrugated specimens

Further investigations and testing are still in progress in order to assess the mechanical strength of the corrugation obtained and, if necessary, to further optimise the forming process in such a way as to meet GTT technical requirements.

Regulations

The list of qualified metallic materials to be used in LNG tanks (materials with sufficient toughness at -165°C) according to the IGC and IGF codes is very limited and mainly includes: 9%Ni steel, austenitic stainless steels (304, 304L, 316, 316L, 321 and 347), austenitic Fe-36%Ni alloy and some aluminium alloys.

Since 2015, GTT has been participating actively in the Correspondence Group of the IMO subcommittee on Carriage of Cargoes and Containers (CCC) on the suitability of alternative metallic material for cryogenic service. The working group has reached the validation of the Guidelines for the Acceptance of Alternative Metallic Materials for Cryogenic service in ships carrying liquefied gases in bulk and ships using gases or other low-flashpoint fuels (MSC.1/Circ.1622 ; 2nd, December 2020).

The performance of our high-manganese alloy CRYOSTAL® is in accordance with all the criteria defined in the Guidelines.

Conclusion and perspectives

The development of this new metallic alloy CRYOSTAL® is above all the result of successful collaboration between a designer GTT and a steelmaker APERAM.

It provides very interesting properties at very low temperature. This alloy has higher mechanical characteristics and the cost is independent of nickel prices.

We will continue to assess the applicability of this alloy for future cargo containment systems.

By the middle of 2022, we plan to be able to propose a technology with this high-manganese alloy.

INNOVATION

Flexible Multigas Carriers - Essential to a diversifying liquefied gas market

Recently introduced by GTT and ABS, the notation *"LNG Cargo Ready[1]"* supports the development of Very Large Ethane/LPG Carriers (VLEC) and Ultra Large Ethane/LNG Carriers (ULEC), the preferred capacities for the actual growing Ethane trade from USA to Europe, India and China. Through this notation and associated record comments, (see Table 1) the vessel's main components can be certified as fully compliant or compliant with minor retrofit for LNG service.

Going bigger in an emerging ethane market comes with associated uncertainties, therefore, the option of having the ethane carriers being capable of transporting LNG, with or without retrofit, becomes very attractive, providing the possibility of a second life in a diversifying LNG market. An Ethane carrier, which can be beforehand adapted to handle LNG, presents itself as a significant advantage within a growing and diversifying small – mid scale LNG market giving ship-owners the possibility of making the most of the freight market as it evolves.

ABS records confirm that such a supplementary notation can contribute positively to a vessel valorisation in the sales and purchase market.

Operations not only as mid-size LNG Carrier, but also as Floating Storage Unit (FSU) or even Floating Storage and Regasification Unit (FSRU) units can be envisaged.

[1] *"LNG CARGO READY VESSELS", American Bureau of Shipping. September, 2019.*

System	Descriptive Letters
Cargo Containment	CC*
Cargo Piping	CP
Cargo Pump	PP
Cargo Gas Compressor	CO
Re-liquefaction System	RS
Gas Combustion Unit	GC
Fuel Gas Supply	FG
Dual Fuel Engine	DF

Table 1: LNG Cargo Ready Systems Groups and Descriptive letters.
Cargo Containment letter is mandatory for the vessel to receive "LNG Cargo Ready" notation.

The new established notation, announced at GASTECH 2019, is now applied to SERI EVEREST, the very first[2] vessel of the second generation and world's largest VLEC delivered to MISC in November 2020 and identified as one of the *"Great Ships of 2020"* by the Maritime Reporter[3]. At the origin of the notation, GTT has assisted exchanges with ship-owners, shipyard and equipment makers with the objective of assuring the vessel to be granted a maximum of possible of descriptive letters. SERI EVEREST shall receive the following notation: CC, PP, FG and DF. As the owners of the second generation of VLECs push to acquire higher notation, more shipping actors move on the compliance direction.

Figure 1: SERI EVEREST the largest VLEC to be granted ABS notations "LNG Cargo Ready" (Courtesy of MISC).

In order to benefit from the notation and its implications on the shipping market, necessary measures should be made at early project stage, assuring compliance at a marginal cost.

[2] *Seri Everest was followed by her sister vessels: Seri Erlang, Seri Emei, Seri Emory, Seri Emperor and Seri Elbert.*
[3] *"GREAT SHIPS OF 2020", Maritime Reported and Engineering News, December 2020, No. 12, Vol. 82.*

For acquiring the notation, the Cargo Containment (CC) record comment is mandatory. GTT's membrane containment systems are already multigas ready. The compliance with ethane and other liquefied gases came with technical developments, initiated in the context of Floating LNG vessels (FLNG) fitted with LPG storage tanks, this has been optimized through first and second membrane VLECs generations and most recently with the design of a Gravity-based Structure (GBS) for Ethane storage. The technical innovations include the optimization of the gas detection and sweeping system for membrane insulation spaces to take into account greater density of ethane when compared to nitrogen. Membrane materials were proven through experimental tests to ensure chemical compatibility and performance stability. Immersion campaigns with specimens of the various membrane components were performed in a dedicated setup; and then validated with mechanical or thermal performance analyses. The increased liquid cargo density in multigas applications also leads to greater sloshing loads. On top of that, as bubble point temperature is usually greater, the strength of the containment system decreases. GTT overcame such technical challenges by validating optimized foam densities and applying specific reinforcements. Increasing membrane strength without impairing boil-off ratio is the challenge.

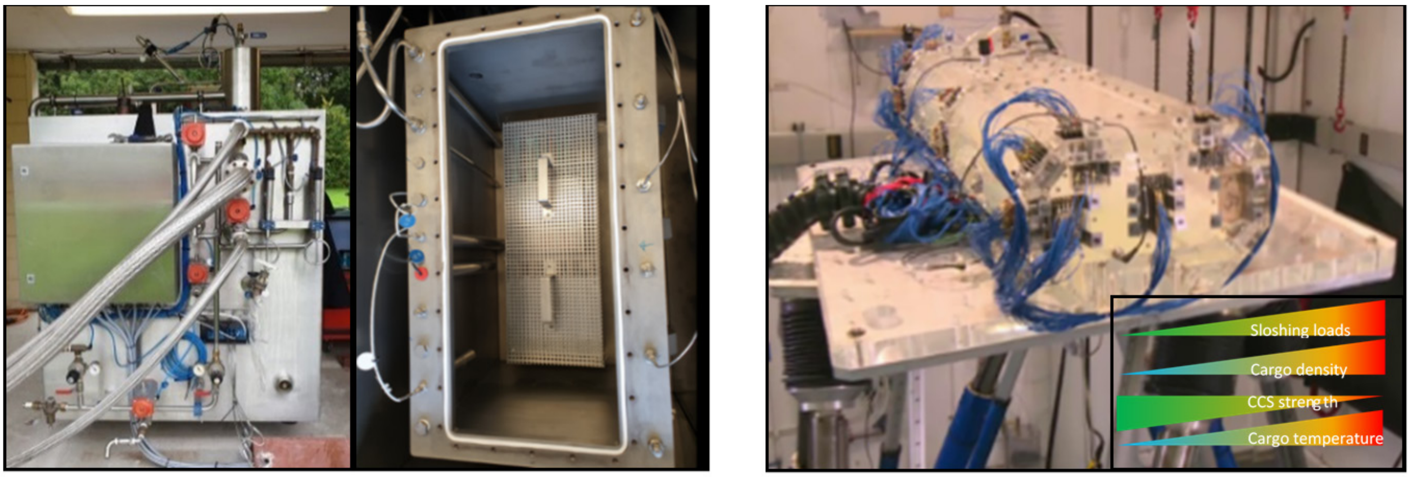


Figure 2: The technical developments to achieve multigas compliance includes material compatibility immersion tests and detailed analysis on CCS strengths under different cargo densities and temperatures.
On the left: material testing set (©TNO).On the right: GTT's Hexapod, part of the sloshing assessment infrastructure.

Concerning cargo handling, the pump tower, the liquid dome and guiding system used on GTT membrane tanks with submerged pumps are readily applicable for Ethane and LNG. Moreover, GTT has recently developed a pump tower design capable of accommodating the largest deepwell cargo pumps on the market. Deepwell pumps are well known in the LPG sector and are certified LNG ready.

The exact implications of the notation and its real value will be proved in the coming years, through the second and third (two hulls to be constructed by HHI) generations of VLECs and possibly the very first ULEC. In the meantime, GTT continues to anticipate and to provide support for the shipping market segments willing to acquire this innovative notation, bringing value and flexibility to all players.

TECHNOLOGY

A first mock-up for NO96 Super+

Previously, we announced a new evolution of our NO96 system, named NO96 Super+ allowing the reduction of the daily guaranteed boil off rate to less than 0.085%. Now, we can inform you about the tests that we carried out at GTT to validate the assembly of NO96 Super+.

As the corner areas of NO96 Super+ are the same as NO96 GW, the mock-up consists on a flat wall area composed with four NO96 Super+ panels surrounded by NO96 boxes. This mock-up validates the correct assembly of the new containment system and verifies that there are no problems at the interface with the NO96 boxes.

With these assembly tests, GTT will ensure that shipyards will be able to assemble our new technology without difficulty.

The shipyards can now proceed with their own assembly tests and preparations for the construction of the system.

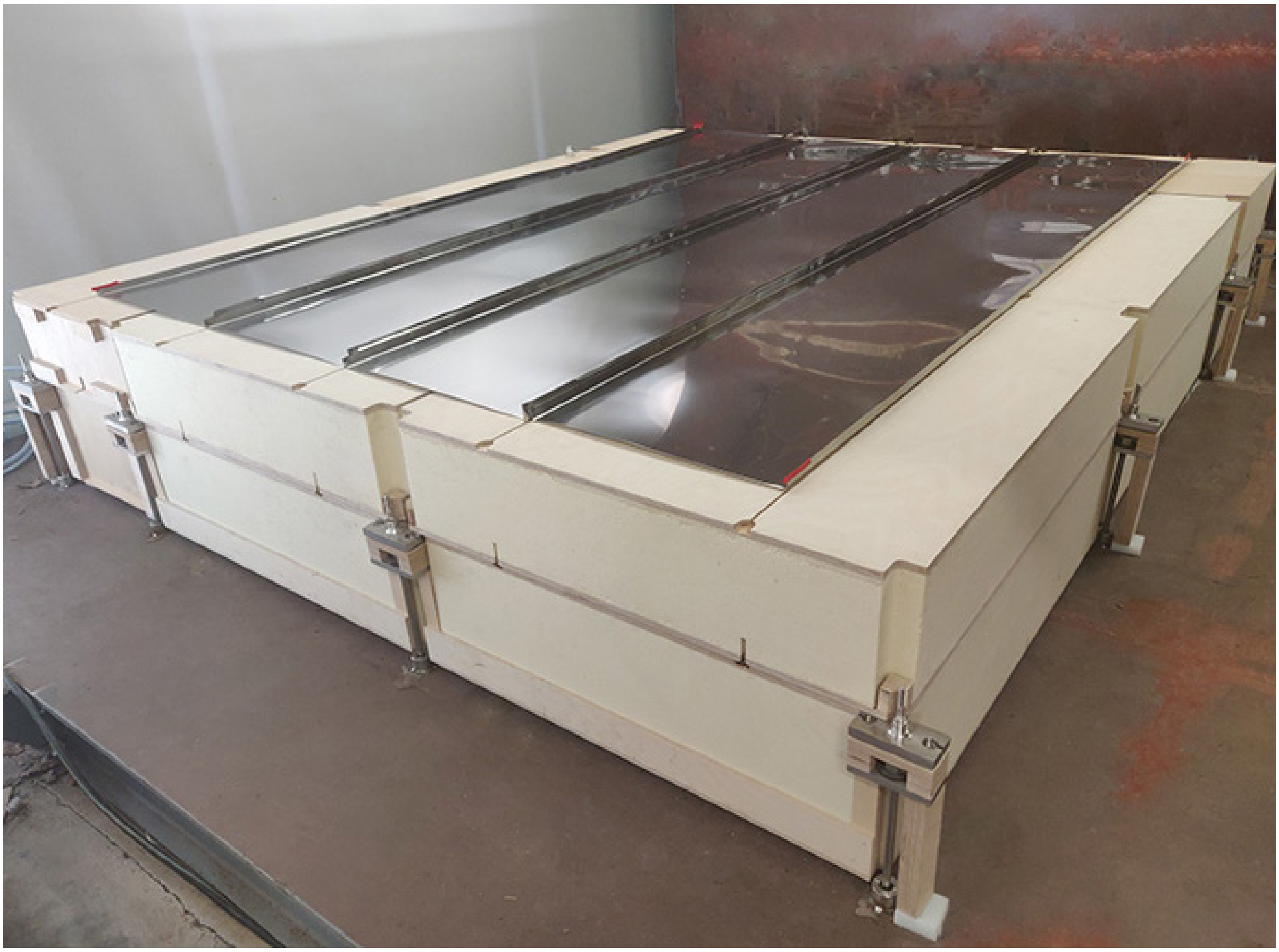
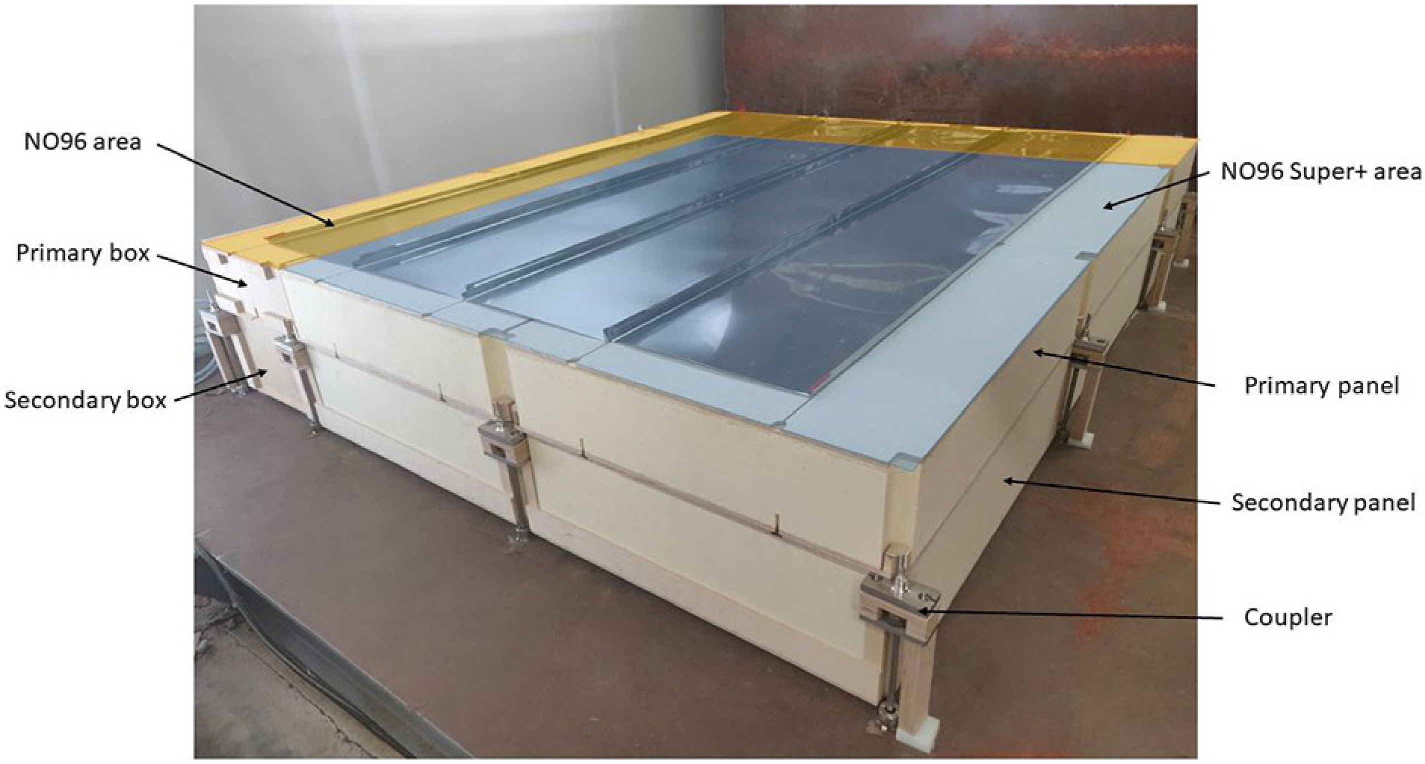
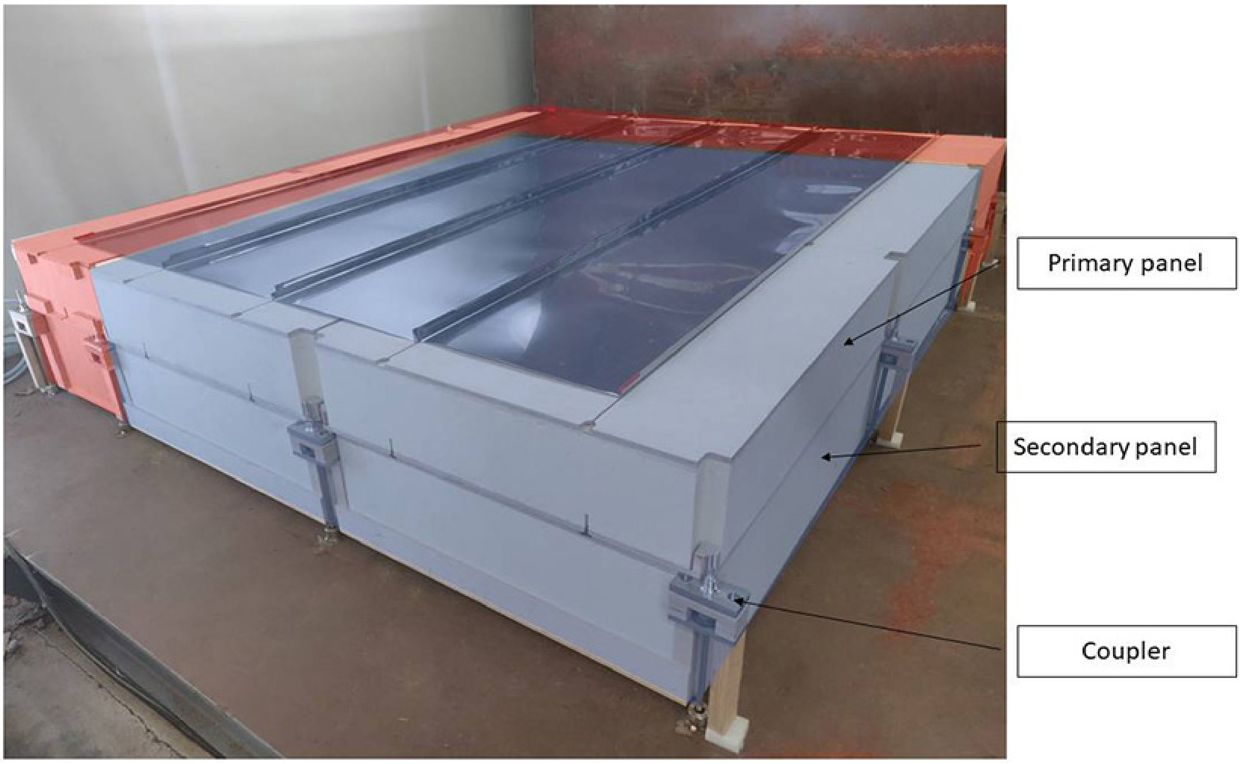


Figure 1: NO96 Super+





Figures 2&3: NO96 Super+ concept

Technology for a Sustainable World

GTT Inside

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OPERATION

World's first LNG containership retrofit fitted with GTT Containment System

The Brussels Express, previously named MV Sajir, was delivered after retrofit by the consortium of Chinese shipyards Hudong Zhonghua (HZ) and Huarun Dadong Dockyard Company (HRDD) to the German ship-owner Hapag Lloyd on April 2nd 2021. This vessel with a capacity of 15.000 TEU is the world first LNG ultra-large containership retrofit. It is now fitted with a 6,700 m^3 LNG tank, whose the structure was pre-equipped with GTT's Mark III cryogenic containment system.

A review of the achievement

What you can see on this picture constitutes a major industrial breakthrough.

But what do we see actually?

A steel structure – or *"exoskeleton"* – already fitted with GTT Mark III Containment System, hooked to a floating crane - 20 meters high above the sea - and about to be lowered inside the first ever ultra large container vessel to be retrofitted to LNG fuel. This occurred on September 25th at HRDD shipyard near Shanghai.

Take a step back, 4 years ago, when GTT and its industrial partners joined efforts to define and pre-validate the industrial process to convert a 15,000 TEU container vessel.

On paper, the technical challenges were numerous and required studies. Among them, the necessity to find the best approach to meet the following criteria:

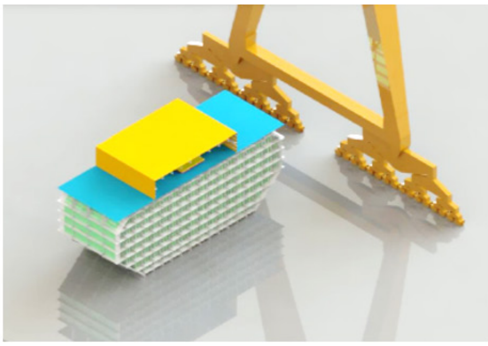
1. To make the best use of the existing available space on board the vessel.
2. To maximise the volume of the tank with the lowest impact on the container capacity.
3. To minimise the extent of the structural modifications in order to secure both construction planning and existing integrity of the vessel.

As for all retrofit projects, flexibility and adaptability of the LNG tank to an already existing environment has been a key selection criterion. Attaining a LNG volume of 6,700 m^3 in the cargo bay closest to the engine room, the exoskeleton solution offers to Brussels Express an autonomy to be able to sail from Europe to China or vice versa and also optimises the overall design of LNG fuel system by bringing the LNG tank as close as possible to the main and auxiliary engines.

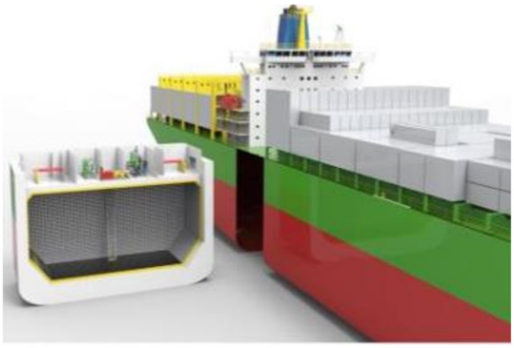
Other tank solutions were evaluated during this pre-project. The type C solution, for instance, was found - early in the process - not adapted / optimal as several tanks were needed to reach a similar volume, all located in 2 cargo holds far from the engine room. Fairly quickly the industrial concept of the membrane exoskeleton was chosen.

Under the exoskeleton concept, the LNG tank is manufactured separately from the vessel, outfitted with Mark III Containment System and then integrated into the vessel.

The difference with the solution called LNG Block™ (refer to the July 2020 edition of GTT Inside for more details) lies on the extent of steel structure. The exoskeleton includes “only” the inner structure of the tank block (on which the containment system is installed) and the external stiffeners which will be connected later to the existing walls or stiffeners inside the vessel. Whereas the LNG Block™ is a structural block as usually built in shipyards, which includes the tank (the block can be a complete section of the vessel for instance). LNG Block™ solution is mainly suitable for new build projects in yards non-familiar with membrane technology but also for future retrofit projects with the possibility to either cut & replace an existing section or lengthen the ship by adding this new LNG section.



Exoskeleton concept



LNG Block™ concept

The Brussels Express, having a large available and accessible space to hold the tank, was decisive in selecting this approach, as there was no need to cut the vessel. The exoskeleton solution was therefore suitable.

This industrial process is a first of its kind in the long history of GTT projects. Usually the containment system is installed on board during the construction of the newbuilding. There is no integration as such. Hence this new approach faces a lot of specific challenges.

One of them, the design of an exoskeleton capable to accommodate:

- the constraints imposed by the vessel, among others the torsion due to the absence of deck (in comparison to LNG Carriers);
- the requirements of the containment system;
- its own weight during the works and especially during lifting.

Through a close collaboration with GTT, the marine engineering company Technolog, in charge of the tank structural design, made the design of the tank structure as an integrated system to benefit from ship hull strength and then optimized the amount of steel material added to preserve the cargo capacity.

On the list of challenges is the lifting of the exoskeleton. A structure weighing 1,300 tons (steel and containment system material), 20 meters high and 44 meters wide to be lifted from the quay and lowered into the 25 m deep cargo bay 9 of the Brussels Express: this is what we can surely call a special lifting operation!

Special care was taken in the design of the lifting gears as well as verifying the adequacy of the structural design of the exoskeleton for such an operation. The focus was to avoid any permanent deformations for the already installed Containment System (outfitted by Hudong Zhonghua).

In the end, this was almost a routine operation for HRDD, the repair shipyard in charge of the conversion works, which ran the show smoothly in less than 24 hours with a certain mastery. All was then in place for the next challenge: the integration itself.

Before the actual work, GTT worked hard to get more familiar with the naval construction in order to assess / anticipate at best the effect of the integration. But what do we mean by integration?

This operation consists in welding all primary stiffeners of the exoskeleton to the existing ship structure (GTT technology being an integrated membrane tank technology).

The conclusion of those studies helped to define, among others, welding gaps, welding sequences, and welding procedure specifications to reach, before execution, a very good level of confidence together with offering a workable industrial scheme for the Yard. Then from theory to practice, it was time for our partner HRDD to mobilise its welding workforce at the end of September and weld all tank faces. The integration of the tank was completed ahead of the schedule, in six weeks.

Finally, any retrofit project involves by its own nature multiple other challenges ranging from integrating new functionalities into an existing set-up (the control system for instance), through accommodating additional equipment within the sometimes already congested layouts, to the usual deviations between as-built documents and actual dimensions of existing pipe routings.

At the end, all these challenges were managed by the consortium and the main subcontractors despite a difficult context due to the world-wide pandemic.

After the completion of the engine upgrade, the FGHS *(Fuel Gas Handling System)* integration and the recent commissioning of the entire fuel gas chain, the conversion of this first ultra large container vessel is now completed and the vessel back in service.

Hapag Lloyd has chosen a package of GTT services to accompany this first of a kind dual fuel retrofit. This package includes training through the G-SIM training simulator especially adapted to replicate LNG operations of the Brussels Express. GTT will also provide on board technical assistance during the commissioning of LNG tanks and during the first bunkering operations. If necessary, Hapag Lloyd may use the *«HEARS®»* service, to obtain 24/7 technical assistance.GTT is proud of having taken part in this atypical project, which demonstrated that the application of the Mark III containment system via an exoskeleton concept is truly feasible; from now on, a realistic alternative exists for bringing LNG to existing ships.

GTT is also working on a new concept of LNG conversion with jumboisation in which the additional container cargo capacity can help monetize the whole retrofit operation.

A ship section with LNG and cargo capacity is built in our LNG Block suppliers in Korea or China. The section is then floated and welded to the existing container vessel. GTT believes there is strong future in both lengthening container ships and LNG conversion.