METALLIC MATERIALS USED IN SHIP CONSTRUCTION - FABRICATION TECHNIQUES, CLASSIFICATION AND CERTIFICATION

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ABSTRACT

Shipbuilding industry is one of the branches that have a wide area in the world. With the developing technology and innovative production techniques, the importance of the materials used in this sector is increasing. Requirements such as low cost, long life, high strength and safe navigation directly depend on the material selection. In this article, metallic materials used in shipbuilding and manufacturing, their usage areas and certification processes are examined.In addition, fabrication techniques were mentioned and the mechanical and chemical properties of the steel and aluminum alloys were examined according to the regulations of the class societies of Turkish Lloyd, Bureau Veritas and Rina.

Keywords: Metallic materials, Turkish Lloyd, Bureau Vertas, Rina

ÖZET

Gemi inşaat sanayisi dünya endüstrisi içerisinde geniş yer tutan sektörlerden birisidir. Her geçen gün gelişen teknoloji ve inovatif üretim teknikleri ile birlikte bu sektörde kullanılan malzemelerin önemi oldukça artmaktadır. Maliyeti düşük olma, uzun ömürlü, dayanımı yüksek, güvenli bir seyir gibi istekler malzeme seçimine doğrudan bağlıdır. Bu makalede, gemi yapım ve imalatında kullanılan metalik malzemeler, kullanım alanları ve sertifikasyon süreçleri incelenmiştir. Ayrıca, fabrikasyon tekniklerine değinilmiş ve incelenen çelik ve aluminyum alaşımların mekanik ve kimyasal özelliklerinin Türk Loydu, Bureau Veritas ve Rina klas kuruluşlarına göre karşılaştırmaları yapılmıştır.

Anahtar kelimeler: Metalik malzemeler, Türk Loydu, Bureau Vertas, Rina

1. Introduction

The history of the ships is very old. The Egyptians started boat building around 4000 BC. Over the years, shipbuilding also developed. Wood material is known as the first material used in shipbuilding in history. Wood, a material that is easily found in nature and easy to process, has maintained its dominance in the shipbuilding industry for years. As time progressed, different materials started to be used in shipbuilding and new production methods started to be applied.
Along with the wooden materials, steel, aluminum and composite material types have also started to be used in shipbuilding. Sub-group materials of these materials continued to be used day by day.

Shipbuilding industry, one branch of heavy industry, has a large trade volume all over the world. It has a wide variety of uses for cargo and passenger transportation and hobby uses. Mines, wood and various auxiliary materials are used in the manufacturing process. Material preferences and choices in shipbuilding have changed overtime. The mechanical, physical and chemical properties of materials play an important role in this.

Three main materials used in shipbuilding industry are given below.

- Steel
- Aluminium alloys
- Composite materials

By steel come into use as a ship building material, the use of wood in the construction of large ships has been reduced. Because of the lightness of the aluminum material type, it has started to be preferred in the superstructures of ships and yachts. Composite material comes to the fore, especially in the manufacture of yachts. Most of the materials used in the shipbuilding industry are metallic materials. Steel materials are highly preferred in terms of price, features and availability. However, aluminum alloys are also preferred due to their specific properties.

In order for metallic materials to be used on the ship, they must be inspected and approved by the class society that will certify the ship. In this study, metallic materials used in shipbuilding, manufacturing techniques, classification and certification procedures were examined. Also, Turkish Lloyd, Bureau Veritas and RINA rules were reviewed in detail.

2. Metallic Materials Used In Shipbuilding

There are different materials used in the shipbuilding industry. Steel materials, aluminum alloys, wooden materials and composite materials can be given as examples. These materials are preferred according to the area of use on the ship.

Materials to be used in shipbuilding must satisfy the compression, tensile and shear stresses, hardness, brittleness and strength values. The main structure of the ship consists of steel and aluminum alloy materials.As summarize, aluminum alloys are the most suitable material for the constructers. Some other suitable lightweight materials can also be used for small ships.

Figure 1. Frames [1]

Figure 2. Pillar [1]

Figure 3. Propeller [1]

Aluminum alloys with many properties that are very interesting to high-speed ship designers and shipyards: they have good corrosion resistance, good attitude to welding, cutting and forming, light weight. In other words, it has a feature that can be developed against production technologies. Some usage area of metallic materials are shown in Figure 1-3 [1].

2.1 Usage Areas Of Metallic Materials

The ship's hull consists of the combination of elements such as keel, shell, pillar, deck, and stringer. These elements ensure the waterproofing, safety and durability of the ship. Extensively used metallic materials are steel and aluminum alloys.

Material selection is made according to the area to be used. Of these materials, especially steel; it is the main material used in the construction of heavy cargo, bulk cargo and ore ships, oil tankers, tugboats, cruise ships, special service vessels, supply vessels, dredgers, and also in the construction of barges, pontoons and floating docks [2].

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2.1.1 Steel

Steel material is obtained with the combination of iron and a small amount of carbon. Steel is the most commonly used material in shipbuilding. Rolled structural steels are used for durability as plates and profiles. High strength steels are required for critical areas of ships, so these steels are normalized and heat treated. The selection, physical and chemical properties of steel are limited according to the class society to which it is affiliated [4].

2.1.2 Aliminum Alloys

Commercially pure aluminum contains a minimum of 99% pure metal. Different special grades of higher purity are also available for some special applications.
Materials that have metallic properties and consist of two or more elements, at least one of which is an elemental metal, are named as aluminum alloys. Most aluminum alloys contain different elements to provide certain characteristics and consist of 90% - 96% aluminum. It is usual to add a few minor alloying elements in addition to the main alloying element for some specific fabrication and properties [8].

2.1.3 Composite Materials

Composite is a material which consist of two or more parts. Composite materials can be summarized as "materials formed by the combination of two or more macro-different components along an interface". The components that make up the composite material mostly retain their properties.

Materials in general; metal, ceramic and organic materials are classified in three main groups. These three classes of materials have some advantages and disadvantages. As can be seen in Figure 4, depending on the technological developments, the new material produced by combining two or more of these materials in a single material is the composite materials. [3]

3. Fabrication Techniques

Since iron and steel products are the main inputs of the durable consumption and investment goods industries, the total industrial output amount is highly correlated with the economic

activities in the economy. For this reason, iron and steel consumption level of a country is often accepted as one of the important indicators of economic growth in that country. The apparent steel consumption per person in the world in 2015 was 208.2. For Turkey, this value is 436.8. If it is necessary to specify the values for some countries and country groups; South Korea: 1113.6; Japan: 497.3; Germany: 483.8; USA: 297.4; UK: 161.9; China: 488.6; AB: 303.5.
As long as it can be preferred in engineering applications (strength, formability, workability, flexibility, versatility, etc.) and maintains its economic feature, steel will be able to continue its usage and consumption trend worldwide as a commercial material. The intensity-of-use hypothesis model suggested by the International Iron and Steel Institute and Malenbaum is very effective in explaining the relationship between steel consumption and the economic size of the country. Here, with the development, it is expected that the intensity of metal use will first increase, then decrease and increase and then reverse after a certain peak. It is stated that the relationship between the intensity of metal use and real national income per capita exhibits an inverted U-shaped trend.

In terms of the production method, two types of methods that are common in the iron and steel industry worldwide can be mentioned: The blast furnace method using iron ore as the primary type of raw material source and the electric arc furnace method using iron-containing scrap material as the secondary type of raw material source.

This is also qualified as a recovery method. In addition, although there are methods such as Siemens Martin and Corex, Finex, which have been discussed in recent years, their industrial examples are quite limited. Considering the weight of production methods for countries, although it varies for each country, 74.4% of the total world production in 2015 was carried out by blast furnace and 25.1% by electric arc furnace method.

In the same year in Turkey, 35% of blast furnace production, 65% is provided by the electric arc furnace method. The electric arc furnace method is generally considered to be a more advantageous method in terms of both energy consumption intensity and carbon emissions. In terms of production costs, periodic changes are observed with the effect of fluctuating ore, coke, coal and scrap prices [3].

4. Certificaiton Process of Metallic Materials

Metallic materials to be used on the ship must be examined and approved by the classification societies that will certify the ship.

4.1 Certification Process

According to Turkish Lloyd (TL) Rules Part A Chapter 2 Material Rules Section 1.A.1, the requests for the fabrication, test procedure and certification process of the materials and products used or to be used by the ships classified or to be classified by Turkish Lloyd (TL) are stated. These rules cover all materials and products whose usage areas are specified [4].

According to Bureau Veritas NR216 Rules on Materials and Welding for the Classification of Marine Units Chapter 1 Section 1-1 specifies requirements for the production, inspection and certification of steel and ferrous products, non-ferrous metals, various finished products and similar equipment. General conditions regarding the manufacture, inspection and certification of

these materials and products are given in this section and they will be complied as appropriate [5].
Rina Rules Chapter D Part 2 and 4 describe the requirements for the production, inspection and certification of equipment such as steel and iron products, non-ferrous metals, and various finished products to be used in the construction or repair of ships subject to classification [6].

4.2 Sampling

The portion of the test piece in predetermined dimensions and conditions to perform a specific test is named a test sample. Enough test material will be provided for the necessary tests and possible retesting. The test material will represent the unit or sample product and will not be separated from the product until all special heat treatments have been completed. Figure 4 and Figure 5 shows the test sample and test specimen examples [4-6]

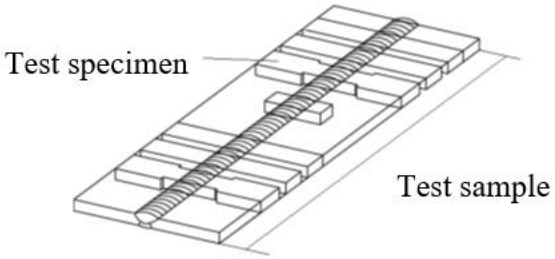

Figure 4. Test specimen [4-6]

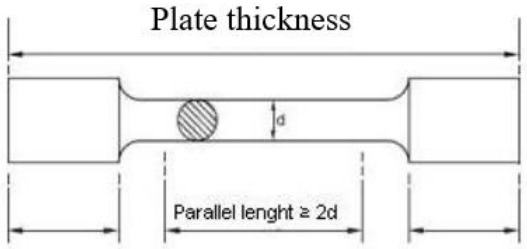

Figure 5. Test sample [4-6]

4.3 Test Procedures

Inspections and test processes should be continuing at the production area as much as possible before delivery. If the necessary facilities and equipment are not available in the production area, tests can be carried out in accredited test laboratories.

The relevant participants apply for the examination at the appropriate time. Before the tests, the manufacturer prepares and presents the details and technical specifications of the products to be certified. All tests and examinations specified according to the rules are carried out with the witness of the surveyor. Test and measurement devices must be kept in the required conditions and calibration records must be submitted to the surveyor [4-6].

4.3.1 Mechanical Tests & Comparison of Mechanical Values of Steels

The mechanical and technological properties of normal and high strength steels are checked according to the values obtained from tensile tests and it is expected that classification societies meet the minimum rules.

When the expect of tensile tests values of three different societies in normal strength steels are compared in Table 1.

Table 1. Comparison of mechanical values of normal strength steels

Quality		Yield Stress ReH (N/mm2)	Tensile strength Rm (N/mm2)	Elongation A5 (%) min
Grade A	**TL**	235	400-520	22
	BV-RINA	235	400-520	22
Grade B	**TL**	235	400-520	22
	BV-RINA	235	400-520	22
Grade D	**TL**	235	400-520	22
	BV-RINA	235	400-520	22
Grade E	**TL**	235	400-520	22
	BV-RINA	235	400-520	22

4.3.2 Chemical Tests & Comparison Of Mechanical Values

The chemical composition of the samples taken from each melting of each casting, equipped by the manufacturer with adequate equipment and experienced personnel. It will be determined in laboratories. The chemical composition must comply with the requirements specified in Tables 2. Thickness 50 mm. Very small deviations from the desired chemical composition for plates and expansions of more than, TL are permitted by agreement. Manufacturers-reported analysis may be accepted based on random checks at the surveyor's request [4].

Table 2. Comparison of chemical composition and deoxidation practice for normal strength steels.

Grade	TL-A	TL-B	TL-D	TL-E
Deoxidation practice	For t ≤ 50 mm Any method except rimmed	For t ≤ 50 mm Any method excep trimmed steel	For t ≤ 25 mm Killed,	Killed and fine grain treated
	For t > 50 mm Killed	For t > 50 mm Killed	For t > 25 mm Fully killed and fine grain treated	
Chemical composition (%) (Ladle analysis)	Carbon plus 1/6 of the manganese content is not to exceed 0.40%			
Cmax.	0.21	0.21	0.21	0.18
Mnmin	2.5xC	0.80	0.60	0.70
Simax.	0.50	0.35	0.35	0.35
Pmax.	0.035	0.035	0.035	0.035
Smax.	0.035	0.035	0.035	0.035
Al (acid soluble)min	-	-	0.015	0.015

4.4 Certification

A certificate is issued for materials or products with appropriate test results, and statin that they have been tested according to TL rules. Depending on the application, a certificate which was issued by the manufacturer, containing the name of the manufacturer, recipient, the order number, ship name, product details, the results of the tests and inspections etc. will be attached to the TL certificate.

Materials and products that will be used within the scope of classification must be delivered together with the material certificate in accordance with TL rules. To obtain this material certificate, TL rules and requirements on the material / product must be provided. The manufacturer must be approved by TL for the material / product.
According to Turkish Lloyd Material Rules, test certificates or an order list of all materials tested by the surveyor, will be provided. When necessary, reports will be prepared one by one for each product type. The documents will contain at least the following details [4-6]:

- Customer and order number
- Yard or shipbuilding number (if known)
- Dimensions of items
- Quality & grade
- Production steps
- Heat number
- Chemical and mechanical characteristics
- Delivery status if not in rolled condition

- Product description
- Test sample number.

5. New Horizons About Metallic Materials and Fabrication Techniques

It is seen that most of the ships were made of wood throughout history. With the industrial revolution, this dominant material used in shipbuilding has been replaced by iron. Currently, the most used material is steel.

With the developing technology, designers and producers have started to search for new alternatives to be used instead of steel due to factors such as reducing fuel costs and environmental pollution and increasing performance.

As a result of this search, aluminum and composite materials have come to the lead. As far as it is known, HSC Francisco, the fastest ferry in the world and cruising between Uruguay and Argentina at 50 knots, is made of aluminum. On the other hand, the M80 Stiletto, which is the secret ship of the US Navy, made of an advanced carbon composite structure, is capable of 60 knots in rough seas.

According to the latest research and studies, graphene seems to be the most promising expectation in shipbuilding. It has been seen that when very small amounts of graphene are added to plastic composite materials and metals, the materials become lighter and stronger.

On the other hand, the US Navy conducts "omniphobic" coating studies and developments for unmanned underwater vessels, submarines and new technological ships. Coatings developed from this material provide aggressive repulsion to the water and significantly reduce hydrodynamic friction. Thus, savings of hundreds of millions of dollars in fuel costs.

The largest superyacht owners in the world also play a major role in the development of new materials and in the financing of research and development studies on them. On the other hand, interestingly, some leading superyacht manufacturers continue to prefer steel-structured ships. The most important reason for this is that steel can be recycled easier and safer than complex composites.

One of the prominent suggestions is that many ship designers and materials scientists should pay more attention to wood due to its environmental responsibility and versatility [7].

6. Conclusion

Ships, which have a long history, were first started to be built by the Egyptians around 4000 BC. In the following years, there were various improvements in shipbuilding with technological developments. Wood was the first material used because it was easy to find and process in history. The construction of wooden ships has maintained its dominance for a long time.

In the following periods, steel, aluminum and composite materials started to be used in addition to wooden materials. With the introduction of steel to the shipbuilding industry, which has a large trade volume, the usage weight of wood has decreased.

Physical and chemical properties play an important role in material selection. It is common to use steel in terms of construction in large ships. However, aluminum is preferred in superstructures due to its lightness. Metallic materials to be used on the ship must be examined and approved by the classification body that will certify the ship.

In this study, the manufacturing techniques and usage areas of metallic materials used in shipbuilding have been examined for three class societies. The mechanical and chemical properties of metallic materials in terms of testing and certification processes are given for Turkish Lloyd, Bureau Veritas and RINA.

Some ongoing research and development studies will change the preference of metallic materials in shipbuilding in terms of some properties. With the work to be done, materials that come to the fore in important issues such as the serious reduction in fuel costs, longevity, strength, lightness, corrosion, and features against environmental pollution will take a large place in shipbuilding in the upcoming processes.

References

[1] Introduction to Metal Shipbuilding Technology, 2012, Appendix C, Underwood, C.J., Bangkok.

[2] Özsoysal, N. & Ünsan, Y., 2005. Gemi İnşaatı Sekörü'nde Çelik Kullanımı, https://www.mmo.org.tr/sites/default/files/P25.pdf, 21 October 2020.

[3] Özkale, L.N. & Bıyık N., 2017. Demir Çelik Endüstrisi Üretim Yöntemleri İle İhracat, Katma Değer ve Karbon Emisyonu Azaltma Politikaları Arasındaki İlişki. Uluslararası Yönetim İktisat ve İşletme Dergisi 13(13), 718 – 735.

[4] Turkish Lloyd, 2021. Material Rules, Part A Chapter.

[5] Bureau Veritas NR216 Rules on Materials and Welding for the Classification of Marine Units.

[6] Rina Rules for the Classification of Ships Part D Materials and Welding.

[7] Radical new materials in shipbuilding, 2020. https://www.msamlin.com/en/chart-hub/english/radical-new-materials-in-shipbuilding.html, 20 January 2021.

[8] Kaufman, J.G. Introduciton to Aluminum Alloys and Tempers (2012). Portland, Book News Inc.