International Science and Technology Journal
المجلة الدولية للعلوم والتقنية

Volume 34 العدد
Part 1 المجلد
April 2024 ابريل

تم استلام الورقة بتاريخ: 4/ 4/2024م وتم نشرها على الموقع بتاريخ: 30/ 4/2024م

Casting High-Alloy Steel AISI 321 Using Sand Casting

www.doi.org/10.62341/aalb3045

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Abstract

In this work, sand casting was used to obtain high-strength steel AISI-321 by melting alloy AISI304 using sand casting. This is in addition to titanium using an induction furnace, which is considered one of the metal forming processes that originated from the principle of casting in sand molds. In general, Ti will oxidize quickly in the melt if it is exposed to air in typical sand/investment casting processes; Titanium element provides greater resistance to inter granular corrosion. Stainless steel alloy 321, which differs from 304 in that it contains a percentage of titanium, which has given it the property of being used at high temperatures, which has increased the need or demand for stainless steel casting in some industries and due to the difficulty and complexity of producing some pieces or parts using SS304 (wrought) forging alloy by Machines, so that it became necessary to search for a way to improve quality and reduce time and cost, using plumbing technology, although information about this technology is not available in open references. The ability to cast stainless steel is affected by a variety of factors, such as the time and degree of melting, the types of additives, and the time of total solidification. In addition, there are some other casting factors that have a direct impact on the quality of casting stainless steel, such as the sand mold materials, their type, preparation of the sand mold, and the heat treatment steps. This research includes two parts, a

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theoretical part that includes the steps of sand casting, and the second part related to the practical side, where the effect of some casting factors was studied, which includes the weight and quantity of addition of titanium (300 to 1000 grams), the time of addition and pouring from (3 to 15 minutes), as well as a study of heat treatment and its effect. This is due to the quality of the stainless steel alloy under study.

In each experiment, 100 kilograms were used on stainless steel 321 and 304. The practical experiments were completed in several experimental stages, and in each stage, some modifications were made so that they were based on previous results.

The results of the chemical analysis of the last five samples showed a gradual increase in the amount of Ti% until it reached about 0.4%. The tensile strength and yield strength were at acceptable values compared to the Wrought SS321 and cast SS (CF) alloys, an austenitic stainless steel, where the lowest value was (200 and 198) MPa and the highest value was (559 and 315) MPa, respectively. The hardness values were between (145 to 149).

Key words: sandcasting, Austenitic SS321, SS304, FeTi.

سباكة الصلب عالي السبائكية AISI321 باستخدام السباكة الرملية

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الخلاصة

في هذا العمل، تم استخدام السباكة الرملية للحصول على الفولاذ عالي القوة AISI-321 عن طريق صهر السبيكة AISI304 باستخدام السباكة الرملية. هذا بالإضافة إلى اضافة عنصر التيتانيوم في الفرن الحثى الذي يعتبر أحد عمليات تشكيل المعادن التي نشأت من مبدأ الصب في القوالب الرملية. بشكل عام، سوف يتأكسد Ti بسرعة في المصهور إذا تعرض للهواء في عمليات السباكة الرملية/السباكة الاستثمارية، يوفر عنصر التيتانيوم

International Science and Technology Journal
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مقاومة أكبر للتآكل الحبيبي. سبائك الفولاذ المقاوم للصدأ 321 والتي تختلف عن 304 في احتوائها على نسبة من التيتانيوم مما أعطاها خاصية الاستخدام في درجات الحرارة المرتفعة مما زاد من الحاجة أو الطلب على صب الفولاذ المقاوم للصدأ في بعض الصناعات ونظراً ل صعوبة وتعقيد إنتاج بعض القطع أو الأجزاء باستخدام سبائك المطروقات (wrought)304 بواسطة الآلات، بحيث أصبح من الضروري البحث عن طريقة لتحسين الجودة وتقليل الوقت والتكلفة، باستخدام تكنولوجيا السباكة، على الرغم من عدم توفر معلومات حول هذه التكنولوجيا في المراجع المفتوحة.تتأثر القدرة على سباكة الفولاذ المقاوم للصدأ بشكل أساسي بمجموعة متنوعة من العوامل، مثل وقت ودرجة الذوبان، وأنواع المواد المضافة، ووقت التصلب الكلي. بالإضافة إلى ذلك، هناك بعض عوامل الصب الأخرى التي لها تأثير مباشر على جودة صب الفولاذ المقاوم للصدأ، مثل مواد القالب الرملي، ونوعها، وتحضير القالب الرملي، وخطوات المعالجة الحرارية.يشتمل هذا البحث على جزئين الجزء النظري الذي يتضمن خطوات السباكة الرملية، والجزء الثاني يتعلق بالجانب العملي حيث تمت دراسة تأثير بعض عوامل الصب والتي تتضمن وزن وكمية إضافة التيتانيوم (300 إلى 1000 جرام) زمن الإضافة والصب من (3 إلى 15 دقيقة) بالإضافة إلى دراسة المعالجة الحرارية وتأثيرها. ويرجع ذلك إلى جودة سبيكة الفولاذ المقاومة للصدأ قيد الدراسة.

وفي كل تجربة تم استخدام 100 كيلو جرام على الفولاذ المقاوم للصدأ 321 و304. وتمت التجارب العملية على عدة مراحل تجريبية، وفي كل مرحلة تم إجراء بعض التعديلات بحيث تكون مبنية على النتائج السابقة.وأظهرت التحاليل الكيميائية لنتائج العينات الخمس الأخيرة زيادة تدريجية في كمية Ti% حتى وصلت إلى حوالي 0.4%. كانت مقاومة الشد ومقاومة الخضوع قيماً مقبولة مقارنة بالسبائك المطروقة SS321 والسبائك المصبوبةCF،(سبائك الفولاذ المقاوم للصدأ الأوستنيتي)، حيث كانت أقل قيمة (200 و198) ميجا باسكال وأعلى قيمة (559 و315) ميجا باسكال على التوالي. . وكانت قيم الصلابة بين (145 إلى 149).

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الكلمات الدالة: السباكة الرملية، الصلب المقاوم للصداء الاوستنايتي(321,304)، FeTi.

1. Introduction

The metal casting process is done in industries known as foundry. Foundry is the largest contributor to recycling manufacturing as tons of metals are melted and remolded every day in these factories. Metal casting takes place over a series of steps that includes mold making, pouring molten metals in these molds in the foundry, removing the solidified metal from its mold (shakeout), removing runners, gates, risers, heat treatment, surface cleaning, and finishing. In the sand casting process, liquid metal is poured into a hollow sand mold, where it solidifies as it cools. The mold consists of sand particles held in place using an inorganic binder. After the metal has cooled to ambient temperature, the sand mold is opened to remove the casting product [1].

The most common way to make castings is to use a sand mold. Sand mold is made of sand packed into metal or wooden containers[2].

Casting processes are widely used to produce metal parts in a very economical way and to obtain complicated shapes with little or no machining [3].

Alloy 321 stainless steel offers higher creep and stress rupture properties and higher resistance to intergranular corrosion are of major concern than Alloy 304 due to the effect of Titanium contents; this permits the use of this alloy at elevated temperatures [4].Since the rising demand for cast stainless steel in a wide range of industries, moreover, the complicated and difficulty to produce some parts of wrought SS321 by machining, it became necessary to search for methods to improve the quality of stainless steel castabality which usually caste in open and vacuum induction furnaces, Even though this technology information was not published in the open references. Castabality of stainless steel mainly influenced by varying of casting parameters such as melting time and temperature ,types of additive material , total solidification time, furthermore there are some another casting factors has direct effect on the quality of cast stainless steel as sand mold[5].

The high-alloy cast steels can also be classified based on microstructure. Structures may be austenitic, ferritic, martensitic, or duplex; the structure of a particular grade is primarily determined by composition Chromium, nickel, and carbon contents are particularly important in this regard. In general, straight chromium grades of high-alloy cast steel are either martensitic or ferritic, the chromium-nickel grades are either duplex or austenitic, and the nickel-chromium steels are fully austenitic [6].
The CF alloys constitute the most technologically important and highest-tonnage segment of corrosion-resistant casting production. These 19Cr-9Ni alloys are the cast counterparts of the AISI 300-series wrought stainless steels [6].
Casting high alloy steel is widely used for its corrosion resistance in aqueous media at or near room temperature and service in hot gases and liquids at elevated temperatures (>650 °C, or 1200 °F). These alloy designations (for example, CF-8M) have been adopted by the American Society for Testing and Materials (ASTM) and are preferred for cast high-alloy steels.
CF-8M is a designation that represents a corrosion-resistant alloy known as 19Cr-9Ni. This alloy is specifically designed for service in environments where corrosion resistance is crucial. It has a maximum carbon content of 0.08% and contains molybdenum [4].
Include CE-30, CF-3, CF-3A, CF-8, CF-8A, CF-20, CF-3M, CF-3MA, CF-8M, CF-8C, CF-16F, and CG-8M. The microstructures of these alloys usually contain 5 to 40% ferrite, depending on the particular grade and the balance among the ferrite-promoting and austenite-promoting elements in the chemical composition[4].
Type 321 is an austenitic chromium-nickel stainless steel containing titanium that is recommended for welded parts that cannot be subsequently annealed. Type 321 is a stabilized austenitic stainless steel similar to Type 304 but with the addition of titanium. This titanium addition reduces or prevents carbide precipitation during welding and in service of (427 to 816°C). It also improves the high temperature properties of the alloy. Type 321 provides excellent resistance to oxidation and corrosion and possesses good creep strength[7].

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Due to the urgent need for some alloys that are not available and the reliance on them at the present time to produce turbo blades. Due to the lack of availability of the AISI321 alloy and its better features, work was made to produce it from the AISI304 alloy using the sand casting method. Therefore, models were designed and a sand mold was prepared for a group of pieces that could be tested. The titanium element required for this process was provided in the form of molds of FeTi**.**

2. Procedure of sand casting

Sand casting goes through several stages, which are:

2.1 Sand and binder preparation

Most sand casting operations use silica sand (SiO2). A great advantage of sand in manufacturing applications is that sand is inexpensive. Another advantage of sand to manufacture products by metal casting processes is that sand is very resistant to elevated temperatures. In fact, sand casting is one of the few processes that can be used for metals with high melting temperatures such as steel, nickel, and titanium. Usually, sand used to manufacture a mold for the casting process is held together by a mixture of water and clay. A typical mixture by volume could be 89% sand, 4% water, 7% clay. Control of all aspects of the properties of sand is crucial when manufacturing parts by sand casting; therefore a sand laboratory is usually attached to the foundry.

In sand casting, the sand must contain some type of binder that acts to hold the sand particles together. Clay serves an essential purpose in the sand casting manufacturing process, as a binding agent to adhere the molding sand together. In the manufacturing industry, other agents may be used to bond the molding sand together in place of clay. Organic resins, (such as phenolic resins), and inorganic bonding agents, (such as phosphate and sodium silicate), may also be used to hold the sand together [8].

2.2Mold setup for sand casting.

The setup of a sand mold in manufacturing involves using a pattern to create an impression of the part to be sand cast within the mold, removal of the pattern, the placement of cores, (if needed), and the creation of a gating system within the mold. A solid pattern is a onepiece pattern representing the geometry of the casting. The split pattern is comprised of two separate parts that when put together will represent the geometry of the casting. When placed in the mold properly the plane at which the two parts are assembled should coincide with the parting line of the mold. This makes it easier to manufacture a pattern with more complicated geometry. Also mold setup is easier since the pattern placement relative to the parting line of the mold is predetermined [8].

2.3Cores preparation

In some time we need Cores; Cores form the internal geometry of the casting. Cores are placed in the mold, and remain there during the pouring phase of the sand casting process. The metal casting will solidify around the core [8].

2.4Cope and drag pattern

The cope and drag pattern is typical in sand casting processes for high production industry runs. The cope and drag pattern is the same as the match plate pattern in that it is a two-piece pattern representing the casting and divided at the parting line. Each of the two halves is mounted on a plate for easy alignment of the pattern and mold. The difference between the cope and drag pattern and the match plate pattern is that in the match plate pattern the two halves are mounted together, whereas in the cope and drag pattern, the two halves are separate. The cope and drag pattern enables the cope section of the mold and the drag section of the mold to be created separately and latter assembled before the pouring of the sand casting [8].

2.5Sand casting operation

The sand casting operation involves the pouring of the molten metal into the sand mold, the solidification of the casting within the mold, and the removal of the casting [9].

After the sand casting is removed from the sand mold it is shaken out, all the sand is otherwise removed from the casting, and the gating system is cut off the part. The part may then undergo further manufacturing processes such as heat treatment, machining, and/or metal forming. Inspection is always carried out on the finished part to evaluate the effectiveness and satisfaction of its manufacture [8].

3. Experimental design

Due to the limitation of the required material for casting this type of stainless steel, we decided to make only some experimental trials to evaluate the effect of varying casting parameters which include the amount of adding titanium, time of adding Ti to pouring liquid metal while the other parameters were fixed, the sequence of experimental work was as shown in the following Table 1.

Table 1 Experiment trial design

Experiment	Starting material	Wt. in Kg	Additive Element Kg	Ti-adding time	Melting Temp C°
A	SS321	100	0.0Ti,	NO	1660
B	SS304 wrought	100	0.5Ti	At last 15min	1660
C	SS304 wrought	100	0.6Ti,	At last 10min	1660
D	SS304 wrought	100	0.8Ti,	At last 2min	1660
G	SS304 wrought	100	1kg Ti	At last 2min	1660

4. Experimental work

4.1 Making patterns

The pattern was manufactured from wood according to the design drawings of the shape produced. In general, we can use the wooden pattern to produce single parts. The mold was prepared in the carpentry workshop as shown in figure 1.

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Figure 1. Wood pattern

4.2The mold

The pattern is placed in the mold and the mold material is packed around it. The mold contains two parts, the drag (bottom) and cope (top), as shown in figure 2.

Figure 2. Drag and cope mold

4.3The procedure of melting stainless steel

In this study, electromagnetic induction was used to melt metals. Induction heating is a non-contact heating process in which high frequency electricity is passed through a coil. The coil generates a rapidly changing magnetic field within the coil. By induction, eddy currents are created within the metal. Due to the resistance of the metal, heat is generated. The oven used in this study is shown in figure3 [7,10].

Type 304 stainless steel alloy was melted in an induction furnace after conducting a chemical analysis and ensuring it conformed to the standard specifications. The titanium element was heated to a suitable temperature to facilitate the process of rolling in the molten, and the melt was brought to a temperature of 1640℃. Before adding titanium to the induction furnace or molten stainless steel 304, we must put titanium in a special fixture from SS304 and dropped into molten metal as shown in figure 3.

The titanium element was added and a sand material was added to collect the slag. The temperature of the melt was measured using a manual device (galvanometer) and it was about 1660 ℃ as shown in Table1. After that, the refuse is removed from the surface of the melt manually in preparation for the pouring process.

Figure 3. The induction furnace

It should be taken into account that the pouring process and the addition of the titanium element are completed within a period of (2-3) minutes because it quickly volatilizes, and immediately after that the pouring is done in the sand molds that you hollow out are shaped like rectangular parallelepipeds as shown in figure 4.

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Figure 4. Pouring the metal

After the casting process, the sand mold is broken, then the castings are cut, cleaned, and the feeding channels are removed.

4.2 Mechanical properties testes

4.2.1 Chemical analysis test

Chemical analysis was performed at Misurata Iron and Steel Factory by device (ARL 3460-OES-METALS ANALYZER).

The chemical analysis shows that the sample conforms to the chemical composition of the standard specifications for stainless steel 321

4.2.2 Tensile testing

The tensile test aims to find the yield point and maximum stress, for samples of Cast type 321 stainless steel under static and axial tensile loads.The specimens were prepared according to (ASTM E8-81)[11].

Samples of the cast metal were taken and compared with the standard specifications, then run on an electric wire cutting machine to obtain accurate dimensions. These samples were divided into three groups, and each group contained three samples as shown in figure 5 [11-14].

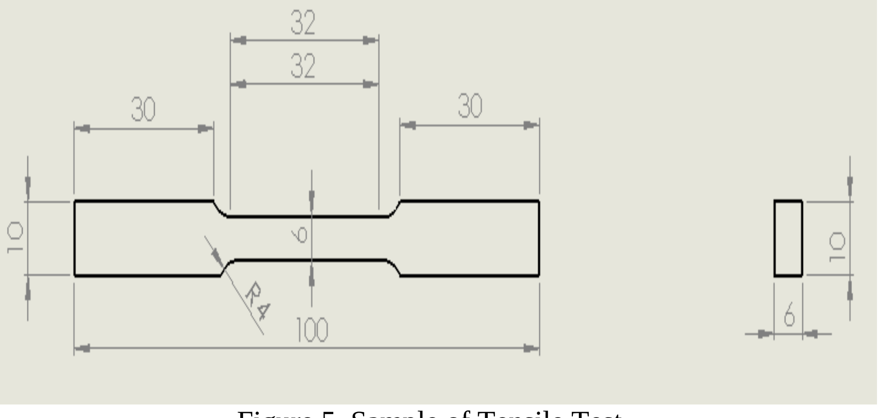

Figure 5. Sample of Tensile Test

Tensile properties often are used to predict the behaviour of a material under forms of loading other than uniaxial tension,the tensile plotted data are presented in Table2.

Table 2 The result of Tensile test

Groups of specimens		Tensile test	
		Yield stress	Tensile strength
Group one	A01	198	200
	B01	312	545
	C01	315	546
Group two	A02	314	553
	B02	312	520
	C02	313	552
Group three	A03	305	558
	B03	307	559

4.2.3 Hardness test

Hardness is considered one of the important mechanical properties for studying the surface of a material, and it is defined as the

resistance of the surface of the material to stitches or scratches, or it is the resistance of the material to local plastic deformations [15]. The hardness of materials depends on the type of bonding force between molecules or atoms, the type of surface (smooth, rough), the temperature, and the conditions affecting it. There are several ways to measure hardness, the most important of which is Shore (Durometer) Hardness Test, Meyer Hardness, Vickers Hardness, Rockwell Hardness and Brinell Hardness [15,16].
The Brinell hardness test method consists of indenting the test material with a 10 mm diameter hardened steel or carbide ball subjected to a load of 3000 kg. The full load is normally applied for 10 to 15 seconds in the case of iron and steel and for at least 30 seconds in the case of other metals.
The device used to measure hardness is Rockwell (Brinnel) hardness tester digital type. This device is located higher institute of Engineering and Technologies as shown in figure 6. After cutting, the sample surface is smooth surface to get accurate results [12, 13].

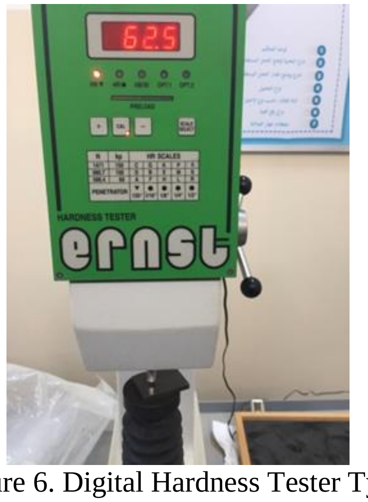

Figure 6. Digital Hardness Tester Type

A hardness test was performed on three samples of stainless steel 321 in the Material Properties Laboratory at the Higher Institute of Engineering Technologies.

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4.2.4 Measuring of surface roughness

The surface roughness was measured by using ALPA-SM Dives shown in figure7. The surface roughness values were recorded at locations around the circumference at a random distance from the edge of the edge of the specimens to obtain statistically meaningful data for each factor level combination. Surfaceroughness (R_A) was chosen as a major parameter in this study.

Figure 7. Surface Roughness Testers

5. Steps to perform heat treatment

The first group was not subjected to heat treatment, and the second group was treated at a temperature of 600 degrees Celsius and a time of 4 hours. The last group was heat treated at a temperature of 700 degrees Celsius and a time of 4 hours.

The second group was hardened by placing them inside the electric oven, setting the temperature to 600 degrees Celsius, and leaving the samples inside the oven for 4 hours, after which the samples were taken out of the oven and left to cool in the air. The last group was treated in the same way, except for the temperature difference, which was 700 degrees Celsius.

The Temperingprocess is carried out immediately after the hardening process, to increase the metal's formability and reducethe hardness. The Tempering process was carried out at a temperature of 300 degrees Celsius, and it was left in the oven for 4 hours. Then it was taken out of the oven and left to cool in the air.

6. Results and discussion

This research work was carried out at the Tripoli Casting Research Center. The result and discussion of the research paper under investigation presented here will indicate the effect of some parameters during the sand casting process, which include, for example, pouring time, amount of material addition, and temperature.

Table 3 shows the results of the chemical composition of casting material experiments for five of the latest samples

Table 3 The result of the chemical composition of the final experiment cast steel321

Samples	Element%							
	C	Mn	P	S	Si	Cr	Ni	Ti
(1)	0.086	1.053	0.017	1.053	7.569	16.656	7.56	0.232
(2)	0.074	0.798	0.024	0.003	1.198	17.425	7.85	0.253
(3)	0.045	0.808	0.538	0.0053	0.968	19.018	8.73	0.331
(4)	0.073	1.219	0.023	0.004	1.091	17.493	7.62	0.392
Cast alloy321(5)	0.081	1.989	0.046	0.031	0.751	18	9.98	0.401
Standard alloy%	0.08 <	2<	0.045	0.030	1	(18-19)	(9-12)	C*5 <

6.1 Discussion of the chemical analyses results

The chemical analyses of the last five sample results show that the amount of Ti% gradually increases with reducing the pouring time as shown in figure 8.

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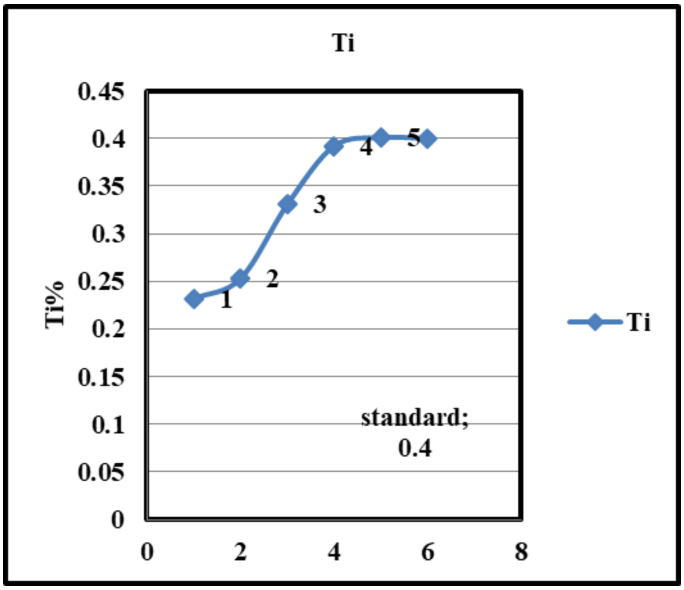

Figure 8. Casting sample at different times in a minute

Generally, the hardness tester is equipped with one or more hardness test blocks. The hardness tester is then calibrated, using the test block as shown in figure 6, where the test result was 62.25, operates according to ASTM E18 for light load Brinell and plastic hardness. The device is easy to use and gives very accurate readings as shown in figure 9.

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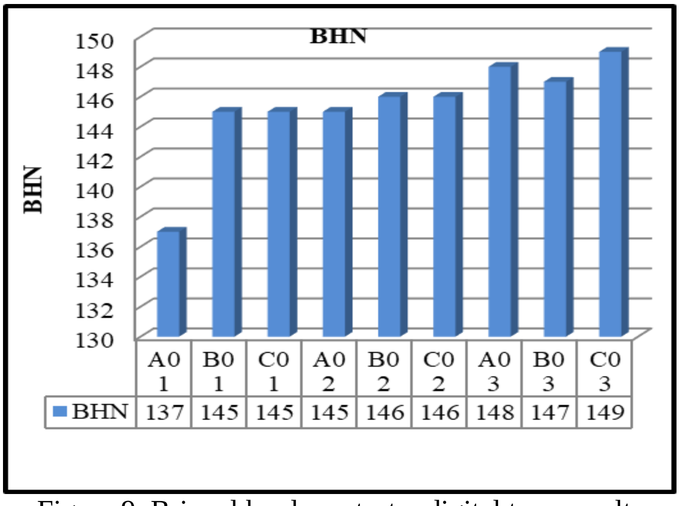

Figure 9. Brinnel hardness tester digital type results

Hardness values were improved and increased compared to the first group. After the casting process, the tensile strength of the samples was tested, and the results of the tensile test are shown in figure 10.

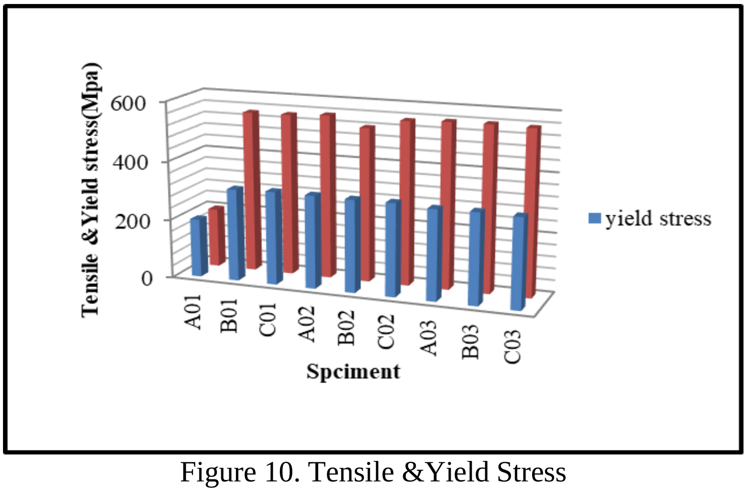

Figure 10. Tensile &Yield Stress

The result of mechanical properties given in Figure 10 shows the values of yield strength, and tensile strength were improved with the first group specimens, the sample NumberA01 shows a minimum

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value of yield strength &tensile strength (198,200MPa) of cast alloy. This is due to defects in the casting,including cavities.
The yield strengths and tensile strengths between the three groups resulted in a slight difference in value.

6.2 Results of visual inspection

The surface roughness R_A of these samples was in the limit $6.7\mu m\ to 7.8\ \mu m$

7. Conclusion

Through this study, it became clear to us that all the results show that it is possible to obtain or produce Type 321 stainless steel castings in several ways, the most common of which is sand casting. The casting and heat treatment process depends on experience.
We obtained the required ratio of Titanium compared to the specifications in the cast alloy by adding this element in different amounts as well as the addition time.
Heat treatment has a significant impact on increasing the tensile strength and hardness of the alloy. The best sample was the one that was heat treated at 750 degrees Celsius, with a setting time of 4 hours, and Temperingat 300, so that the mechanical properties of the casting can be controlled through heat treatment.
The result of the hardness and tensile test of cast metal shows that properties were in the recommended range compared with wrought stainless steel.

References

[1] M. Goenka, C. Nihal, R. Ramanathan, P. Gupta, A. Parashar, and J. Joel, “Automobile parts casting-methods and materials used: a review,” Materials Today Proceedings, vol. 22, pp. 2525–2531, 2020.
[2] M. Goenka, C. Nihal, R. Ramanathan, P. Gupta, A. Parashar, and J. Joel, “Automobile parts casting-methods and materials used: a review,” Materials Today Proceedings, vol. 22, pp. 2525–2531, 2020

[3] guleyupoglu,s.”casting process desigin Guidelines ”,AFS Transaction 97-83,pp.869-876
[4] High Alloy Data Sheets--Corrosion Series, Supplement 8, Steel Castings Handbook, Steel Founders' Society of America 1981
[5]W.J. Jackson, Ed., Steel Castings Design Properties and Applications, Steel Castings Research and Trade Association, 1983.
[6] W.J. Jackson, Ed., Steel Castings Design Properties and Applications, Steel Castings Research and Trade Association, 1983
[7] D.M.stefanescu, Chairman ASTM HANDBOOK volume 15 casting.
[8] [8] Vasylkiv, V., L. Danylchenko, and D. Radyk. "Technological Methods of Workpieces Manufacturing Metal Casting." (2021).
[9] M. Goenka, C. Nihal, R. Ramanathan, P. Gupta, A. Parashar, and J. Joel, “Automobile parts casting-methods and materials used: a review,” Materials Today Proceedings, vol. 22, pp. 2525–2531, 2020
[10] P.R. Wieser, Ed., Steel Castings Handbook, 5th ed., Steel Founders' Society of America, 1980.
[11] ASTM E8 [Annual book of ASTM standards (2004) American Society for Testing of Materials. Philadelphia, PA.
[12] ASM International, Hardness Testing, 2nd Edition, 06671G.
[13] Metals Handbook, 9th ed., Mechanical Testing, Vol. 8, 1990.
[14] N. Dowling, Mechanical Behavior of Materials, Prentice Hall, 1993
[15] D. William callister. Jr. "Materials science and Engineering An Introduction", 7th ed., 2007.
[16] Walkerm P.M.B., "Materials Science and Technology Dictionary", 1999.