FAILURE ENERGY OF STAINLESS STEEL AISI 304 HEAT TREATED AT DIFFERENT FURNACE TEMPERATURES

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Abstract. The toughness of materials such as Stainless Steel AISI 304 is of special concern because of its various applications. Thus, the failure energy has great impact on the analysis of its physical and mechanical characteristics. This study aimed to focus on the rupture and energy failure of AISI 304 treated at different temperatures. The experiment was performed using AISI 304 as the test specimen which was heat treated at various temperatures ranging from 0 ^{0}C to 250 ^{0}C evaluating the toughness by means of an improvised Izod Testing Machine (ITMach). The specimen was cut into an equivalent length of 127mm with a 45^0 V-notched to the center. The failure energy – temperature curve was drawn by getting the value of impact energy (PE = mgH) with the corresponding temperature in energy test procedure. The results were recorded which show that the rupture of different specimens has a value of 88.29 Joules for 8mm size, 1,706.34 Joules for 10mm, 3,708.18 Joules for 12mm size of AISI 304 at a temperature of 0^{0}C. On the other hand, when temperature reaches to 250^{0}C maximum, the rupture occurred at 16.19 Joules for 8mm, 529.74 Joules for 10mm and 8,711.28 Joules for 12mm at a striker's height of 500mm. The failure energy is the energy absorbed by the test specimen impacted by the striker or pendulum at the given height and mass of the striker. The failure energy relative to the temperature for three different sizes of the specimen showed a unique characteristic at specific degree of temperature. The dimension of the test specimen indicated how deformation occurred during the test runs. It was observed during the testing process which showed that the larger in size the harder the material and difficult to break relative to the temperature.

***Keywords**: stainless steel, toughness, rupture, failure energy, impact energy*

1. INTRODUCTION

The selection of stainless steel for some applications is based on the mechanical properties, corrosion resistance, fabrication characteristics, working environment, service temperature and the cost. But, the corrosion resistance and mechanical properties are the most important factors whenever selecting a grade of stainless steel for a given application**.** Among the many series of austenitic stainless steel grades, AISI 304 is widely used because of its corrosion resistance in many environments and relatively at low cost as compared to other series of steels (Muhammad, 2010). The stainless steel AISI 304 is typically used in various applications such as sinks and splash backs, saucepans, cutlery and flatware, architectural paneling, sanitary ware and troughs, tubing, brewery, dairy, food and pharmaceutical production equipment, springs, nuts, bolts and screws, and in the medical implants. The so-called stainless steel is widely known for resisting basically in corrosion. There are many alloys of this kind, but proper alloy must be selected for each intended purpose. Chromium is the principal alloying element, and occurs in the percentages from 11.5 to 30. In some alloys, nickel is also present in amounts up to 20%. Closed control must be exercised on the carbon content of these materials (Spotts). Based on their crystalline structure, stainless steels are classified into three basic groups such as austenitic, ferritic and martensitic (Kumar, 2004). Studies have revealed that virtually all grades of austenitic stainless steels are susceptible to serious stress corrosion cracking given the right environment and conditions. Corrosion is the deterioration or destruction of a material because of reaction with its environment. It is electrochemical in nature and frequently a very complex process. Intergranular corrosion, or the failure of grain boundaries, may occur especially if impurities are present. The metal as a whole is largely unaffected, but a network of the fine cracks spread over each surface. This type of failure includes what is called "caustic embrittlement" of steel (Dante, 2011). Most often cracks are initiated as a result of combined action of stresses developed during welding and the presence of a chloride containing environment due to seawater. It was further observed that improper welding parameters were employed for weld repair which resulted in sensitization of the structure and post weld heat treatment to remove weld sensitization and minimize the residual stresses was not done.

The toughness of material such as Stainless Steel AISI 304 is of special concern because of its various applications. Toughness is the capability of the metal to absorb through yielding highly localized and rapidly applied stress. One of the novel test methods used to determine the strength of a material was invented by Edwin Gilbert Izod (Izod, 1903), known to be one of the greatest metallurgists in history. This method is called to be Izod Impact Test which is one of the ASTM standard methods of determining impact strength. This present investigation focuses on the failure energy which has great impact on the analysis of its physical characteristics. Hence, this study of failure energy requires attention due to the wide applications and complex nature of the AISI 304.

2. MATERIALS AND METHODS

2.1 The Improvised Izod Impact Testing Machine

The improvised Izod testing machine is constructed using locally available materials with the striker made of solid hexagonal iron steel. This testing machine is an improvised one since it is assembled using the available scrapped materials. The cost is very minimal compared to the commercial availability in the market. It is attached to a fixed pillow block and can swing freely as a pendulum under the influence of gravity in order to hit the specimen. The isometric view of this device is shown in Figure 1.

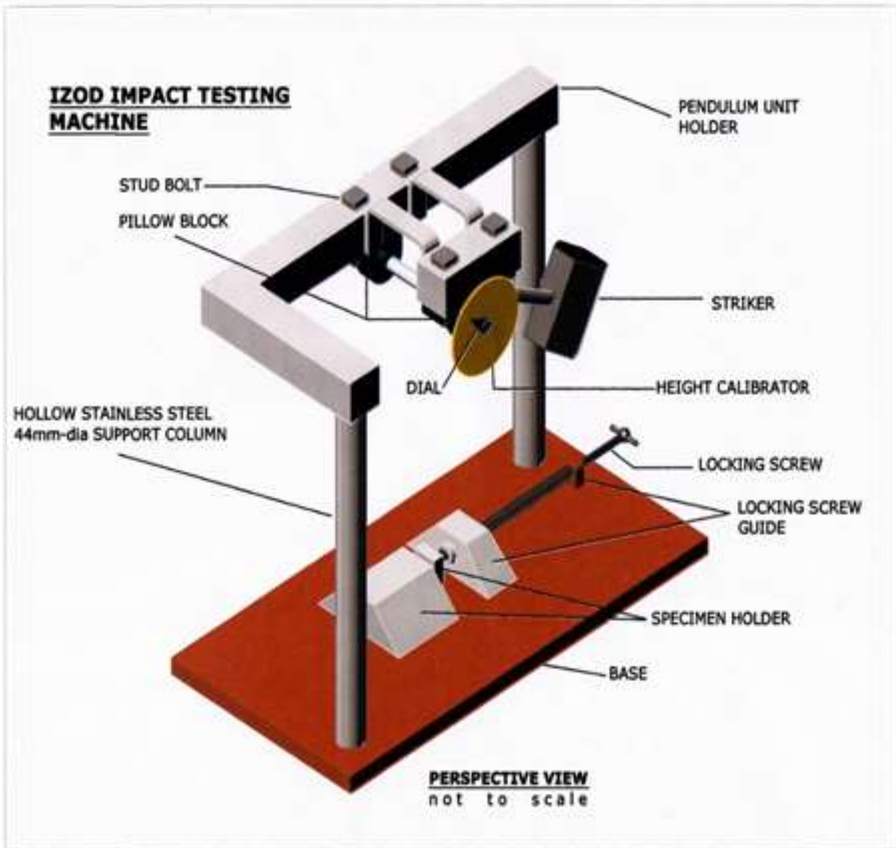

Figure 1. Improvised Izod Testing Machine

2.2 The Specimen

In the experiment we used Stainless Steel AISI 304 as the test specimens in determining the toughness and the failure energy during impact loading. The specimen is made of square bar with dimension of 10mm x 10mm and a length of 127mm. The V-notched is cut in a specified angle of 45^0 at the center of the specimen as shown in Figure 2 below.

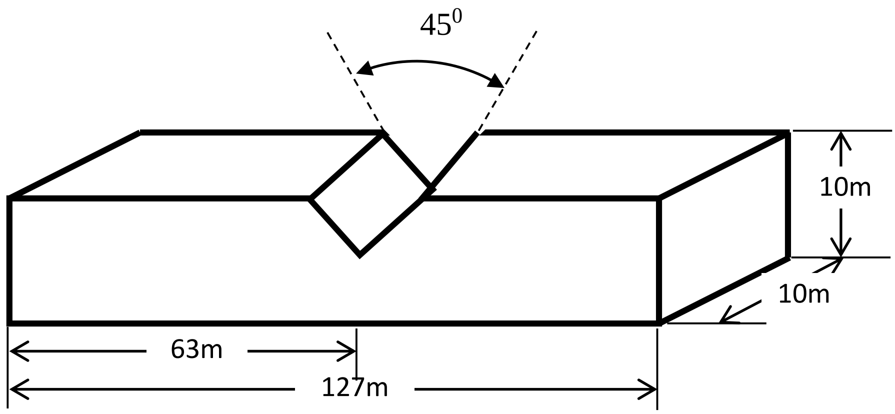

Figure 2. Profile of the specimen

2.3 Experimental methods

During the test runs the specimen is treated at various temperatures ranging from 0^0C to 250^0C using freezer and electric oven, respectively. Specimen is placed in the holder of the device located at the bottom and it is tightly inserted between the locking screws to make sure that it will not move while the pendulum strikes it. It is done repeatedly by releasing the striker at different height until the specimen has reached its rupture point. The test run of each specimen of each size was done for about 20 trials or until rupture is reached. Only the specimen is heated at a desired temperature ranging from 0deg to 250deg Celsius. All necessary observations during the experiment had been noted especially at the start of the deformation, cracking and the rupture where data were taken. The impact energy is determined relative to its potential energy and its value depends on the height of the striker. The procedure of determining its impact energy is standard based on other methods used in other experiments done by other researchers. In this case the impact energy is determined using the simple relationship of the mass, standard gravitational attraction and the height of the striker. On the other hand, the failure energy is calculated by getting the value of impact energy taken at a corresponding temperature during the test run. Hypothetically, the failure and impact energy are similar in value. It is known theoretically that the relationship between the failure energy and temperature for high strength steel is evidently proportional. Thus, as the temperature increases the failure of crystalline structure of steel is substantially high as well.

3. RESULTS AND DISCUSSION

The impact energy to initiate dynamic failure of the specimen, Stainless Steel AISI 304, was recorded in the following tables at different temperatures during the test runs ranging from 0^0 to 250^0.

Table 1. The impact energy of three different sizes of specimen.

Specimen	Impact Energy (Joules)				
	0 deg C	30 deg C	100 deg C	175 deg C	250 deg C
8 mm	88.29	612.04	23.54	17.66	16.19
10 mm	1,706.34	176.58	88.29	117.72	529.74
12 mm	3,708.18	10,153.35	10,418.22	10,800.81	8711.28

Generally, it was observed that the larger the specimen the greater value of the energy was needed to attain its rupture at a desired temperature. When the specimen was heated the deformation took place as observed in all specimens having a lower value of impact energy. This means that the physical and mechanical properties of Stainless Steel AISI 304 were greatly affected by temperature rise.

Table 2. The impact energy at the onset of crack of three different specimens.

Specimen	Impact Energy (Joules)				
	0 deg C	30 deg C	100 deg C	175 deg C	250 deg C
8 mm	17.66	20.6	16.19	7.36	8.83
10 mm	17.66	20.6	11.77	14.72	7.36
12 mm	26.48	765.18	26.48	29.43	23.54

In Table 2 showing the value of impact energy during the onset of cracking which is very evident and it differs on various temperatures except for 8mm and 10mm when temperature is at 0^0C and 30^0C, respectively. However, it was noted that the impact energy is the same for 8mm and 10mm when the temperature of the specimen was set at freezing point and at 30^0C. On the other hand, for the 12mm dimension a large value of about 765.18 Joules is calculated when cracking of the specimen started, which is substantially higher compared to other values. Generally, the resistance to rupture of the Stainless Steel AISI 304 decreases while temperature increases.

The failure energy is the energy absorbed by the test specimen impacted by the striker or pendulum at the given height and mass of the striker. The relationship between the failure energy and temperature as shown in Figure 3 indicated that for 12mm square bar recorded a large amount of energy due to impact loading compared to 8mm and 10mm dimensions at room temperature. Basically when the specimen is heated to a temperature equivalent to 250^0C the failure energy decreases because of the alteration of the grain boundaries and microstructures of this material.

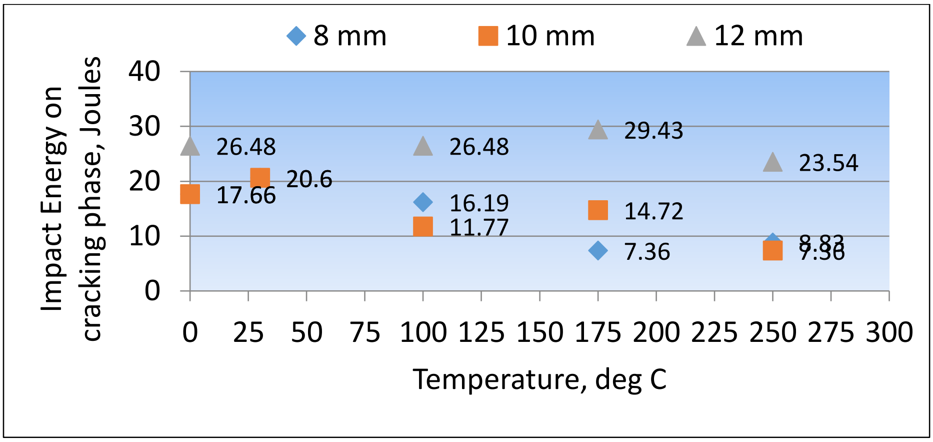

Figure 3. Relationship between Failure Energy and Temperature

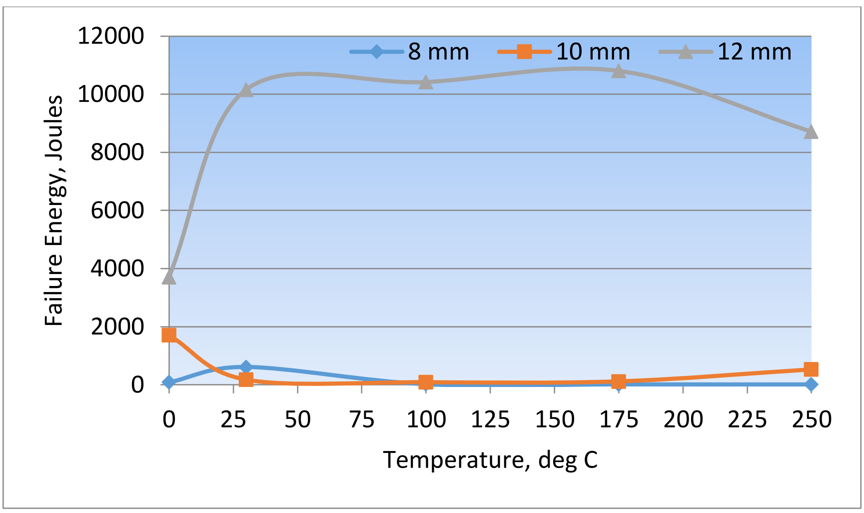

Figure 4. Impact energy on cracking phase.

During the onset of cracking, the 12 mm stainless steel specimen indicated a high value of impact energy from among other dimensions. For a temperature of 175^{0}C, the values of impact energy are 7.36 Joules, 14.72 Joules, and 29.43 Joules for 8mm, 10mm and 12mm, respectively as shown in Figure 4. This means that great amount of energy is needed for large dimension before this material will deform or attain its rupture. However, when it is heated further to a higher temperature the energy requirements tend to decrease.

4. CONCLUSIONS

This Izod Impact Testing Machine offers best performance in order to determine the toughness of the Stainless Steel AISI 304, which is commonly used from among the available testing machines. Because of its usefulness for instructional and laboratory purposes, an improvised model was made to primarily use it in getting the strength for this kind of material. The Stainless Steel AISI 304 is very strong because of its chemical composition. It appears that the difference in sizes of the test specimen showed how deformation, cracking and rupture occurred during test runs. Generally, the larger in size the harder the material was even if it is heated at a certain temperature. The deformation of the test specimen is also evident during impact loading relative to the height of the striker. To obtain better results a careful technique on the setting up of the specimen in the device holder is advised while using this improvised machine.

5. REFERENCES

Dante D. Espina. 2011. Toughness of Stainless Steel Using Improvised Izod Testing Machine, Unpublished Thesis.

Izod, Gilbert. 2003. 'Testing brittleness of steel', Engineering

Kumar, T. 2002. Surface Hardening of AISI 304, 316, 304L and 316L SS using Cyanide Free Salt Bath Nitriding Process, International Symposium of Research Students on Materials Science and Engineering, December 2002-04, Chennai India.

Muhammad Sajid Ali. 2010. Failure Analysis of AISI-304 Stainless Steel Styrene Storage Tank, Journal of Failure Analysis and Prevention, Vol. 10, Issue 4, pp.303-311.

Spotts M.F., Design of Machine Elements, 6^{TH} edition, Prentice Hall.