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Charpy Impact Test on Mild Steel

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ABSTRACT
The overall purpose of this research is to explore the usage of an impact testing machine, specifically the Charpy Impact Test device, to better understand the principles behind impact testing in order to further develop engineering skills in materials selection. In this context, the research problem focuses on the importance of subjecting sample materials to impact testing and its implications to the profession. This author utilizes information from reliable sources of engineering literature and applies the information to experimentation using the Charpy Impact Test to develop the most ideal approach to materials testing and selection. The author found that engineers must always be aware that the strength of a material can only be increased at the expense of toughness, and this means that engineers must ensure that there must be sufficient strength with maximized toughness to avoid experiencing cracks that may hit a critical flaw size which would progress toward material failure.

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I. INTRODUCTION

The concept of toughness in products, structures, or anything useful is important in the day-to-day lives of people. If a mobile phone is accidentally dropped on the ground and the glass does not shatter, this is because the glass is specifically engineered to have a certain degree of toughness to it. Or perhaps if a person is hitting something with a hammer, it would not be good for the head of the hammer to shatter, so it must have a sufficient level of toughness associated with it. For impact testing of mild steel, the Charpy Impact Test can provide information on how much energy a specimen such as mild steel can absorb under an impact scenario. In this context, the following sections will present information on: 1) impact testing; 2) effect of temperature; 3) 17-4PH test material; 4) impact toughness of 17-4PH in H900 condition; 5) impact toughness of 17-4PH in H1025 condition; 6) impact toughness of 17-4PH in H1150 condition; 7) plotting, and; 8) conclusion. Engineers must always be aware that the strength of a material can only be increased at the expense of toughness, and this means that engineers must ensure that there must be sufficient strength with maximized toughness to avoid experiencing cracks that may hit a critical flaw size which would progress toward material failure.

II. IMPACT TESTING

The Charpy Impact Test was named after the man who invented it in the late 1930s as the United States was getting ready to enter World War II when one of the problems that the US Navy was facing was that they did not have a complete understanding of the impact of the heat treatment that the metal would experience as the process of welding took place, and how that welding would have an impact on the mechanical properties [1]. The Charpy Impact Test was developed as a quick way to see how tough the metal was. If a person wants to know if a piece of material will dent or shatter when it is hit with a hammer, the Charpy Impact Test can give an idea regarding this. This can be useful in finding out how tough a certain material, or a certain treatment for a material, is. There are instances when the strength of the material, or how much weight it can hold, is not the primary concern; rather, it may be more important how the material would respond to impacts or cracks. Although the Charpy Impact Test device cannot be used for design purposes, the Charpy energy value allows a quick comparison of different materials or different treatments.

The physics behind the Charpy Impact Test device is quite simple. As shown in Figure 1 below, it begins by using a bar with a v-notch; the bar is hit with a pendulum which has a potential energy associated with it: Mass x Gravity x Height. If the pendulum were to swing freely, it would end up on the opposite side of the swing and reach the same height. However, if the pendulum is made to impact a specimen or sample, it would take a certain amount of energy to break the sample. In doing this, the energy associated with the pendulum is reduced. When the pendulum breaks the specimen, it swings to a lower height: Mass x Gravity x Height, minus the energy absorbed by the test sample. By doing this, it is possible to characterize how much energy different materials [with same size] can absorb.

Charpy Impact Test Unit

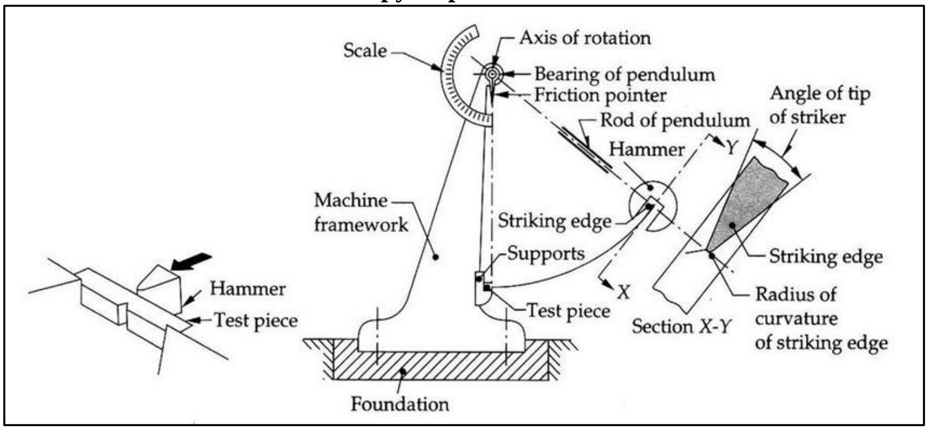

Fig. 1: Mechanical principle of the Charpy Impact Test device [2].

Results gathered from the Charpy Impact Test are important because they determine the right material for a specific application. The use of materials that do not meet the requirements can have fatal consequences. When coldness and strong force impacts are combined, some steel can become brittle and can soon break. The Charpy Impact Test is a destructive material method. This test method provides information about the material's resistance to sudden stress. The toughness depends on three factors: 1) temperature; 2) notch form, and; 3) the material's composition or the resulting lattice structure.

The specimens that are used for the Charpy Impact Test are 55 millimeters long and a cross section of 10x10 sq. mm. The specimens are notched for better control of the fracture process. Two different notch shapes can be used: v-shaped notch or u-shaped notch. Since the toughness of the materials also depends on the temperature, specimens can be brought to a desired temperature on a climatic cabinet and then removed immediately before the test. The specimen is then placed in the Charpy Impact Test unit with the notch facing the direction of the pendulum impact, and the pendulum is released.

When the pendulum hammer breaks the specimen, a portion of its kinetic energy will be absorbed by the deformation process; therefore, the pendulum would not swing as high on the other side, as compared to the height of the pre-release [i.e. initial] position. The difference between the initial and the final height of the pendulum determines the notched bar impact work of the specimen. The notched bar impact work is given in joules and can be read from the scale on the testing device.

2.1. Effect of Temperature

Some metal materials such as structural steel with body-centered cubic [BCC] lattices tend to become brittle at low temperatures. If such materials are tested with a Charpy Impact Test at low temperatures, the result would be a brittle fracture wherein the specimen would have a smooth fracture and the fracture surface would have a micro crystalline appearance. Ductile materials deform first before breaking, and the observer can recognize such ductile fracture by their deformed edges. There are, however, also specimens that can exhibit both micro crystalline areas as well as deformed spots. This type is called a mixed fracture.

Since notched bar impact work strongly depends on the temperature, the measured values can be plotted against the temperature. As presented in Figure 2, the energy absorbed temperature curve can be divided into three sections: upper shelf, transition zone, and lower shelf.

Energy Absorbed Temperature Curve

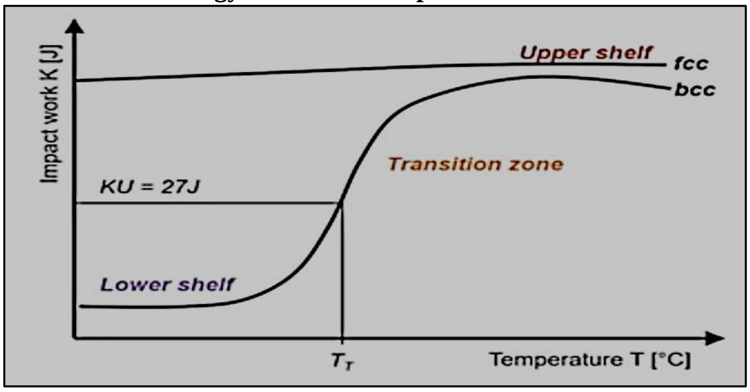

Fig. 2: Upper shelf, transition zone, and lower shelf curve.

The upper shelf would indicate good toughness at high temperatures. Ductile fractures also occur in the upper shelf. The lower shelf, on the other hand, would indicate lower notched toughness values at low temperatures, and the material would have a smooth fracture which is indicative of a brittle fracture. Finally, the transition zone would indicate the transition range between the upper shelf and the lower shelf. The measured values would be scattered extensively in the transition zone; mixed fractures occur here.

The difference between face-centered cubic metals and body-centered cubic metals exhibit itself especially at temperature-dependent impact stress. The resistance to slip increases sharply with decreasing temperature, especially in metals that does not have close-packed slip planes. After evaluating the tests carried out with variety test temperatures, it is possible to obtain clear indications of a possible transition temperature [TT]. Since knowledge of the transition temperature from ductile to brittle mature behavior can be of vital importance to the material selection, both the temperature as well as the value obtained for the notched bar impact work [as shown in Figure 2: KU = 27J] can be specified in the materials designation, especially when it comes to structural steel.

2.2. 17-4PH Test Material

The sample material that will be discussed in the following subsections is the 17-4PH steel. Three sample materials of this steel, each with a different heat treatment, will be used. One steel bar is at H900 condition, another at H1025, and a third steel bar at H1150 condition; the numbers correspond to the temperature of the treatment [i.e. 900F, 1025F, and 1150F]. It can be observed in Figure 3 that the ultimate tensile strength and the yield strength vary quite a bit between the different heat treatments. As the temperature is increased, the yield strength and ultimate tensile strength decreases. The Charpy test will show that as strength goes down, toughness goes up.

Heat Treatment Effects to 17-4PH

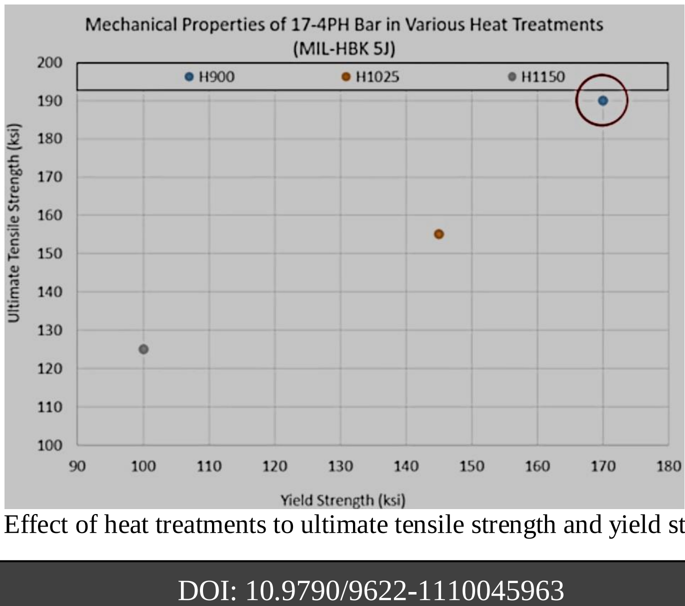

Fig. 3: Effect of heat treatments to ultimate tensile strength and yield strength.

It is important to realize that within a given material like 17-4PH, there can be a number of different treatment options available to strike a balance between strength and toughness. For instance, making a sharp knife would require a higher strength or higher hardness like the H900 condition. But if the steel should be mildly structural and it needs to take a beating, the H1025 or H1150 condition would be more ideal, assuming that weight is not a concern. The higher strengths tend to allow less material due to strength to weight ratio but in doing this, damage tolerance or toughness is sacrificed.

2.2.1. Impact Toughness of 17-4PH in H900 Condition

Upon subjecting the test material at H900 condition, results showed that the impact energy value was measured to be about 25 ft-lbf which is not really good or bad per se because it is all about what the application requires and it is up to the engineer to figure out what level of toughness or damage tolerance is required. During the actual testing, it was observed that the impact produced a somewhat high-pitched sound. This is because as the energy absorbed changes, the sound that is produced when the sample fractures also changes.

Fracture-Induced Shear Lips

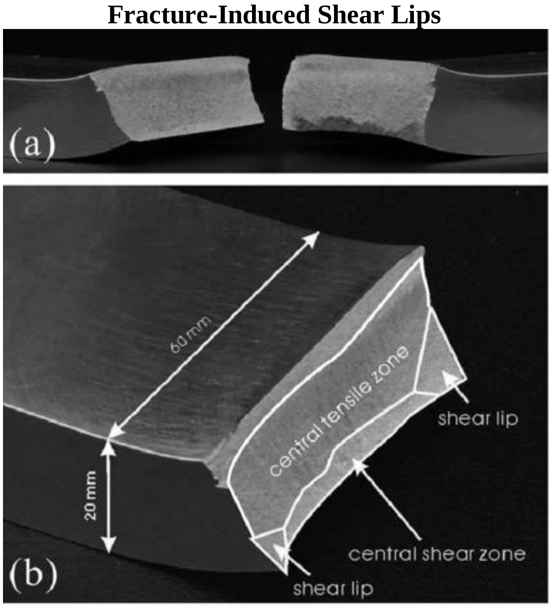

Fig. 4: Physical appearance of shear lips due to fracture [3].

On the sample material after impact, it was also observed that the fracture surfaces of the pieces that are broken open are relatively flat and there are 'ears' along the edges of the sample. These are called shear lips, similar to what is presented in Figure 4 above, which indicates that the material underwent very severe deformation at those areas where a lot of energy was absorbed. This means that the larger the shear lip area, the larger the energy that was absorbed.

2.2.2. Impact Toughness of 17-4PH in H1025 Condition

The H1025 condition is not as strong as the H900 condition. As shown in Figure 2, the ultimate tensile strength has dropped from about 190ksi down to 155ksi and the yield strength has dropped from about 170ksi to about 145ksi. However, it can also be observed in Figure 3 that the toughness has improved as a result of the change in heat treatment. After testing, it was measured that the impact energy for 17-4PH 1025 was about 55 ft-lbf in this case. This is more than twice the energy absorbed by the previous test material even though the ultimate tensile strength and yield strength did not drop by half.

This shows that although not a lot of strength was given up, the sample material gained a lot of toughness. It was also observed that the sound produced when the sample material broke was much deeper than the H900 condition sample. In regard to the appearance of the fracture surfaces of the samples, it was observed that the shear lips were much larger than they were in the H900 condition sample. This indicates that the H1025 condition sample went through much more deformation across the entire surface of the sample and was able to absorb more energy.

2.2.3. Impact Toughness of 17-4PH in H1150 Condition

The 17-4PH in the H1150 condition is the softest of the standard heat treatments available for this material. It can be observed in Figure 2 that the ultimate tensile strength is about 125ksi and the yield strength is about 100ksi. In view of this, it is expected that the impact toughness will be substantially higher than either the H1025 or H1150 conditions. After testing, it was measured that the impact energy was about 97 ft-lbf, which is almost double the H1025 condition and almost quadruple the H900 condition.

Based on Figure 3, it can be observed that not a lot of ultimate tensile strength and yield strength was given up. This resulted in a slight decrease in toughness as the heat treatment temperature was increased, although this does not necessarily equate to a good or bad condition because it all depends on what the engineer needs in relation to design requirements or constraints. This highlights the importance of understanding what is required in the design.

During testing, it was observed that the sound produced when the test material broke was much deeper than either the H1025 or H900 conditions. Looking at the fracture surfaces of the sample, the shear lips are also much larger than either of the two previous samples. This indicates that there was more deformation and more energy absorption in the H1150 condition sample testing.

2.2.4. Plotting

After all the Charpy impact energy values have been measured, the final step is to plot the impact energy versus the strength of the materials. Whether looking at the ultimate tensile strength or the yield strength, it can be observed in Figure 5 below that as one goes along the X-axis and increase in strength, the toughness drops off quite significantly.

Plot for 17-4PH after Testing

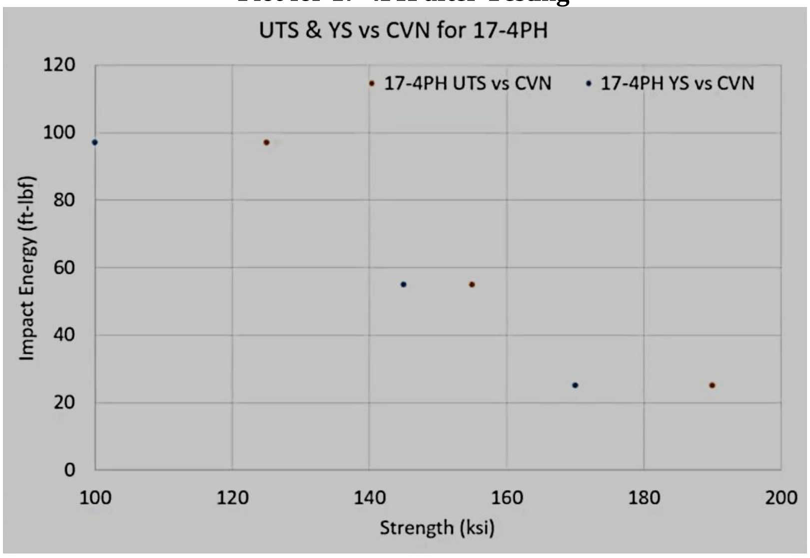

Fig. 5: Correlation between increase in strength and decrease in toughness.

This paper has discussed how a particular sample material reacts to the Charpy Impact Test unit but regardless of the material at hand, whether it is 17-4PH, a typical carbon steel that is quenched or tempered, or arsenic steel that has been cold-worked to increase strength, it is important to understand the behavior of the material and how different processing and treatments affect the material properties. In the case of aircraft, for example, it should be noted that aircraft are notorious for experiencing fatigue cracks. This means that engineers must ensure they are using the right type of material for the design it is intended. In this aspect, the Charpy Impact Test can help identify the correct material and should therefore be used prior to the adoption of the said material, especially in structural designs where a critical failure would result not only in the loss of property but, most importantly, in the loss of lives.

III. CONCLUSION

In the discussions presented above, it was observed that as the strength increased, toughness was slightly reduced. This can be helpful when making structures that are sensitive to cracks. The engineer must ensure that a crack does not hit a sufficient size to cause a part to break, so there must be sufficient strength with maximized toughness to make sure that the crack does not hit a critical flaw size that will lead to a failure.

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