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The Effect of Notch Depth and Angle onThermal Wear Fracture Energy for the Casting Plain Carbon Steel Process

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Abstract:

Engineering materials are used in many engineering applications in various forms; these materials may be subjected to wrong or sudden applications during use. This is why the knowledge of the characteristics of these materials bearing different forms of sudden loads is essential for the success of the engineering design and the performance of the desired end.In this research, the effect of the angles and thickness of engineering materials on the value of the energy required to fracture when loads suddenly shed was studied. To study these effects, test samples were prepared (Izod samples) with notch depths of 2, 4, and 6 mm at fixed angles; samples were also prepared with a fixed notch depth and different notch angles (60º, 120°,180°). Three tests were conducted in each case and the results showed that the differences in the resulting values did not exceed 3%. The average of the absorbed energy values demonstrated the impact of the variables. Increases in the depth of the notch were also found to increase the value of energy absorbed per unit area, as well as the notch depth, leading to ductile fracture compared with the standard notch depth. Furthermore, increases in the notch angle to 120º caused a marked change in the ductile fracture.The process parameters were optimized using RSM and from the obtained model, the optimal condition was determined at a 95% confidence interval.

Keyword: Fracture energy; Engineering design; Ductile fracture.

Introduction

Various structures and machines, such as bridges, cranes, aircraft, ships, etc. are composed of several parts that are interconnected with each other. The resistance of any structural part and the body depends on its size and shape, as well as some natural and chemical properties. These properties are usually determined by the experimental study of the material behavior using material testing devices that determine the validity of these materials for use for a specific purpose. Many engineering materials are designed based on static properties that are often exposed during use; the most important of which is durability and crawling. However, the materials may be exposed to sudden loads that must be taken into consideration when designing. Some engineering materials may be exposed for any reason to different temperatures during operation and this changes the nature of their fracture [1-4].

The shock resistance tests, although simple, are more complex to take advantage of in the design. The failure of a material under sudden stress demonstrates the level of energy needed for failure and the mechanism by which energy is absorbed during failure. It is important to study the effect of the section and the angle of slitting of materials because of their ability to cause a fragile fracture in design when using certain values regardless of the pleated nature of the material [5-8]. This research focused on examining the impact of both the dimension models and the notch angles on the nature of the fracture and both the energy values required for the breakage and the fractional sections.

While effect of carbon content,the first and the most seasoned sort of steel utilized as underlying prepares are plain carbon prepares. The expansion in strength depended on the increment in carbon content. Carbon in Fe is a strong arrangement, with restricted dissolvability[9, 10]. During distortion, because of applied pressure, disengagements through their development communicate with obstructions, what thusly requires expanded of applied strength for additional misshapening. The impact of carbon content on progress temperature on carbon prepares appears in Figure 1. Plainly the increment of carbon content expands change temperature and brings down the upper rack of effect durability. In these prepares, the microstructure relies upon carbon content, and is mostly feritic or feritic-pearlitic, and now and again even bainitic.Increase of carbon gives expansion in carbide part. Carbides (cementite) are lengthened with exceptionally sharp tips; they go about as stress concentrators, in this way diminishing strength.

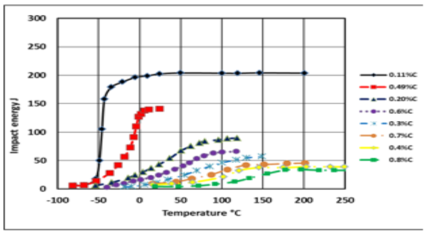


Figure 1.The relationship between the angle value and the amount of energy per unit area [10]

Influence intensity is the capability of a material to resist failure when loaded suddenly high speed"[11] that is energy lost per cross sectional area, signifying that an impact strength test measures the exact energy that would cause a material to fail and it is reported as Joules per square meter (J/m^2). The influence asset of a material is specified by jointly inner factors and exterior factors [12]. Interior factors contain the real mechanical properties of the material while the external factors include; temperature, rate of loading, geometry of the sample and the description of disappointment.

The present studies focused an analysis on the samples were prepared with different notch depths and microstructure changes of fracture in carbon steel with different notch angles.

Carbon Steel

Steel that does not contain other distinct elements except carbon is called carbon steel; carbon steel is divided according to the percentage of carbon as follows:

Low Carbon Steel

It is called mild steel and contains up to 0.25% carbon. It is used in the manufacture of bridges and for general purposes in workshops, such as nails and nuts. If the carbon percentage is less than 0.25%, then, it is used in the manufacture of steel reinforcement and the manufacture of thin sheets and drawn tubes [13-16]. The response of this type of steel to heat treatment is not as great as the response of steel types with high carbon contents [17-19].

Medium Carbon Steel

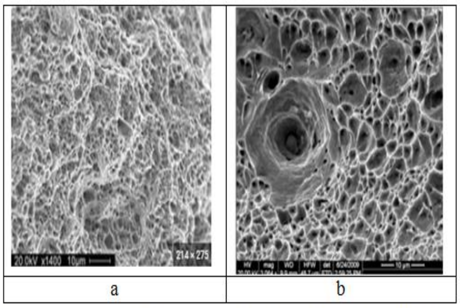
Steel that contains a carbon percentage of 0.6 - 0.25%; this type of steel is considered important in many applications, for example, in the manufacture of wheel hubs, and in the manufacture of wires that are subjected to high tensile strength; it is also used to manufacture the outer tires of train wheels, hammers, and gears. It is a steel that responds efficiently to heat treatment.

High Carbon Steel

It contains a carbon content of 1.2 - 0.6%; it is used in services that require high hardness and wear resistance. Hence, it is used to make springs, standard molds, screw bits, carpentry tools, and axes. This type of steel responds well to heat-treatment; the heating cycle involves heating and cooling in water or oil.

Fracture

A dynamic fracture occurs under impact or explosive detonation loads. The conditions for kinetic loads have higher load rates compared to static loads. The final rupture of the fracture may involve a ductile fracture in which the plastic deformations persist until the section area fades. The final rupture may be the result of a brittle fracture in which the adjacent parts of the material are separated perpendicular to the cross-sectional area [20-22]. Figure 2 showed the section of the ductile fracture and the brittle fracture.



a b

Figure 2: A magnified section: (a) ductile fracture, (b) brittle fracture.

Being that brittle failure does not produce elastic de formations, it requires less energy than ductile failure. Energy is absorbed in ductile failure to form dislocations and other deformations within the crystal structure. As for the notch fracture, it is either a separation between the crystal levels or fissures within the granular boundaries in the internal structure of the crystals. The type of fracture depends on four factors which are temperature, stress, speed, and shape/size of the material [23].

Standard Impact Test

Materials are studied for toughness via impact tests; the toughness of any material depends on its energy absorption capability during deformation. Hence, the toughness of brittle materials is low due to the low level of deformation they can endure. Temperature can also affect the impact value of a material; the impact energy of materials generally decreases at low temperatures. Another factor that can affect the impact value of a material is the size of the specimen; the presence of numerous impurities in a material can increase the stress level and lower the impact energy.

Normally, impact tests are done using Charpy & IZOD specimen configurations. For the Charpy impact test, it is done using machines that can measure <1 foot-pound to 300 foot-pounds and a temperature coverage of -320°F to >2000°F. The types of specimen used for impact tests include notch configurations, such as Key-Hole Notch, V-Notch, U-Notch, as well as a notched and ISO (DIN) V-Notch with impact testing capabilities of sub-sized specimens down to ¼ size. Regarding IZOD impact testing, it can be done up to 240 foot-pounds using type-X3 and standard single notch specimens. This test is used to study the toughness of materials as a measure of the ability of materials to absorb energy during plastic deformation. The impact test is performed on standard notched test pieces that display the impact of breaking them; the values of energy expended in breaking the test piece are specified in joules, such as Izod, Charpy, Scattered, and Stanton tests.

The Charpy and Izod tests are the two primary tests for impact tests. Between the two methods, the difference is in the method of the World Trade Organization (simply supported) and in a cantilever threshold test (cantilever beam). Likewise, the position of the groove direction in the iodine test is against the hammer and in a preferred environment. Hammer drop angle in the IZOD test is 90° (horizontal position) but in the Charpy test, the angle of incidence is 120º. Figure 3 showed the dimensions and method of fixation for a standard ionic sample. Figure 3 showed the dimensions and method of installation; it uses a square metal pattern (10 ×10) mm and a total length of 125 mm. Displaying the groove as a stress center facilitates model fracture [24-26].

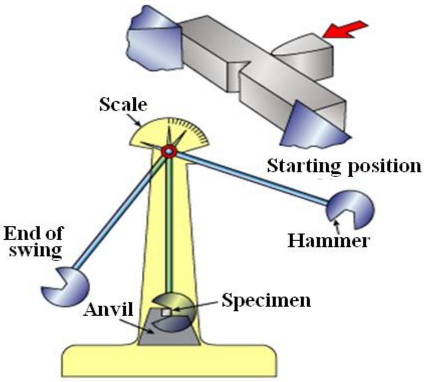


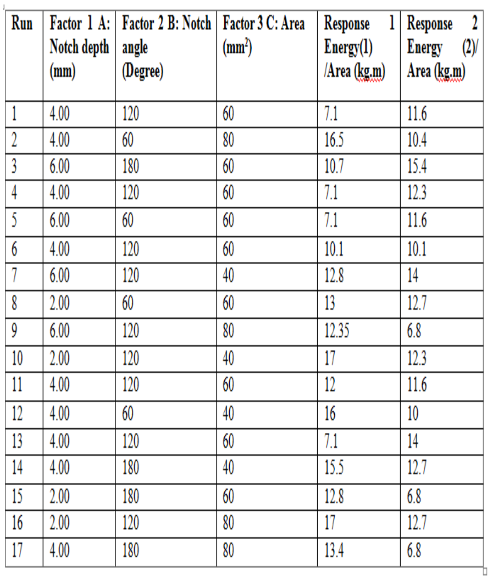
Figure3: The dimensions and installation method for a standard Charpy sample with a shock measured

Sample Preparation

The test pieces were prepared from carbon steel for the samples being heat-treated (normalize) and with a carbon ratio of 0.38% with a square section of dimensions (10 × 10 mm) and a length of (125 mm so that they have three notches. The samples were carefully prepared so that no indentation appears at the bottom of the grove; the angle of the grove was changed using scraping machines. The angles of the scraping pen were changed according to the required angle using milling machines (a cutter was used to make an angle of 180°). Nine samples were obtained, each sample containing three equal notches; the angle, depth, and radius of the notch depth are 0.2 mm. The values of the angles subjected to the shock test were 60º, 120º, and 180º, and the depth of these angles was 2, 4, 6 mm, respectively. After preparing them, they were smoothed using sandpaper to ensure there are no notches.

Test Application and Results

The test piece was held in the correct position in the anchorage site located at the level of the swing in the center of gravity of the hammer. The zero error value in this test was + 0.9 kg. The results obtained from the effect of changing the angle and depth of the groove on the energy required for breaking are shown in Table 1.



Run	Factor 1 A: Notch depth (mm)	Factor 2 B: Notch angle (Degree)	Factor 3 C: Area (mm^2)	Response 1 Energy(1) /Area (kg.m)	Response 2 Energy (2)/ Area (kg.m)
1	4.00	120	60	7.1	11.6
2	4.00	60	80	16.5	10.4
3	6.00	180	60	10.7	15.4
4	4.00	120	60	7.1	12.3
5	6.00	60	60	7.1	11.6
6	4.00	120	60	10.1	10.1
7	6.00	120	40	12.8	14
8	2.00	60	60	13	12.7
9	6.00	120	80	12.35	6.8
10	2.00	120	40	17	12.3
11	4.00	120	60	12	11.6
12	4.00	60	40	16	10
13	4.00	120	60	7.1	14
14	4.00	180	40	15.5	12.7
15	2.00	180	60	12.8	6.8
16	2.00	120	80	17	12.7
17	4.00	180	80	13.4	6.8

Table 1: Absorbed energy values for the test samples

Table 1 showed that the notching angle has a greater influence on the energy absorbed value; increases in the notching angle by more than 120º significantly increased the value of the energy required for fracture as shown in Figure 4. This evidenced the relationship between the angle value and the amount of energy per unit area.

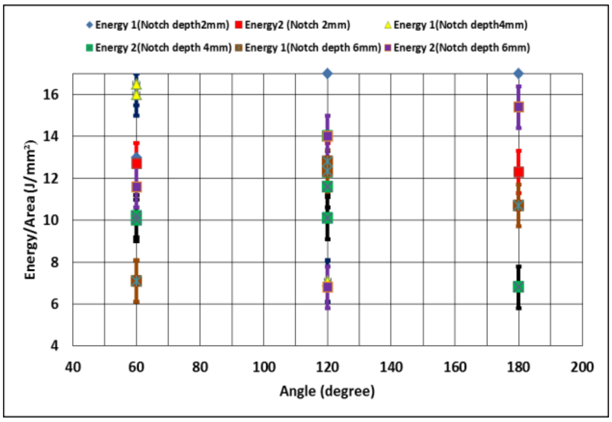
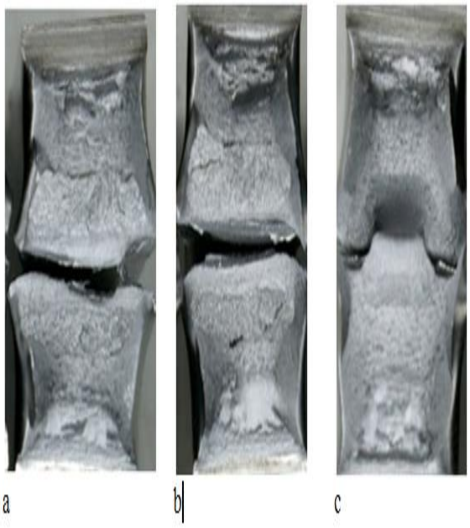


Figure 4.The relationship b

Results and Discussion

After much research, it is necessary to assess the shock resistance of engineering materials and it is sometimes difficult to obtain standard samples of Charbi or IZOD. Samples must be prepared with non-standard removal, especially the angle of slitting and the area exposed to shock. The main objective of this research is to study the effect of non-standard sample dimensions of shock resistance of the resulting nature of carbon-equivalent steel samples (0.38%) with a rain-breaker. The results in Table 1 showed the average amount of energy required per unit space; from the results, it was found that decreases in the standard fraction value from 80 mm^2 to 40 mm^2 at a 6 mm slit depth led to an increase in the value of the energy needed for breakage. The examination of the fracture section showed that there is a rain breaker without any ratio of the fragile fraction of the less spaced samples as in Figure 5a. The examination of the fracture section of the sample at an angle of 45º and a depth of 2 mm showed that the ratio of the fragile fracture ranging from 25% to 30% as in Figure 5b, while the fraction of the sample examined at an angle of 60º at a depth of 6 mm was characterized by a completely lithoid breaker. From this, it is concluded that increases in the dissection depth lead to a decrease in the ratio of the fragile fraction; therefore, the value of the energy required for the fraction of the unit of space is greater, regardless of the decrease in the total energy value of the break (due to the decrease in the area of the section). The previous conclusion applies to the different slitting angles when changing the depth of the slit. However, the nature of the breaker varies with changes in the angle of the slit at the sample depth of 2 mm and 4 mm; the slit angle of 60º was characterized by a substitrome for the eyes but with different energy values. The change in the nature of the fracture is complex and depends directly on the angle of the slitting. Samples with a notch angle of 120º and a depth of 4 mm, 2 mm featured different fractions, where there is a fragile fraction ratio of about 10% to 15% of the sample with a slitting depth of 2 mm as in Figure 5c. From this result, it is concluded that the depth of the slit has a significant effect on the rate of fragile failure at the corresponding slitting depth at a standard depth of 2 mm.



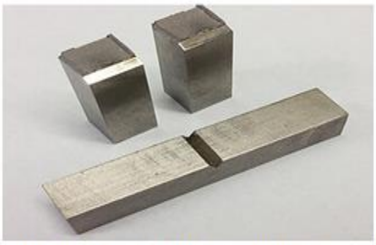


Figure 5: An amplified section of the crushed test specimen: (a) 100% ductile crushed (b) 85% ductile crushed (c) 70% ductile crushed

The effect of the slitting angle shown in Table 1 and the chart in Figure 5 indicates that the effect of the angle notching (up to 120º) on the energy value required for breakage (energy per unit of space) is low regardless of the presence of the fragile fraction of the samples at the angles of 60º and 120º. The previous simple change confirms that the total energy value depends on both the energy portion needed for fragile fracture and the energy portion required for the rainy break, as well as the effect of the failure mechanism. Increasing the angle to 120º has a clear effect on the energy needed for breakage; similarly, increases in the plastic formation increased the value of the energy absorbed during the breakage. The increase in slitting above 120º led to a clear increase in the value of the absorbed energy and that part of this absorbed energy was used to obtain the material's run-off before the breakage [27, 28]. This has been observed from a careful examination of the fracture synopsis. From this, it can be said that the flowability of the material, which is based on the quality of the engineering material, is also clearly influenced by the angle of the slit. Previous results showed that changing the standard slit angle in the IZOD test to 180º resulted in an increase in the value of absorbed energy by 1.36 times. An important result upon careful analysis of the samples is that the determination of the shock resistance of engineering materials at low temperatures is complex even for the metaphysical materials where the slit angle may change the nature of the fraction of the material.

Based on Figures 6(a) and 7(a), the residuals maintained a straight line and the errors were normally distributed. Hence, several process parameters were carefully removed from the model to justify the test. Figures 6 (b) and 7 (b) showed that the response model (Notch depth and Notch angle) determined above was relevant to the energy (1) and energy (2). The unaccounted factors in the plot were maintained at their average levels. The plots exhibited an ANOVA response which suggests that the surface quadratic model (Energy (1) and notch depth) contributed equally to reducing the notch angle. Meanwhile, the ANOVA for response surface 2FI model reduced the notch depth and extended the resistance of the materials, but this factor cannot annul the side effect of the increase in the other factors. Energy (1) increases if the notch depth is 2 mm with a decrease in area, while energy (2) increases with increasing notch angle and decreasing notch depth.

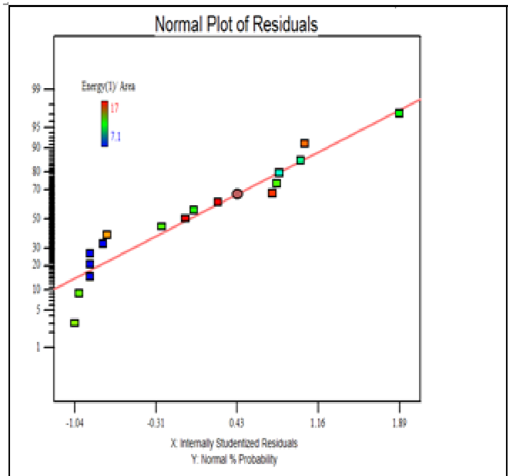


Figure 6(a). Normal probability plot of residuals.

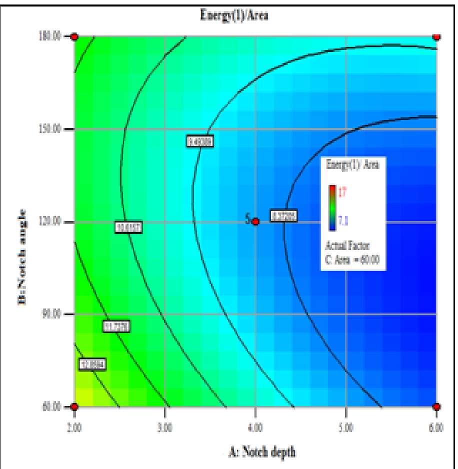


Figure 65(b). Contour plots of Energy (1) /Area responding to A=Notch depth, B=Notch angle.

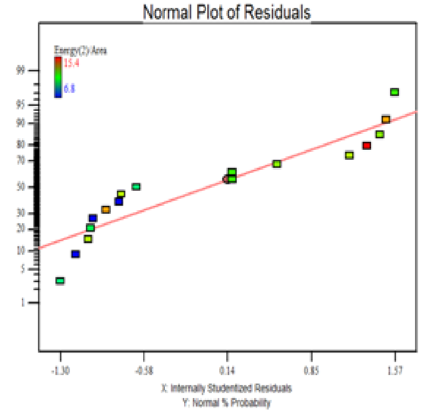


Figure 76(a). Normal probability plot of residuals.

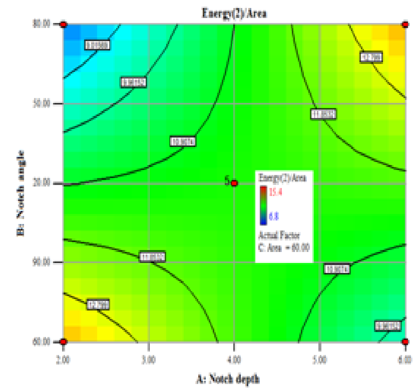


Figure 7(b). Contour plots of Energy (2) /Area responding to A=Notch depth, B=Notch angle.

Conclusion

Ductile materials may fail with a percentage of brittle failure when the angle and depth of the groove are changed.Increases in the depth of the notch reduced the rate of fragile failure of the materials (reached 100% rain failure when the standard notching is doubled).The value of the energy needed for the break/unit of space increases by increasing the depth of the slit.At a notch angle of up to 120º, the amount of energy change required for the break is low regardless of the ratio leading to the fragile fraction.

The total energy absorbed during stress is complex and depends on the mechanism of the plastic fracture and not only on the ratio of the fragile fracture.By increasing the angle of notch above 120º, there is a clear increase in the value of energy needed for breakage, as well as changes in the nature of the plastic fracture, accompanied by an increase in the flow of the material after the break.Where the failure mechanism of plastic materials is complex when subjected to mechanical shock.Finally the energy (1) increases if the notch depth is 2 mm with a decrease in area, while the energy (2) increases with increasing notch angle and decreasing notch depth.

References

[1] H. N. Gilbert, "Some Unique Properties of Sodium and Potassium," Chemical & Engineering News Archive, vol. 26, pp. 2604-2606,2660, 1948/09/06 1948.

[2] M. May, "Rate-Dependent Material Properties of Adhesively Bonded Joints - Must Have or Nice to Have ",?Key Engineering Materials, vol. 858, pp. 14-19, 2020.

[3] Z. J. Pu, K. H. Wu, J. Shi, and D. Zou, "Effect of notches and microstructure on the fracture toughness of TiAl-based alloys," Materials Science and Engineering: A, vol. 192-193, pp. 347-355, 1.1995 /15/02/995

[4] R. J. Damani, "A Simple Technique for Fracture Toughness Measurements Using Specimens with Very Thin Notches," Key Engineering Materials, vol. 132-136, pp. 484-487, 1997.

[5] Materials Selection and Design: ASM International, 1997.

[6] G. E. Dieter, "Materials Selection and Processing, Relationships Between," in Encyclopedia of Materials: Science and Technology, K. H. J. Buschow, R. W. Cahn, M. C. Flemings, B. Ilschner, E. J. Kramer, S. Mahajan, et al., Eds., ed Oxford: Elsevier, 2001 ,pp. 5236-5240.

[7] Schindel, Polyakova, Harding, Weinhold, Stenger, Grünewald, et al., "General approach for technology and Process Equipment Assembly (PEA) selection in process design," Chemical Engineering and Processing - Process Intensification, vol ,159 .p. 108223, 2021/02/01/ 2021.

[8] C. E. Albright, "The fracture toughness testing of steel□aluminum deformation welds," Engineering Fracture Mechanics, vol. 15, pp. 193-203, 1981/01/01/ 1981.

[9] "International conference on fracture mechanics technology applied to material evaluation and structure design," Engineering Fracture Mechanics, vol. 16, pp. 457-458, 1982/01/01/ 1982.

[10] R. H. Sailors and H. T. Corten, "Relationship between Material Fracture Toughness using Fracture Mechanics and Transition Temperature Tests," H. T. Corten, Ed., ed West Conshohocken, PA: ASTM International, 1972, pp. 164-191.

[11] A. Manouchehrian and M. Cai, "Influence of material heterogeneity on failure intensity in unstable rock failure," Computers and Geotechnics, vol. 71, pp. 237-246, 2016/01/01/ 2016.

[12] M. Li, K. Zeng, L. Wonnell, and I. A. Bolotnov, "Development of a New Contact Angle Control Algorithm for Level-Set Method," Journal of Fluids Engineering, vol. 141, 2018.

[13] I. N. C. Board, "Treaty provisionsfor the control of substances frequently used in the illicit manufacture of narcotic drugs and psychotropic substances," in Precursors and Chemicals Frequently Used in the Illicit Manufacture of Narcotic Drugs and Psychotropic Substances 2019, ed: UnitedNations, 2020.

[14] I. N. C. Board, "Annual legitimate requirements for ephedrine, pseudoephedrine, 3,4-methylenedioxyphenyl-2-propanone and 1-phenyl-2-propanone; substances frequently used in the manufacture of amphetamine-type stimulants," in Precursors and Chemicals Frequently Used in the Illicit Manufacture of Narcotic Drugs and Psychotropic Substances 2019, ed: United Nations, 2020.

[15] H. A. Abdulhadi, B. H. Abbas, S. M. Rajaa, and K. S. Jabur, Influence of shot peening on stress corrosion cracking in 1100 – H12 aluminum alloy vol. 2059, 2019.

[16] E. N. Abbas, S. Omran, M. Alali, M. H. Abass, and A. N. Abood, "Dissimilar Welding of AISI 309 Stainless Steel to AISI 1020 Carbon Steel Using Arc Stud Welding," in 2018 International Conference on Advanced Science and Engineering (ICOASE), 2018, pp. 462-467.

[17] D.-h. Li, W.-c. He, X. Zhang, M.-g. Xiao, S.-h. Li, K.-y. Zhao, et al., "Effects of traditional heat treatment and a novel deep cryogenic treatment on microstructure and mechanical propertiesof low-carbon high-alloy martensitic bearing steel," Journal of Iron and Steel Research International, 2021/03/01 2021.

[18] H. A. Abdulhadi, S. Aqida, M. Ishak, and G. Mohammed, "Fatigue Mechanical Behavior of (PMMA) Poly (methacrylate) Under Shot Peening Treatment," Journal of Computational and Theoretical Nanoscience, vol. 14, pp. 2927-2930, 2017.

[19] H. Abdulhadi, S. Ahmad, I. Ismail, M. Ishak, and G. Mohammed, "Thermally-Induced Crack Evaluation in H13 Tool Steel," Metals, vol. 7, p. 475, 2017.

[20] "Brittle Fracture of a Crane Hook," in ASM Failure Analysis Case Histories: Material Handling Equipment, ed: ASM International, 2019, p. 0.

[21] "Modeling of Brittle Fracture," in The Fracture of Brittle Materials, ed, 2018, pp. 145-166.

[22] H. A. Abdulhadi, S. N. Aqida, M. Ishak, and G. R. Mohammed, "Thermal Fatigue of Die-Casting Dies: An Overview," MATEC Web Conf., vol. 74, p. 00032, 2016.

[23] V. Weiss, "Notch Analysis of Ductile Fracture," Dordrecht, 1981, pp. 165-167.

[24] W. Xu, B. Chen, X. Chen ,and C. Chen, "Influence of aggregate size and notch depth ratio on fracture performance of steel slag pervious concrete," Construction and Building Materials, vol. 273, p. 122036, 2021/03/01/ 2021.

[25] M. R. Ayatollahi, A. Ajdani, A. Akhavan-Safar, andL. F. M. da Silva, "Effect of notch length and pre-crack size on mode II fracture energy of brittle adhesives," Engineering Fracture Mechanics, vol. 212, pp. 123-135, 2019/05/01/ 2019.

[26] H. A. Abdulhadi, S. N. A. S. Ahmad, I. Ismail, M. Ishak, and G. R .Mohammed, "Experimental Investigation of Thermal Fatigue Die Casting Dies by Using Response Surface Modelling," Metals, vol. 7, p. 191, 2017.

[27] S. Zeng, S. Chen, and G. Wu, "Effect of inclination angle on melting process of phase change materials ina square cavity under mechanical vibration," Journal of Energy Storage, vol. 36, p. 102392, 2021/04/01/ 2021.

[28] A. I. N. Korti and H. Guellil, "Experimental study of the effect of inclination angle on the paraffin melting process in a square cavity," Journal of Energy Storage, vol. 32, p. 101726, 2020/12/01/ 2020.