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The effect cooling media in pack carburizing quenching on the corrosion resistance of ASTM A36 steel

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ABSTRACT

Rotary plow on hand tractor functions as a tool to plow the land efficiently in agricultural mechanization. This tool is made of ASTM A36 steel which functions to cut, chop, and turn the soil, thus improving the soil structure and preparing the land for planting. The disadvantages of ASTM A36 steel are low impact toughness and corrosion resistance. In this study, ASTM A36 steel was pack carburizing quenching, with variations in cooling media in the form of water, coconut oil , and SAE 40 oil. The results of the studythe use of coconut oil as a cooling medium in the pack carburizing quenching process of ASTM A36 steel cause lower corrosion rates, slower cooling rates so that energy and impact toughness are higher compared to water as a cooling media So that coconut oil as a cooling media can be applied to the pack carburizing quenching rotary plow process to increase corrosion resistance.

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1. INTRODUCTION

The material ASTM A36 steel is a type of medium carbon steel, with a C content of 0.26%. The use of this material is very familiar in the manufacturing industry, especially the agricultural machinery industry. The use of this material is very familiar in the manufacturing industry, especially the agricultural machinery industry. such as chisel plows and rotary plows, Hamid (2024). The reason for using it as a material for agricultural equipment is because ASTM A36 steel is easy to shape and has good welding ability, Preedawiphat et al. (2020). In agricultural mechanization, the use of hand tractors equipped with rotary plows can plow the land efficiently. Rotary plows function to cut, chop, and turn the soil, thereby improving the soil structure in order to prepare the land for planting rice. However there are several disadvantages, the energy and impact toughness are lower than other high alloy steels. Corrosion resistance is also low, so it requires additional protection such as coating or galvanizing to prevent corrosion, Serrano. Various aspects of the pack carburizing quenching process, including the impact of cooling media, the viscosity of quenching media, and the combination with other techniques to enhance the mechanical properties of carbon steel materials, have been the subject of research

In this study, Ikumapayi et al. (2021) the effect of heat treatment on mechanical properties of ASTM A36 mild steel overlap welding joints was investigated. The samples were heat treated in an electric muffle furnace and held at 600 ˚C for 65 minutes. After the heat treatment process, the specimens were cooled in the furnace, air,

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water, used engine oil, and diesel oil. Furthermore, hardness and impact tests were carried out. From the research results, the Brine hardness number (BHN), impact energy and impact toughness of ASTM A36 overlap welding joints that were heat treated and cooled in various media experienced a significant increase in the Heat Affected Zone (HZ) in all cooling media.

Pack carburizing quenching is a heat treatment process used to increase the surface hardness of low carbon steel or other metal alloys. This process involves two main stages: pack carburizing and quenching. According to Akinlabi (2021) pack carburizing at this stage, the steel specimen is placed in a carburizing box that has been filled with carburizing media in the form of charcoal and energizer. Energizer in the form of $BaCO_3$, $NaCO_3$. The function of the energizer is to accelerate the chemical reaction, so that the carbon coating process on the surface of the carburized material. The specimen is arranged in such a way that the carburizing media evenly coats the specimen in the carburizing box. The carburizing box is inserted into the electric furnace and heated at a certain temperature and time. In order to achieve optimum surface hardness and carburizing layer thickness, according to Akanji et al.(2015) the pack carburizing process is carried out at a carburizing temperature range (around 900-950 ˚C), with a soaking time range of 2-6 hours. In this process, carbon from the carburizing medium diffuses into the surface of low carbon steel. This process increases the carbon content in the surface layer of the steel, making it harder (surface hardness number increases) and wear-resistant. After the carburizing process is complete, the workpiece is rapidly cooled in a cooling medium commonly called the quenching process. The cooling media used include water, oil, and salt solutions. This rapid cooling causes the transformation of the austenitic microstructure on the steel surface into martensite. The combination of these two processes produces steel with a hard surface and a core that remains softer and more ductile, providing a balance between surface hardness and resistance to cracking or breaking.

The service life of soil processing tools such as chisel plow, rotary plow, mainly depends on the wear resistance and strength of the raw material used to make it. Sujita et al.(2018)conducted study on chisel plow was given heat treatment of pack carburizing process with carburizing media of corn cob charcoal and pictada maxima shell powder. The physical properties of chisel plow from various carburetor media competitions were analyzed. The findings of this study indicate that the pack carburizing process with carburizing media of corn cob charcoal - pictada maxima shell powder (PMSP) can increase the hardness number and carburizing layer of P chisel plow. The highest hardness number is 662 Kg/mm^2, and the maximum effective depth of the carburizing layer reaches 372 µm at a carburizing temperature of 950 ˚C and a PMSP percentage of 30%.

The study Fatoba et al. (2021) examined the use of oyster shells, animal bones, and Na_2CO_3 as energizers and charcoal as a carbon source for hardening mild steel. Variations in the percentage of energizer used (10, 20, 30, 40, and 50%, respectively). The pack carburizing process was carried out at a carburizing temperature of 950 ˚C, soaking time of 4, 6, and 8 hours, and cooled in oil, tempered at a temperature of 200 ˚C for 1 hour to eliminate the stress formed during cooling. The results showed that the hardness value of untempered mild steel samples was slightly better than samples forged at a carburizing temperature of 9500 C and a carburizing time of 4, 6 and 8 hours. Impact results show that the carburized sample at 9500 C in seashell energizer for 8 hours has the highest impact value of 184 J for the tempered sample which is higher than the untempered sample due to the increased toughness resulting from tempering. The results also show that seashell and animal bones are potential energizers for the mild steel pack carburizing process.

Iorga et al. (2014)report the changes in microstructure, hardness and corrosion properties of carbo chromized 316L stainless steel. Thermochemical treatments were carried out using pack cementation. Carburization and chromization were carried out between 1153 K (880 °C)/4 h to 1253 K (980 °C)/12 h and 1223 K (950 °C)/6 h to 1273 K (1000 °C)/12 h in a solid powder mixture of charcoal/$BaCO_3$ and ferrochromium/alumina/NH4Cl, respectively. The obtained coatings were investigated using X-ray and electron diffraction, optical and scanning electron microscopy, Vickers microhardness and potentiodynamic measurements. The thickness of the carbo-chromized coatings ranged between 300 and 500 µm. The coating consists of carbides (Fe7C3, Cr23C6, Cr7C3, and Fe3C) and traces of α'-martensite. The average hardness number decreases smoothly from 650 HV on the surface of the sample to 200 HV in the center of the sample. Potentiodynamic tests revealed that the carbo-chromized treated sample has lower corrosion resistance, but the micro hardness of the coating increases three times.

In the study Kolawole et al. (2023), the effect of bio-mineral oil mixture on the mechanical properties of mild steel treated with pack carburizing was studied and reported experimentally. The carburizing medium was egg shell/date seed particulates with a mixture ratio of 50%:50%. Pack carburizing was carried out at a temperature of 950 oC, soaking time of 3 hours, at a heating rate of 5 °C/min and after quenching in water and bio-mineral oil (a mixture of peanut oil and SAE40 oil) cooling media. The experimental conclusion revealed that water and bio-mineral oil cooling media significantly affected the mechanical properties and microstructure of mild steel, treated with pack carburizing. The best combination of mechanical properties (tensile strength 738.66 MPa, strain 17.12%, hardness 169.5 HV, and impact energy 51.1 J) was obtained in specimens quenched in a mixture of peanut oil and SAE40 oil, with a percentage of 60%:40% and SAE40 oil.

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Based on the research that has been done, the effect of the type of cooling media on the pack carburizing quenching process on ASTM A36 steel (raw material for agricultural equipment) has not been carried out. The cooling media used is still conventional in the form of water and fossil oil. This study wants to determine the effect of bio oil (coconut oil), on the impact toughness and corrosion resistance of ASTM A36 steel..

2. RESEARCH METHODS

The research specimen was ASTM A36 steel, with chemical composition and mechanical properties as in Table 1. The samples were first carburized and quenched using cooling media in the form of water, SAE 40 oil, and coconut oil. Pack carburizing treatment was carried out using a mixture of 80 percent charcoal powder (as a carbon source) and 20 percent $BaCO_3$ (as an energizer). Carburizing temperature 900 °C, soaking time 6 hours. Before the process was carried out, the specimen was inserted into a carburizing box made of fire-resistant steel with a diameter of 120 mm and a height of 130 mm. The specimen and carburizing media were arranged in such a way in the carburizing box so that the specimen was evenly covered by the carburizing media.

Table 1. The chemical composition and mechanical properties of specimen

Content	Specification
Carbon, C	0.25 - 0.290 %
Copper, Cu	0.20 %
Iron, Fe	98.0 %
Manganese, Mn	1.03 %
Phosphorous, P	0.040 %
Silicon, Si	0.280 %
Sulfur, S	0.050 %
Tensile Strength, Ultimate	250 MPa
Tensile Strength, Yield	400 - 550 MPa
Elongation at Break (in 200 mm)	20.0 %
Elongation at Break (in 50 mm)	23.0 %
Modulus of Elasticity	200 GPa
Bulk Modulus (typical for steel)	140 GPa
Poissons Ratio	0.260
Shear Modulus	79.3 GPa

After the pack carburizing treatment process, it is continued with a quenching process with variations in cooling media: water, SAE 40 oil and coconut oil, as shown in Table 2. To determine the effect of pack carburizing quenching treatment on the mechanical properties of specimens with variations in cooling media, impact tests and corrosion resistance test were carried out. Impact testing using the Charpy method refers to the ASTM E23 test standard and corrosion resistance testing, using the weight reduction method due to immersion in corrosive media refers to the ASTM G162-99 (Standard Practice for Conducting and Evaluating Laboratory Corrosions Tests in Soils). Specimens for corrosion resistance test and impact test as shown in Figure 1.

Table 2. The cooling media for pack carburizing quenching

Sample	Treatment Process
A	Control sample
B	Pack carburizing quenching, water cooling media (PQ-W)
C	Pack carburizing quenching, coconut oil cooling media (PQ-C)
D	Pack carburizing quenching, SAE40 oil cooling media (PQ-S)

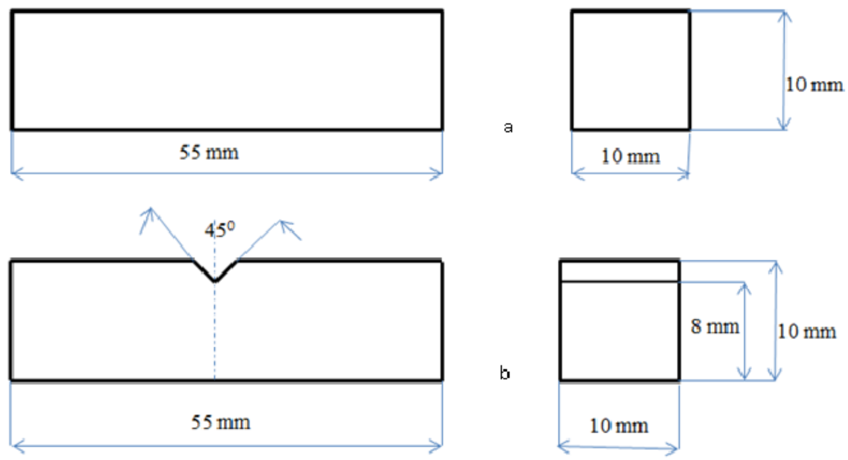

Figure 1. Size of the specimen, a. Corrosion rate specimen ASTM G31-72, b. Impact test specimen ASTM E23

The results of the corrosion resistance test in the form of weight loss data are used to determine the corrosion rate. The corrosion rate which has undergone pack carburizing quenching treatment with a variety of cooling media can be calculated using the equation

$$V = \frac{\nabla W}{A.t} \quad (1)$$

where V is the corrosion rate (gr/mm^2.hours), ∇W is the mass loss (gr), A is surface area of the specimen immersed in the corrosion medium (mm^2), t is immersion time (hours).

$$V_y = \frac{\nabla W}{2.400\, x30} x365 \quad (2)$$

a b

Figure 2. The main research equipment, a.Impact testing machineCharpyInstron 450J, b. Digital scales brand Kern

whereV_y is the corrosion rate per year (gr/mm^2.year). Impact energy is the amount of energy absorbed by a material when subjected to impact loading in an impact test. In the Charpy test, this energy is calculated from the difference in potential energy of the pendulum before and after it strikes the specimen. Impact energy indicates how much resistance a material has to shock or impact loading. Impact toughness is the ability of a material to absorb energy before breaking under impact loading conditions. This value is usually expressed in Joules per unit area of fracture cross-section (J/mm²). The impact energy and impact toughness can be calculated using the equation

$$E = mgl(\cos\beta - \cos\alpha) \tag{3}$$

$$HI = E / A \tag{4}$$

where E is the impact energy (J), m is the pendulum mass (Kg), g is the gravitational acceleration (9.8 m/s^2) l is the pendulum arm length (m), cosβ is the initial angle before the pendulum is swung, cosα isthe initial angle after the pendulum is swung, Aarea without notches (mm^2), HI is the impact toughness ((J/mm^2).

This research is an experimental research with the main equipment being an impact tester and digital scales as shown in Figure 1. Specifications of the impact testerCharpyInstron 450J, with tool specifications: pendulum weight: 24 kg, arm radius: 80 cm, arm angle: 150°. Specifications of precision digital scale capacity 12kg: 0.05gr, brand Kern. Digital scales, used to determine weight loss, then by using equations 1 and 2, the corrosion rate per hour (gr/mm^2.hours) and the corrosion rate per year (gr/mm^2.year) are obtained. Impact test equipment is used to determine the energy absorbed by the material, according to calculations based on equations 3 and 4, the impact energy (J) and impact toughness (energy per unit area) (J/mm^2) are obtained.

3. RESULTS AND DISCUSSION

The use of cooling media in the form of water, SAE 40 oil and coconut oil, in the pack carburizing-quenching process of ASTM A36 steel, affects the corrosion rate, as seen in Table 3. In addition, the use of different cooling media also affects the energy and impact toughness as seen in Table 4.

3.1 The effect of cooling media on corrosion rate

The influence of cooling media on the corrosion resistance of specimens subjected to pack carburizing quenching is shown in figure 3. The specimens were submerged in seawater for one month. Based on observations with SEM, the corrosion that occurred was different. The corrosion resistance was calculated based on the mass loss that occurred on the surface of the specimens (measured with digital scales) due to corrosion over one month.

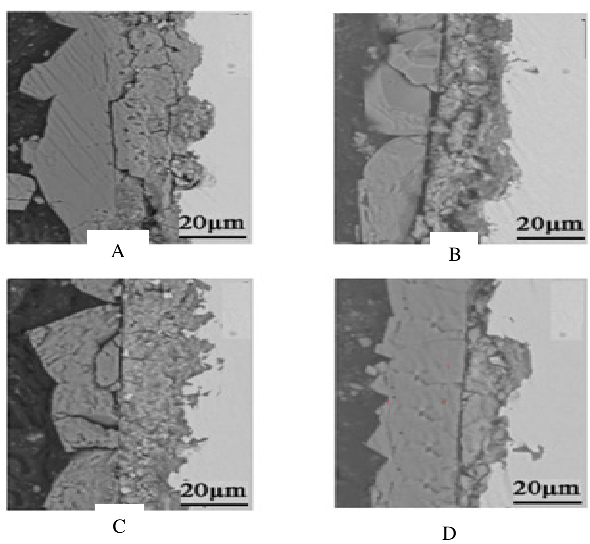

Figure 3. Results of observations with SEM of the corrosion occurring on specimens A, B, C, and D

The results of corrosion resistance testing of ASTM A36 steel, after pack carburizing-quenching treatment, with different cooling media are shown in Table 3 and described as in Figure4.The corrosion resistance of ASTM A36 medium carbon steel is affected by the cooling rate. The difference in cooling media causes changes in the cooling rate, which causes changes in the microstructure and residual stress.

Table 3. Corrosion rate test results

Sample	Weight Loss (gr)	Corrosion Rate (gr/mm^2.year)
A	3.84	0.0195
B	2.22	0.0113
C	0.83	0.0042

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D	0.74	0.0038

As shown in Figure 4, the watercooling medium causes the fastest cooling rate compared to the SAE 40 oil and coconut oil cooling media. As a result, it can increase residual stress and cause the surface to become rougher, thereby increasing the tendency towards greater corrosion. The corrosion rate per year reaches 0.0195 (gr/mm^2.year). The results of this study are in accordance with the results of the study, Odusote et al. (2012).Medium carbon steel samples quenched with water cooling media have higher hardness compared to samples quenched with oil cooling media. This phenomenon may be due to the faster water cooling rate, resulting in carbon microstructure in the form of martensite microstructure, Rochmad et al. (2023). Furthermore, the presence of fine dispersion of small particles in pro-eutectoid ferrite and pearlitic ferrite, which will inhibit the movement of dislocations, may also contribute to the hardness value of samples quenched with water cooling media.

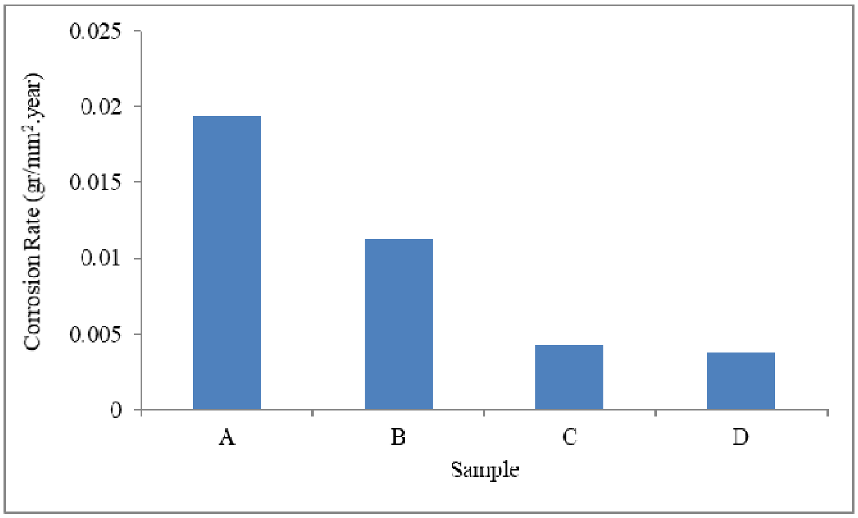

Figure 4. Effect of cooling media on corrosion rate

Coconut oil provides a temporary protective layer on the steel surface and causes lower residual stress, so it can slightly increase corrosion resistance compared to water. The corrosion rate per year reaches 0.0042 (gr/mm^2.year). The use of coconut oil as a cooling medium causes a lower corrosion rate compared to water as a cooling medium, on ASTM A36 steel specimens treated with pack carburizing quenching. The lowest corrosion rate of 0.0038(gr/mm^2.year)was produced on specimens treated with pack carburizing quenching, using SAE40 oil cooling media.

3.2 The Effect of cooling media on energy and impact toughness

Impact energy is the amount of energy absorbed by a material when it experiences a sudden impact or blow before the material breaks or is damaged. In the study, it was measured using the Charpy impact test method which provides an overview of how resistant a material is to sudden loads/shock loads. Impact toughness is the ability of a material to absorb energy during plastic deformation due to impact, without breaking. The higher the impact toughness, the more resistant the material is to sudden cracking, especially at low temperatures. Impact toughness is mathematically formulated as the impact energy per unit area (cross-sectional area without notches).

Table 4. Charpy method impact test results

Specimen	Area (mm^2)	α angle (deg)	β angle (deg)	Pendulum Length (m)	Pendulum Weight (Kg)	Impact Energy (J)	Impact Toughness (J/mm^2)
A	800	150	107	0.8	24	108.192	0.135
D	800	150	112	0.8	24	92.575	0.116
C	800	150	117	0.8	24	77.710	0.097
B	800	150	119	0.8	24	71.877	0.090

In the impact test, samples that have gone through the pack carburizing quenching process measuring 55 mm long, 10 mm wide, and 10 mm thick are used. In the middle of each sample, a V-shaped groove/notch is made with a depth of 2 mm. Specimen testing using the Charpy method according to the ASTM E23 standard using a CharpyInstron 450J testing machine. The test was carried out with three repetitions for each sample. The average impact test results are shown in Table 4 and Figure 5.

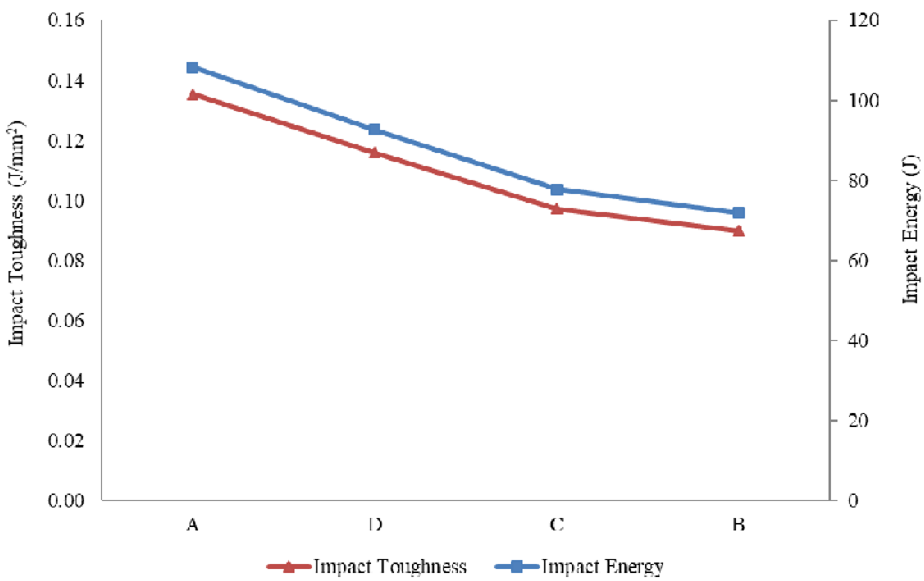

Figure 5. Effect of cooling media on energy and impact toughness

Based on Figure 4. the cooling media affects the energy and impact toughness of ASTM A36 steel that is pack carburizing quenching. The highest decrease in energy and impact toughness occurs in the use of water cooling media. The impact energy is around 71.88 J, the impact toughness is 0.09 J/ mm^2, a decrease of around 33.56%. With coconut oil cooling media, the impact energy is around 77.71 J, the impact toughness is 0.10 J/ mm^2, a decrease of around 28.17%. The lowest decrease in energy and impact toughness occurs in the use of SAE40 oil cooling media. The impact energy is around 92.58 J, the impact toughness is 0.12 J/mm^2, a decrease of around 14.43%.

The above phenomenon is caused by cooling with water media the cooling rate is very fast, causing the formation of hard but brittle martensite. Impact energy and toughness decrease because medium carbon steel becomes harder but tends to crack easily due to the brittle structure. According to the research results, Matien (2016).With coconut oil cooling media (moderate cooling occurs) the cooling rate is slower than water but faster than SAE40 oil cooling media. The resulting structure is a mixture such as bainite or fine pearlite, which has good strength and better toughness than martensite, according to the study results, Lebea and Pita (2024). Impact toughness increases compared to water quenching and is a good compromise between hardness and toughness. Furthermore, SAE 40 oil cooling media (slow cooling occurs), the slowest cooling rate among the three. Formation of coarse pearlite or ferrite-pearlite structure, which is softer but very ductile, according to the research results, Lebea and Pita (2022). The highest impact energy and toughness because the material is not too hard and has high flexibility.

4. CONCLUSION

It has been established that coconut oil can also be used as a cooling medium for pack carburizing quenching treatment of medium carbon steel (ASTM A36), because the corrosion rate of several samples cooled with coconut oil decreased significantly when compared to samples using water cooling media. The use of coconut oil cooling media produces higher energy and impact toughness, compared to water cooling media. In general, pack carburizing quenching treatment can reduce the corrosion rate so that the corrosion resistance of ASTM A36 steel increases.

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NOMENCLATURE

V : Corrosion rate (gr/mm^2.hours)
V_y : Corrosion rate per year (gr/mm^2.year)
t : Time (hours).
W : Mass loss (gr)
m : Pendulum mass (kg)
l : Pendulum arm length (m)
A : Area without notches (mm^2)
E : Impact energy (J)
HI : Impact toughness ((J/mm^2)

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