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HEAT TREATMENT OF MEDIUM CARBON STEELS AND ANALYSE ITS PROPERTIES USING MODIFIED U.T.M

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ABSTRACT

This project report aims to study and calculate two of the most fundamental properties of a metal – it's Young's Modulus of Elasticity and hardness. For this experiment, the metal chosen was Steel on which different heat treatment and hardening processes were conducted. Hardness test helps in measuring the resistance of a material to plastic deformation on indentation.Hardness is a feature of a given object, and not a basic physical property. The hardness values can be calculated on three different scales which helps in giving a better idea and precision about the material's hardness.

The Young's modulus of a material is an important attribute to understand for analyzing how the material will behave when the force is applied. In this experiment, the Young's Modulus was found out by the application of Euler's Buckling Formula. Buckling is the loss of stability that occurs when the applied compressive loads exceed a certain value causing the shape of the bar to change. The variables are calculated using the Universal Testing Machine (UTM), which are then substituted to find Young's Modulus for different cases. The experimental values shows that the young's modulus of heat treated steels don't vary much.

1. INTRODUCTION

The demand for modern and complex engineering structures which are durable for longer periods of time are increasing day by day. Hence, material selection becomes one of the most important fac- tors. Cost effectiveness also comes into play dur-ing selection of materials. Several variations of the same metal/material are used for different applica- tions. These variations arise with change in the mi- crostructure of metals which is achieved by differ- ent heat treatment and hardening processes. Our project aims to compare the hardness and young's modulus of different "variations" of medium carbon steel – one of the very important materials used for several applications in today's world. The hardness test is a mechanical test for material properties whichare used in engineering design, analysis of structuresand material development. The hardness test is per- formed to determine the suitability of a material fora given application. The Rockwell hardness test is based on the measurement of the depth to which anindenter is forced by a heavy(major) load beyondthe depth resulting from a previously applied pre- liminary(minor) load.

Buckling is the loss of stability that occurs when the applied compressive loads exceed a certain valuecausing the shape of the bar to change. Its hap-pen when the load is applied axially and load is high enough. The deformation within the beam is perpendicular to the compressive force then it is known as buckling. In this experiment, we performedcoloumn buckling and used a monosymmetric speci- men(symmetric along the plane).

2.AIM

Comparing hardness and Young's Modulus of Elas- ticity of heat treated medium carbon steels.

3.THEORY

Heat Treatment is defined as the combination of heating and cooling operations applied to a metal in a solid state for a specific time in a way to get the de- sired properties. These properties are dependent on the microstructures of the alloys and the percentage composition of different phases present in that alloy, which depends on the change in alloy composition and the heat treatment. This is primarily conducted to either soften or harden the metal. The softening processes which include annealing and normalizing will increase the ductility and toughness of the ma- terial at the expense of the strength and hardness of the material. Whereas hardening processes which include quenching and tempering and age hardening increase the hardness and strength and decrease the ductility and toughness of the material. Annealing and normalizing refer to heating the material to the austenite temperature, soaking it at this tempera- ture, and then cooling it slowly in the furnace and the air respectively. Both these processes will give pearlite as the

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product which is a ductile and tough material however, they differ in their microstruc- tures. Annealed product has coarse lamella structure whereas normalized product has fine lamella struc- ture. Also, as the cooling rate in the normalizing process is faster it will produce harder material than the product formed in annealing.

Quenching and tempering are widely used heat treatment processes for getting highly hardened steel which includes the heating of material at approxi- mately 700oC - 1000oC to the austenitic range and then holding at this temperature for a time which de- pends on the dimensions of the material used. Then the material is quenched in water or oil to increase the cooling rate drastically which leads to the forma- tion of martensite, which is the hardest steel alloy. This structure will decrease the ductility and tough- ness of the material and to achieve the desired com- bination of properties in the material it is then tem-pered to soften the material again by heating. This will improve the toughness and ductility while main- taining a high strength level. Tempering includes the heating of quenched material again to a temperature below the austenitic temperature which will disasso- ciate the hard martensite to ferrite and iron carbide which is also known as tempered martensite in which cementite is dispersed in the matrix of ferrite.

The hardness of a material represents its resis- tance to abrasion, scratching, and cutting. In a hard- ness test, a defined force is mechanically applied to the specimen. Rockwell hardness tester presents a di- rect reading of hardness number on a dial provided with the machine. The loading of the specimen is done in two steps, initially, a minor load of 10kg is applied to a penetrator causing an indentation of di- ameter d1 in the test specimen. Application of a minor load eliminates backlash in load terrain and causes the indenter to break through surface rough- ness, contributing to accuracy in the test. With mi- nor load still operating major load is added according to the scale in which the hardness is to be measured. The application of a major load increases the depth of penetration. So, the values of the HRC scale for the annealed, normalized, quenched and tempered materials should follow the order of hardness as fol- low:

Annealed < Normalized < Tempered < Quenched

Column: long slender member subjected to an axial compressive force are called column. It's a monosymmetric bar with uniform cross section along its length. Column which is perfectly straight called ideal column.
Column Buckling: when load is applied along the axis of bar and deformation happen perpendicular of the load then it is called column buckling.
Critical load(Pcr): smallest value of load at which bucking just begin to start within the column. There are three stage of column which in under axial com- pressive load :

1. Stable equilibrium: when applied load (P) is less than critical load ($P < P_{cr}$)
2. Neutral equilibrium:when applied load is equal to critical load ($P = P_{cr}$)
3. Unstable equilibrium: when applied load is more than critical load ($P > P_{cr}$)

In stable equilibrium stage bar will not fail, neu- tral equilibrium stage bar just begins to buckle(fail) and unstable equilibrium stage bar will fail. When axial load applied to a sample which is homogenous, linear, isotropic, elastic material then buckling hap- pens as sine wave(kind of). Euler's Buckling formula is used to design column and other truss members

which are loaded in pure compression. Depending on end conditions there is factor K multiply with L, and it's considered as Leff . Factor K show how much length get buckled.

$$P_{cr} = \frac{\pi^2 EI}{(KL)^2} \qquad (1)$$

Slender columns are at a much greater risk of buckling than thick columns. If the load is applied at the centroid of the cross-section, then there is no displacement of the column until the critical load is reached when the displacement becomes very large.

4. MATERIALS

For performing the project, we used medium car- bon steel rod (%C: 0.4% - 0.6%) of dimension 1cm ×1.1cm× 100cm.As in order to form martensite during hardening at low %C is not possible. Rod was further cut into 5 equal pieces of dimension 1cm× 1.1cm 20cm each and heat treatment process was performed on it. For Rockwell Hardness Test, 1cm ×1.1cm× 2cm was further cut out from the 20cm specimen and buckling by uniaxial compressive test was performed using UTM on the remaining sample of dimension 1cm × 1.1cm × 18cm.

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Figure 1: samples for Rockwell hardness test

Medium Carbon Steels are mainly used for mak- ing shafts, axles, gears, crankshafts, couplings, and forgings. Some of them are also used for rails, rail- way wheels, and rail axles. Quenched and tempered steel is particularly useful in machinery and struc- tures where greater abrasion resistance and higher yield strength are necessary, such as mining, quarry- ing, earth moving, and construction.

5. MACHINE OVERVIEW

This test is performed on Rockwell hardness tester(model no. RASNE 1), a Universal Testing Machine (UTM) also known as universal tester and a muffle furnance.

5.1 Rockwell Hardness Test

The componants of rockwell hardness test are:

1. Observing LCD Display-Various parameter such as scale, dwell time, hardness reading value as well as HIGH/OK/LOW etc. display on this.
2. Anvil -It provides base where the workpiece will be placed.
3. Anvil handle-The handle facilitates vertical movement of anvil such that workpiece will come in contact with indenter
4. Indenter -Diamond indenter having depth an- gle of 120, used to make indentation on work- piece.
5. Load selector -A circular dial having load mark- ing, it allows one to set an appropriate inden- tation load to be set on workpiece.

Figure 2: Rockwell Hardness testing machine

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Preliminary Force	Intender	Scale
60*kgf*	Diamond 120^o	A
100*kgf*	Diamond 120^o	D
150*kgf*	Diamond 120^o	C

Table 1: Rockwell hardness testing machine specifica- tions

5.2 Muffle Furnance

Muffel furnaces are heat treating furnaces having high temperature alloy removable chambers which operate under protective atmosphere, the high qual- ity heat treating furnaces having the capability to operate at high temperatures of up to 1100oC with heating chamber dimension 300 300 450mm and we have performed heating at 850oC for time interval of 1hr.

5.3 Universal Testing Machine

Model no. of our UTM is UTE-20. It is electronic control machine. Its max load capacity is 200 KN. Some parts of this UTM are following:

1. Main hydraulic cylinder assembly –It consists of piston and cylinder. piston moves vertically up-down with the help of hydraulic mechanism. It is the base of UTM.
2. Main platen – Above the hydraulic cylinder as- sembly, there is thick plate base of compression section. It consists of two vertically main col- umn (without any threading).
3. screw column – There are two other vertical column which are threaded. These two rotate clockwise as well as anti-clockwise.
4. Cross heads – There are two cross heads. Lower and upper cross head. During tension and compression test lower cross head moves vertically up-down. Upper cross head fixed at higher end of main column. The lower cross head attached to the threaded column. In these cross heads there are jaws in middle these jaw holds specimen during uniaxial tensile test.
5. Controlling panel – It is electronic panel which control the hydraulic mechanism.

Figure 3: Universal Testing Machine in the lab

5.3.1 Modifications

Figure 4: Modified part added in UTM

We performed buckling using this UTM with some modifications. There are two thick discs part in the UTM. One is threaded and other one has movable bush(kind of). We had a M14 bolt (from SM lab) of same size as of the threaded disc. That bolt is larger than required that's why we took 6 broken Charpy sample and using rubber band we attached 3-3 bro- ken sample in such a way (as seen in Fig.4). We use rubber band to ensure that these broken sample doesn't fall into jaw hole during installation of the bolt into jaw. After putting this bolt into the jaw, we tight that threaded disc at the lower face of lower cross head and tight jaw.

Figure 5: Specimen cap used to fix one end

We remove disc(which has removable bush) from the base of main platen. There is hole at below this disc, we placed a cap to ensure that lower end of our sample get fixed. We made that cap as we take a waste thread pipe of outer diameter 18mm and in- ner diameter 12.6mm. since inner diameter is not equal to our desired diameter 14.8mm. That's why we have to cut the cap along its axis and put it into the sample using a hammer Fig.5. Placed the sam- ple associated with cap in that hole. By this modifi- cation we made end condition that one end is fixed while the other end is a free joint.

6. PROCEDURE

1. Initially, we took medium Carbon Steel of di- mension 1.0cm× 1.1cm ×100cm. The sample (100cm length) was cut into 5 pieces of 20.0cm each.
2. Heat treatment process was carried out for 4 of the samples inside the muffle furnace at 850oC for 1 hour. The samples undergo different cool- ing process after being heat treated in the fur- nace. As we know that the microstructure changes if the cooling rate of the specimen is changed. These different processes can be cat- egorized in this way –

a) Normalising–One specimen is cooled in air.

b) Annealing –One specimen is cooled inside the furnace.
c) Quenching–Two samples are cooled by quenching it in water for 10 minutes.
d) Tempered –One of the quenched samples is reheated to 400oC for 45min and quenched in water.

3. As inside the furnace atmosphere is of air, a oxide ayer is developed on the surface of the sample. In order to avoid change in results hand grinding(face) is necessary.
4. After performing these processes, we cut 2.0 cm from all the specimens to perform Rockwell's hardness test.

a) Before performing the Rockwell Hardness test, the surface of the specimen is rubbed with emery paper(220) to make the sur- face smooth and avoid deflection in re- sults.
b) Select the desired scale and correspond- ing loads such as HRC (150kgf), HRD (100kgf).
c) Rotate the anvil handle in clockwise direc- tion such that indenter will come in con- tact with specimen and set preliminary load.

5. We take the remaining 18 cm of each speci- men and calculate its young's modulus by per- forming buckling test in the compression sec- tion of the Universal Testing Machine. In order to buckle the specimen by fixing one end and freeing the other end, we made some modifica- tions in the UTM.
6. Specimen is placed inside the cap to fix one end and held by the roller's of the UTM used in bending test in order to ensure that the load is applied in uniaxial direction only.
7. Parallelly, the critical load and displacement values are noted. When the load will remain constant and the displacement is changing will give the value of critical load for buckling. Us- ing the Euler's equation for bucking we can find young's modulus of elasticity for different sam- ples.

7.RESULTS

Sr. no	Scale	Load(L) Applied (in *kgf*)	Minor Load	Specimen	Avg Rockwell hardness number
1	HRC	150	10	Medium Carbon Steel	29.867(ok)
2				Annealed Steel	24.67(ok)
3				Normalised Steel	31.83(ok)
4				Tempered Steel	54.46(ok)
5				Quenched Steel	63.83(ok)
6	HRD	100	10	Medium Carbon Steel	28.6(ok)
7				Annealed Steel	26.57(ok)
8				Normalised Steel	32.17(ok)
9				Tempered Steel	59.07(ok)
10				Quenched Steel	64.1(ok)

Table 2: Results of the Hardness Experiments

Specimen	Critical Load(in kN)	Young's modulus(in GPa)
Medium carbon steel	35.3	183.7-240
Annealed Steel	30.5	158.7-207.3
Normalised Steel	35.5	184.8-241
Tempered Steel	38.4	199.9-261.0
Quenched Steel	38.9	202.5-264.4

Table 3: Results of Buckling test

8.CALCULATIONS

Euler's Formula for buckling

$$P_{cr} = \frac{\pi^2 EI}{(KL)^2} \quad (2)$$

Where-
E= Young's modulus
I= Area moment
L= Original length(15.5cm)
K= 1.4-1.6

1. *Medium Carbon Steel*
   $P_{cr} = 35.3kN$
   for K= 1.4 we will get $E_{min} = 183.7GPa$
   for K= 1.6 we will get $E_{max} = 240GPa$
   Hence, Young modulus of normal steel will range from (183.7 to 240.0)GPa

2. *Annealed Steel*
   $P_{cr} = 30.5kN$
   for K= 1.4 we will get $E_{min} = 158.7GPa$
   for K= 1.6 we will get $E_{max} = 207.3GPa$
   Hence, Young modulus of annealed steel will range from (158.7 to 207.3)GPa

3. *Normalised Steel*
   $P_{cr} = 35.5kN$
   for K= 1.4 we will get $E_{min} = 184.8GPa$
   for K= 1.6 we will get $E_{max} = 241.3GPa$

   Hence, Young modulus of normalised steel will range from (184.8 to 241.3)GPa

4. *Tempered Steel*
   $P_{cr} = 38.4kN$
   for K= 1.4 we will get $E_{min} = 199.9GPa$

9. DISCUSSION

The hardness test is a mechanical test for material properties which are used in engineering design, anal- ysis of structures and material development. The hardness test is performed to determine the suitabil- ity of a material for a given application.The hard- ness of a material represents its resistance to abra- sion, scratching, and cutting. This implies the move- ment of dislocation should be highly prohibited, for obtaining greater hardness. The hardness test was perfomed on the five samples: annealed, normalised, medium carbon steel, quenched and tempered us- ing the Rockwell hardness test. From the tests con- ducted we could observe the annealed to be the least hard and quenched to be hardest. The hardness property of a material changes on heat treatment. The annealed sample is allowed to cool within fur- nace, this is a slow cooling process. The slow cool- ing process facilitates higher growth rate of nucleus than the nucleation rate. Because of this we ob- serve coarse grained structures. In case of normalised sample, the heated sample is cooled in air, which comparatively a fast cooling process than anneal- ing. The fast cooling process facilitates higher nu- cleation rate than the growth rate, hence more nu- cleus is formed and fine grained structures are ob- served. Fine grained structures have closely packed grain boundaries due to which the movement of dislo- cation gets hindered. The dislocations comes across the grain boundaries in its close vicinity which highly prohibits the motion. Since the movement of dislo- cation is key reason for hardness, that is greater the hardness greater the resistance of dislocation move- ment and vice versa. Hence, annealed steel is less hard than normalised steel. Medium carbon steel has an intermideate carbon structure between annealed and normalised, hence it has hardness between an- nealed and normalised samples.

In case of quenched material, rapid cooling is done, the carbon gets into the interstitial position of the ferrite which forms the metastable martensite, which hinders the movement of dislocation. During tempering, the prevalent unstable martensite precipitates out the carbide particles into the ferrite ma- trix solution. Hence, the hinderance caused by the presence of carbide gets relieved and the hardness de- creases and ductility increases. Therefore, we can in- fer that quenched is harder than tempered steel. We could finally conclude that changing the microstruc- ture highly contributes to the hardness of the mate- rial.

There are many applications in which column and bar are under high compressive load, due to this high compressive load, bar (I section, C section etc) and column get deformed perpendicular to the axial ap- plied load. These phenomena are observed in warp- ing the railway lines, beam of building, rack column, bridge beams etc. Buckling happens due internal moment generated within the structure due to axial compressive load. The material property associated with Buckling is young's modulus. Material with more young's modulus that can bear more compres- sive load. In aircraft's structure there is a failure which is called crippling failure. Buckling occurs before this failure. For elastic material there are two regions of buckling failure, elastic region and plastic region. When buckling failure is in elastic region, structure come back in its original shape but when it is in plastic region, structure won't come back in its original shape and size. We performed buck- ling test using uniaxial compressive load. We have conducted this experiment on different heat-treated samples of medium carbon steel(like annealed, nor- malized, quenched, and tempered). In the

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modifi- cation we made on UTM, we try to fix lower end and free upper end, but due to some tolerance in cap's outer diameter and hole diameter the lower end is not completely fixed similarly, between the upper end and disc there will be friction due to which the upper end is fully free. Due to tolerance, we use value of factor K = 1.4 1.6 to calculate the value of young's modulus. The indication of critical load in UTM is when critical load achieved that load change negligibly and displacement will change as usual due to buckling happens (as we see in load-displacement graph Fig.7).

This indication will depend on material as well as region of failure (elastic or inelastic). In the tem- pered sample buckling happens and when we un- loaded it sample came back in its original shape (al- most) it means buckling failure was in elastic region. Since tempered sample has high young's modulus and it remains ductile, due to this it is elastic region will be more in load-displacement curve (for tensile test).

Quenched sample has broken during experiment because of quenching sample gets brittle and due to hand grinding of surface, due to this process, there might be a developed crack, during compres- sive loading the cracks propagated and material failure happen in arbitrary manner. Rest of the sam- ple have gone to plastic region due to human er- ror in performing experiments. That is why we got that kind of shape after unloading (as we see in Fig.6). For the calculation, we assume that all samples are homogeneous, linear, isotropic, elastic material. Young's modulus depends slightly on mi- crostructure morphology of material [1]. Since we have done heat treatment on medium carbon steel which led to change the microstructure of the sam- ple so young's modulus will be change. Value which we got in experiment it shows young's modulus will be highest for quenched sample and lowest for an- nealed sample. We need this test to find out young's modulus because all time we do not have such sce- nario in which structure fail due to tensile load some time failure happens due to compressive load, that's why it is also important as tensile test.

Figure 6: Sample's after buckling test

9.1. Graphs

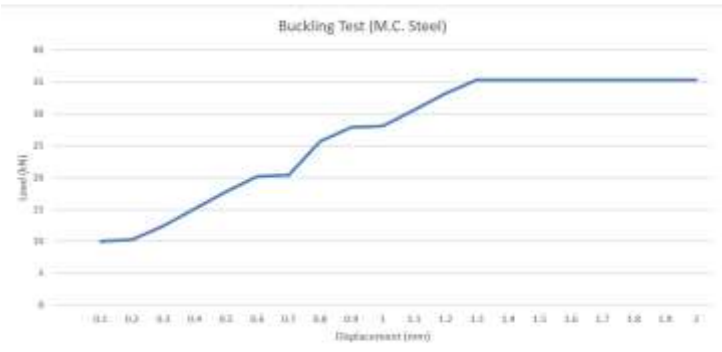

Figure 7: ***Load v/s displacement of medium carbon steel***

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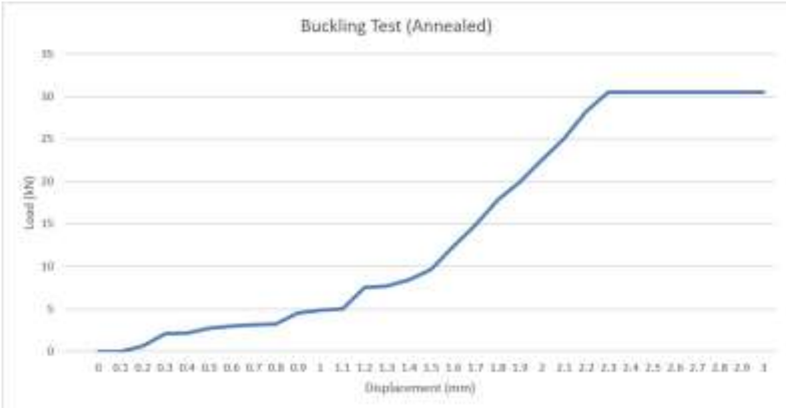

Figure 8: ***Load v/s displacement of annealed steel***

Figure 9: ***Load v/s displacement of normalized steel***

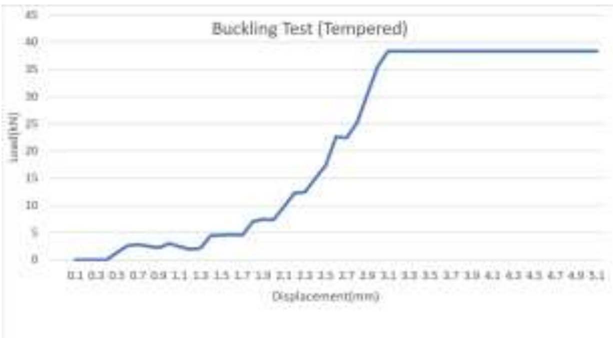

Figure 10: ***Load v/s displacement of tempered steel***

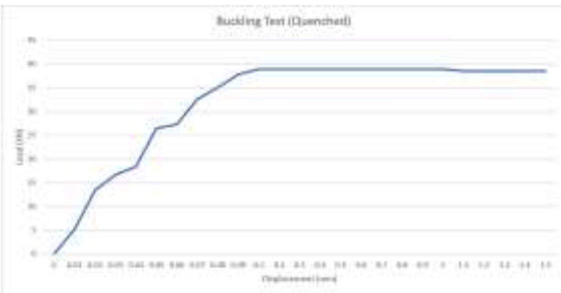

Figure 11: ***Load v/s displacement of quenched steel***

10.PRECAUTIONS

10.1. Sources of Error

1. human error: Error in measurement of dimen- sion of sample and experiment performing.
2. Machine error: Machine has some fluctuation that's why there will be error in critical load value.
3. Load is not perfectly axial that is why there will be some error in area moment of inertia.
4. There is not perfect end condition that's why factor K also vary from our considered range (1.4 − 1.6).

10.2 Precautions for Hardness test

1. Before testing for the sample, make sure the samples are polished using the emery paper to make sure the surface is flat and free of oxide layers.
2. It is important to reset the settings before test- ing each material. Failure to do so can affect the hardness values and the machine too.
3. The indentor is subject to multiple tests, which leads to wear and tear, because of this the in- dentor angle change and adversely affect the hardness values.

10.3 Precautions for Buckling Test

1. Take strip at place of bar to make sample buckle at lower load and better accuracy.
2. Take axisymmetric sample and a little bit lengthy sample for easier calculation and per- fect buckling.
3. Be careful when you perform buckling on quenched sample. Since it becomes brittle, it will break during the experiment.
4. Take measurement accurately and calculate the young's modulus.

11.CONCLUSION

From the results obtained from the conducted ex- periment we can interfer that the hardness of the heat-treated medium carbon steel samples is as fol- lows:
Annealed < Normalised < Tempered < Quenched
From the buckling test conducted on the UTM machine, the order of young's modulus is as follows:
Annealed < Normalised < Tempered < Quenched

This order is for our experiment only. Prior there is no theoretical backgroud whether young's modu- lus increases or decreases as we go from annealed to quenched samples. Young's modulus depends slightly on microstructure change and will slightly change as we observed in our experimented value. This project gives a good hand-on experience on dif- ferent machines.

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