REPORT ON THREE MONTH FELLOWSHIP TRAINING PROGRAMME

ON

DETERMINATION OF CUTTING FORCES AND TEMPERATURE CHANGES IN HEAT-TREATED MEDIUM CARBON STEEL DURING LATHE TURNING PROCESS

SUBMITTED BY

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1.0 INTRODUCTION

Steel is a crystalline alloy of iron, carbon and several other elements; it hardens when quenched above its critical temperature. It contains no slag and may be cast, rolled, or forged. Carbon is an important constituent because of its ability to increase the hardness and the strength of the steel. Steel is classified according to the alloying elements it contain and for this reason all steels are classified according to carbon content. Plain carbon steels contain primarily alloy of iron and carbon in which carbon varies from traces to about two percent by weight. Steels have been classified by the Society of Automobile Engineers (SAE) and the American Iron and Steel Institute (AISI). The designation accepted by them as standard for plain carbon steel, as they are classified as 10XX steels, the first two digits refer to plain carbon steel. The third and fourth digits refer to the carbon content in hundredths of a percent.

On the basis of carbon contents, plain carbon steels are categorized into three major classes namely;

(i) Low carbon steel (carbon from 0.2% to 0.3%)

(ii) Medium carbon steel (carbon from 0.3% to 0.6%)

(iii) High carbon steel (carbon from 0.6% to 2.0%) normally the upper limit is 1.4%.

Steel with carbon content from 0.025%C to 0.8%C are called hypo eutectoid steel. Steel with carbon content of 0.8%C is known as eutectoid steel. Steel with carbon content greater than 0.8%C is called hypereutectoid steels. The quality of any steel, in general, depends on sulphur and phosphorus contents, the degree of oxidation and cleanliness. In the case of plain carbon steel the main factors which control the quality of steel are sulphur and phosphorus content, each of 0.04% maximum.

Steel, generally has the following properties;

Chemical properties – These deal with the chemical composition and reactions of metal. Passivity and corrosion resistance are some of its properties.

Structural properties - These are concerned with the grain structure such as orientation, shape, size etc.

Physical properties - These are used to describe properties which are not being acted upon by external forces. These include density, electrical conductivity dimensional change with temperature.

Mechanical properties - These include those characteristic or properties acted upon by external forces such as tensile strength, hardness, ductility etc. Mechanical properties can be changed varying the relative proportions of micro-constituents. Change in mechanical properties is achieved by heat treatment. Heat treatment of meals is an important operation in the final fabrication process of many engineering component.

Medium carbon steel is generally used for general machining and forging of parts that require surface hardness and strength. It forges and machines well and also responds to heat treatment as regards its strength and toughness. It may be heat treated after fabrication and it's relatively cheap and easily affordable.

There are many workshop methods a mechanist can use to identify the basic type of steel in an unknown sample by means of elimination. The following tests can be carried out with hand tools in the workshop which can easily help to distinguish the various grades of steel. The distinguishing tests are carried out mainly for medium carbon steel.

Appearance test - The appearance of medium carbon steel is usually Bluish Black Sheen Smooth.

File test - There will be an increasing difficult in making file bites into metal. Surface becomes more glazed as carbon increases.

Hammer test - Hammering at full red heat, there will be an increasing resistance to flattening as carbon increases.

Spark test - This is when grinding such as strength, ductility and stiffness on an emery wheel, as carbon increases, spark stream becomes bushy with secondary ``burst``.

Heat treatment is any means of controlled heating and cooling operations used to bring about a desired change in properties of metals. The usefulness of steel is largely due to the ease with which its properties can be altered by properly controlling the manners in which is heated and cooled. Heat treatment is concerns with operations or combination of operations involving heating and cooling of a metal or alloy in the solid state for the purpose of obtaining certain desirable properties which includes;

(i) Soften the metal

(ii) Harden to resist wear and to enable it to cut other metals

(iii) Increase its ductility

(iv) Refine the structure after it has been distorted by hammering or working when in the cold state

(v) Increase its strength and shock resistance

Machining operation is carried out on most mechanical parts to get the final shape after their primary production. Metallurgical processes, such as forging and casting processes are mostly followed by a series of metal removing operations in order to achieve parts with desired shapes, dimensions, and surface finish qualities. The machining operations can be classified under two major categories; cutting and grinding processes. Cutting operations are used to remove material from the workpiece, while grinding operations provide a good surface finish and precision dimensions. The main cutting operations are turning, milling, and drilling which may be followed by special operations such as boring, broaching, hobing and shaping.

Machining accounts for approximately half of all metal cutting techniques, which is a reflection of the achieved accuracy, productivity, reliability and energy consumption of this technique.
The thermodynamic approach to the activity at the cutting edge attempts to account for the energy consumed. Research has shown that at least 99% of the input energy is converted to heat used in the deforming process of chip formation and friction losses to tool and workpiece.
The interface at which the chip slides over the tool is normally the hottest region during cutting. Force measurement in metal cutting is important for predicting thermal analysis, tool life estimation, chatter, and tool condition monitoring purposes. Hence significant efforts must be devoted to force profile in metal cutting. The temperature generated is strongly affected by workpiece materials, cutting speed, feed, and depth of cut, tool geometry, coolant, and many other variables. Due to the interaction of the chip and tool which takes place at high pressure and temperatures, the tool will always wear.

2.0 THE RESEARCH WORK

Generally, the work was divided into 3 stages.

Stage 1 - procurement and the production of the sample specimens

Stage 2 - heat treatment operation

Stage 3 - tensile testing and determination of cutting forces and machining temperatures using appropriate instrumentations.

3.0 PRODUCTION OF THE SPECIMENS

The specimens produced were of two categories, the tensile sample specimens and the cylindrical rod specimens. The tensile samples were used for the analysis of the tensile strength of the steel materials and the cylindrical rods were used in the determination of the cutting forces and the temperature distribution during machining.

3.1 Tensile specimen

A 2m long by 25mm diameter medium carbon steel (0.3%C) was procured from the steel vendor here in Tricy. The dimension of the tensile sample is as given in Figure 1 below.

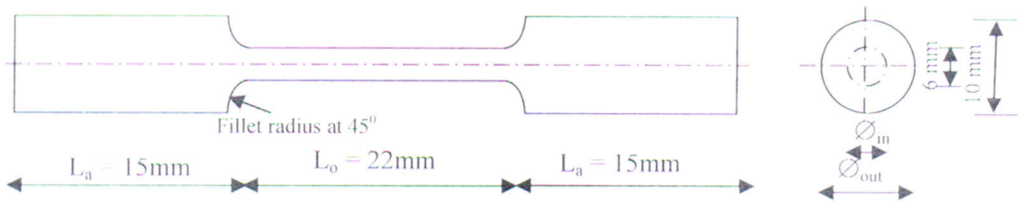

Figure 1: Test specimen from medium carbon steel. $\varnothing_{out}$ Diameter of gripping heads; $\varnothing_{in}$ Diameter of the gauge length; L_a =Minimum gripping length; L_o = gauge length.

The steel rod is cut into 60mm length since the total length of the sample is 52mm. The excess in the length was deliberately introduced to give room for facing off while machining before arriving at the final length of 52mm.

The short length was taken to the lathe machining and with a carbide cutting tool the steel was machined to the required tensile sample as shown above.

The step involves are;

i. Turn the steel to the maximum diameter of 10mm

ii. Mark off a distance of 15mm and with a taper turning attachment, reduce the middle portion to a diameter of 6mm for a length of 22mm.

iii. Mark off a length of 15mm from the 22mm inner diameter, face off the excess length at the other end to have a length of 15mm for the other bigger end to give a total length of 52mm.

iv. The 45° fillet was then cut to reduce the sharp edges at the step turning.

Twenty five pieces of these tensile samples were produced for the experimental analysis of the research work.

3.2 Cylindrical specimen

The cylindrical rode were machined following similar approach, but in its own case, it involve only turning operation to get a perfect cylindrical diameter of 20mm, since from the production stage of carbon steel rod, due to the misalignment of the rolling camber, the eccentricity is always off set, and this is rightly corrected with the turning operation to bring down the diameter to 20mm.

The figure 2 below shows the cylindrical rod used for the determination of cutting forces and machining temperatures.

Ten samples of this cylindrical rod were produced for the experimental analysis of the research work.

Figure 2: Cylindrical rod

4.0 HEAT TREATMENT OPERATION

Standard heat treatment procedures were adapted to heat treat the medium carbon steel as stated below, using a High Temperature Furnace made available at the National Institute of Technology (formerly known as Regional Engineering College) Tiruchirappalli - 620015, India. The available furnaces in the University can cot be used to obtain the higher temperatures needed for the heat treatment operations (870°C), hence, my supervisor had to make personal contact to get the facility at the National Institute of Technology, which was made available to us. The High Temperature Furnace used for the heat treatment is shown in Figure 3 below

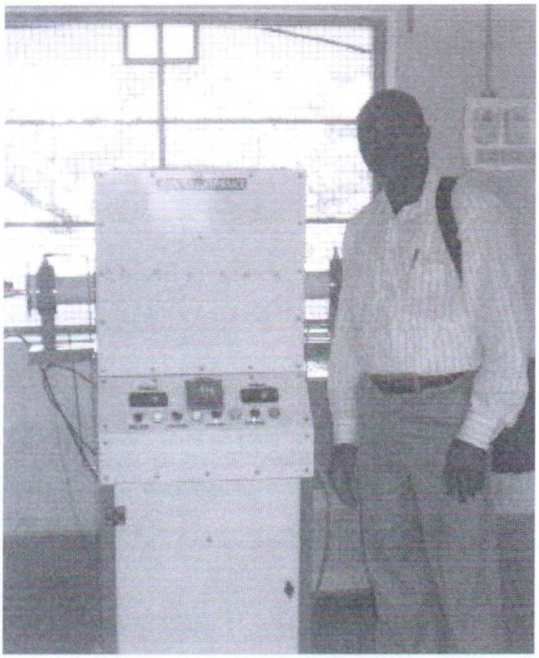

Figure 3: High Temperature Furnace.

3.1 Hardening process

The specimens to be hardened were placed inside the furnace and heated to a temperature of 850°C. At this temperature, there is transformation of the steel to austenite. The samples were retained at this temperature for a period of two hours (because of its mass) during which the transformation must have been completed, after which they were later removed from the furnace and dropped inside different containers of water for rapid cooling to room temperature. The hardening operation was carried out on five medium carbon steel samples having the same dimensions

3.2 Tempering process

In the hardened carbon steel specimens, the as-quenched martensite is not only very hard but also brittle. The brittleness is caused by a predominance of martensile. This brittleness is therefore removed by tempering. Tempering results in a desired combination of hardness, ductility, toughness, strength and structural stability. The process of tempering involves heating the hardened steel specimen to 350°C. At this temperature, the prevalent martensite is an unstable structure and the carbon atoms diffuse from martensite to form a carbide precipitate and the concurrent formation of ferrite and cementite. This process allows microstructure modifications to reduce the hardness to the desire level while increasing the ductility.

3.3 Annealing process

A full annealing was carried out on the specimen by heating the metal slowly at 870°C. It is held at this temperature for sufficient time (about 1 hour) for all the material to transform into austenite. It is then cooled slowly inside the furnace to room temperature. The grain structure has coarse pearlite with ferrite or cementite.

3.4 Normalizing process

Each samples of the medium carbon steel to be normalized were placed in the furnace and heated to temperature of 850°C. The samples were retained at this temperature for the period of two hours for full transformation to austenite. They were later removed from the furnace and left in air for cooling. Meanwhile another set of the sample specimens which were not heat treated were taken directly for the tensile test to serve as control samples.

4.0 MATERIAL TESTING

The material testing consists of;

(i) Tensile testing – to determine the stress strain relationship of the material and to get the materials' constituent properties which will be used in the mathematical modeling programme for further study.

(ii) Determining the cutting temperature as a result of machining to:

  (a) Assess the machinability which is judged mainly by cutting forces and temperature and tool life

  (b) Design and selection of cutting tools

  (c) Evaluate the role of variation of the different machining parameters on the cutting temperature

  (d) Properly select and apply the cutting fluid

  (e) Analyze the temperature in the chip, tool and the workpiece materials.

(iii) Determining the cutting forces to provide information on the limit of cutting conditions, accuracy of the workpiece produced, tool wear and tool life estimation and other machining variables that can lead to economic machining process.

4.1 Tensile testing

The test was performed on Standard Universal Testing Machine. Tensile tests were conducted at various strain rates of 200, 500, 1000, 1500 and 1650 mm/min for all the specimens.

Each of the specimens was inserted one after the other into the machine jaws and having fastened the specimen properly at both ends, tensile test upto the fracture limit was carried out. The arrangement is shown in Figure 4 below.

Figure 4: Standard Universal Testing Machine

The machine recorded the stress, strain, elongation, yield strength and Ultimate tensile strength for all the specimens which were used for further analysis.

The stress/strain values obtained from the tensile test gave the engineering stress/strain values which were based on the original cross sectional area of the test specimens.

4.2 Machining forces and Temperature determination

The effect of cutting temperature, particularly when it's very high, is mostly detrimental to both the tool and the workpiece. Attempt must therefore be made, for adequate monitoring of this temperature during machining so as to improve the cutting tool life during ant machining operations. The following are some of the consequences of very high cutting temperature on both the cutting tool and the workpiece;

(a) Rapid tool wear, which reduces tool life

(b) Plastic deformation of the cutting tool edge

(c) Thermal flaking and fracturing of the cutting edges due to thermal shocks

(d) Built up edge formation

(e) Dimensional inaccuracy of the job due to thermal distortion and expansion-contraction during and after machining

(f) Surface damage by oxidation and rapid corrosion

(g) Induction of tensile residual stresses and microcracks as the surface/subsurface.

4.2.1 Determination of the machining forces

The machining forces were determined using a dynamometer. The steel specimen was mounted on the lathe machine, while the carbide cutting tool was mounted on the dynamometer and the dynamometer was mounted on the lathe machine bed. Various spindle speed and depth of cut were selected. The specimen diameter was 20mm and an automatic feed of 0.1mm/revolution was used for all the machining operations.

The machine was switched on and for various lathe speeds and depth of cut, with a constant feed of 0.1mm per revolution the machining forces were obtained from the reading of the dial gauges attached to the dynamometer which were converted to the machining forces using the calibration and the multiplication factor of the dynamometer as supplied by the manufacturer.

The deformed chips were collected for each depth of cut. The deformed chips were weighted separately for each depth of cut to obtain the deformed chip thickness and the chip thickness ratio.

4.2.2 Machining temperature measurement

The machining temperature was measured with a thermocouple. The thermocouple sensor (probe) was fastened to the tip of the cutting tool, beneath the cutting edge, so that both the sensor and the cutting tool tip are almost at the same point. Since the cutting action is along the shear plane, the tip of the sensor (thermocouple probe) was not affected by the cutting action. Therefore, the sensor can easily monitor the temperature changes within the cutting zone during the cutting process and the results displayed for readout for further actions.

5.0 CONCLUSION

The research work was carried out successfully and had actually enabled me to access some state-of-the-art equipment which are not available in my country. A research paper has been sent for publication from the results obtained and other ones are still coming up once all other data and the results obtained were fully analyzed.

6.0 APPRECIATION

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