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Original Research Article

Comparative Analysis of 0.32% Carbon Heat Treated and Non-Heat Treated Medium Carbon Steel for an Injection Mould Development

Ihueze Christopher Chukwutoo[1], Joseph Michael Irabodemeh[2]
[1]Industrial/Production Engineering Department, Nnamdi Azikiwe University, Awka
[2]National Engineering Design Development Institute Nnewi, Anambra State, Nigeria. P.M.B 5082

***Corresponding author**
Ihueze Christopher Chukwutoo
Email: mikeirabor25@yahoo.com

Abstract: This study, centres on the assessment of the properties of medium carbon steel for injection mould, heat treatment of the mould materials and reassessment of the heat treated medium carbon steel mould material at a temperature of 850^{o}C, 900^{o}C and 950^{o}C respectively and quenched with condemned oil (quenchant) for a period of 40 minutes. Knowledge based softwares: Creo-elements/Pro5.0, Granta and ANSYS workbench 14.0 were used to model the geometry, select material and performed structural and thermal analysis to ascertain the integrity of the assessed and reassessed mould properties. The maximum equivalent von –mises stress and directional deformation of the structural analysis of the mould material before heat treatment were 3.441*10^{9}Pa and 9.0095*10^{-4}m, On the other hand, the maximum equivalent von –mises stress and directional deformation of the structural analysis of the mould after heat treatment were 3.432*10^{9}Pa and 8.4722*10^{-4}m respectively. Also, the maximum total heat flux and directional heat flux of the steady state thermal analysis of the untreated mould material were 4.0978*10^{-6}W/m^2 and 3.7404*10^{-6}W/m^2 respectively, on the other hand, the maximum total heat flux and directional heat flux of the thermal analysis of the heat treated mould material were 4.5502*10^{-6}W/m^2 and 4.3822*10^{-6}W/m^2 respectively. Comparatively, the heat treated mould would perform better in reliability and durability than the un-heat treated.
Keywords: Medium Carbon Steel (MCS), Injection Mould etc.

INTRODUCTION

The application of plastic products as engineering materials is on the increase. The resultant effect has positive impact on the injection moulding industries which has to meet up with the supply of moulds to the consumer. Plastic injection moulding begins with mould making and in manufacturing of intricate shapes with good dimensional accuracy and high precision. Injection moulding is an ideal plastic manufacturing process due to its ability to manufacture complex plastic parts with high precision and production rates at low operating costs with only a relatively high initial investment for mould design and fabrication. The surge in the usage of plastics is mainly due to their lower weight, melting temperature and cost compared to other materials like metal, composites etc, accompany with decent flow characteristics. Hence, the demand for smaller, precise designs with intricate geometries, on using plastics, has to be met. The surge in the usage of plastics is mainly due to their lower weight, melting temperature and cost as compared to other materials like metal, composites etc, accompanied with decent flow characteristics. Thus, the demand for smaller, precise and compact designs with intricate geometries, on using plastics, has to be met. Injection moulding is an ideal plastic manufacturing process due to its ability to manufacture complex plastic parts with high precision and production rates at low operation costs with only a relatively high initial investment for mould design and fabrication. Polymers have played an essential role for a long time in everyday life as well as in industry. The use of injection moulding to manufacture engineering components has been growing rapidly during the recent decades, due to several factors such as the method efficiency when producing complex plastic parts, the lightness, the simplicity of processing plastics, etc. However, the use of analysis tools for the simulation of the moulding process is a neglected area amongst many manufactures of plastic products. Mostly, the design and the choice of different process parameters are based on the experience of mould designers and other engineers. Sometimes the parts that are to be produced are redesigned on account of bad manufacturability of the injection moulding tool.

Especially, regarding complex parts, this iterative process between the designer and mould maker requires a lot of time and the reconstruction of both product and mould. The simulation facilities are vital in order to deliver tools in an efficient manner without unnecessary redesign and retooling. Studies have shown that costs up to 50 percent can be cut for mould modifications and up to 15 percent for cycle time when using simulation, Menges [1]. The injection moulding process can be divided into five separate steps: plasticization, injection, hold pressure, cooling, and finally ejection. Pellets form a melt by heat transfer from the heated cylinder wall, but mainly by shear-induced heating. The melt is then injected through a nozzle into a closed mould. The mold consists of two or three plates, pressed together by a clamping unit. During the injection, a pressure, which is counteracted by the clamping unit, is built up and maintained until the material inside the gate has solidified. When the material in the cavity has solidified and reached a state where it is stiff enough to withstand the ejector pins, the mould opens and the part is ejected.

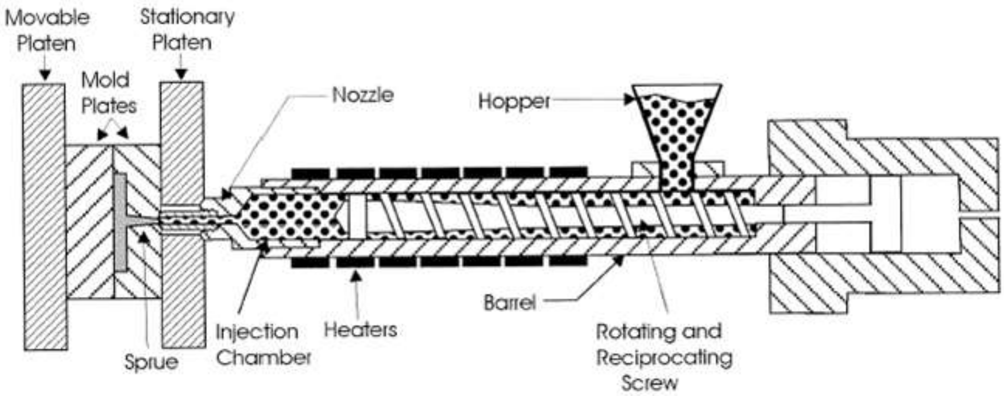

Fig-1: Schematic diagram of an injection mould process
Source: Schmitz et al (2006).

Smith and Hashemi [2] reported that medium carbon steels are widely used for many industrial applications and manufacturing on account of their low cost and easy fabrication. According to Rajan *et al*. [3] stated that steels with carbon content varying from 0.25% to 0.65% are classified as medium carbon, while those with carbon content less than 0.25% are termed low carbon and carbon content of high carbon steels usually ranges within 0.65-1.5%. Rajan *et al*. [3] and Thelning [4] reported that, hardness and other mechanical properties of medium carbon steels increase with the rise in concentration of carbon dissolved in austenite prior to quenching during hardening (heat treatment) which may be due to transformation of austenite into martensite. Therefore, the mechanical strength of medium carbon steels can be improved by quenching in appropriate medium. However, the major influencing factors in the choice of the quenching medium are the kind of heat treatment, composition of the steel, the sizes and shapes of the parts as reported by [5]. Steel is essentially an alloy of iron and carbon or of iron, carbon and other alloying elements as reported in [6]. Medium carbon steels are widely used for many industrial applications and manufacturing on account of their low cost and easy fabrication [2]. Several significant studies have applied mathematical models to understand the mechanical behavior of injection moulds, these behaviours were found to be very important to dimensional accuracy and life of the injection moulds. Thomas [7] applied an elastic finite element model to predict temperature and distortion of a slab mould during operation. The wide faces were predicted to bend inward (toward the steel) with a maximum distortion on the order of 1 mm on the wide face center line between the meniscus and mould mid-height. Ozgu [8] instrumented a slab mould to measure a wide range of operating parameters, including mould wall temperature and deformation. The measured distortion behaviour was consistent with the predictions of Thomas and Dantzig [7], they applied elastic plastic-creep finite element model to predict temperature, thermal distortion, stress, and hot face cracks in a funnel shaped mould for casting thin slabs. Fatigue cracks were attributed to over constraint of the copper plates. Salkiewicz *et al.* [9] measured the effect of copper alloy properties on permanent distortion and wear of 25 mm thick copper mould plates in a cassette mould. Copper CCZ alloy plates revealed a large width contraction of the plates that was 3 times greater across the top than the bottom. The plates also sagged, creating a convex-downward shape across the top and bottom of the plates. High wear was measured very near the mould bottom. Low-conductivity, high creep-resistant alloys had little or no residual distortion, and less wear. This previous work has shown that distortion of the mould is important to mould life and steel quality. This study aimed to examine the effect of clamping force, injection pressure and heat on the assessed and reassessed medium carbon steel injection mould during operation and to ascertain the structural and thermal integrity of the properties of the mould.

MATERIALS AND METHOD

Table 1: showing the composition of the medium carbon steel

Elements	Percentage composition
C	0.32
Si	0.18
Mn	0.85
P	0.06
S	0.012
Cu	0.046

Source: Granter CES Edu pack (2011)

Table 2: Mechanical properties of untreated medium carbon steel

Density (kg/m^3)	7800kg/m^3
Young's modulus (GPa)	205
Yield strength (elastic limit) (MPa)	508
Tensile strength (MPa)	706
Poisson Ratio	0.28
Elongation (% strain)	10
Hardness (Vickers)	200

Source: Granter CES Edu pack (2011)

Experimental Work

Specimen of medium carbon steel mould of dimension (23.35×15×5.05) mm was cut using power hacksaw. The Sample was subjected to heat treatment sequence: condemned oil quenching at three different temperatures at 800°C, 900°C and 950°C for 40 minutes. Heat treated mechanical properties are presented in the below tables.

Table 3: Mechanical properties of treated medium carbon steel under different quenching medium for a period of 40 minutes

Quenching medium	Temperature ^{O}C	Young's Modulus (Gpa)	Tensile strength (Mpa)	Poisson's ratio	Hardness No (Vickers hardness)	% Elongation	Yield strength (Mpa)
As received	1380	205	706.5	0.28	280	7	504
Condemned oil	850	218	860.45	0.291	440	29.5	710
Condemned oil	900	215	930.90	0.293	490	31.7	790
Condemned oil	950	217	1050.75	0.295	510	32.6	810

Clamping Force

Calculation of the 3D model

Part details

Name of component: toilet brush cup mould
Material: polypropylene
Shrinkage: 0.012-0.022
Numbers of cavities: single cavity
Density of polypropylene= $890kg/m^3$
Projected area

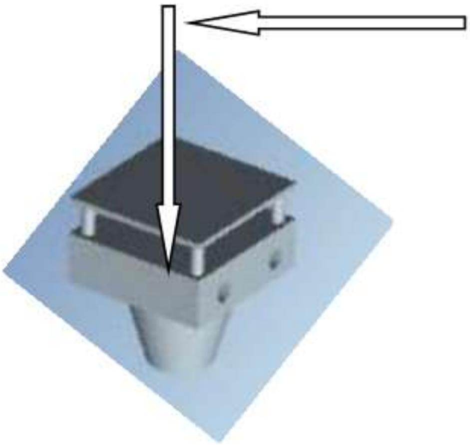

Fig-2: Details of the component of the core

Projected area of component: 552.25cm^2 (from CAD model)

Clamping Tonnage (Force)
Technical directory on design and tooling for plastics, CIPET, [10], stated that:

Clamping tonnage required $=$ Total projected area of the mould $*$ cavity pressure $*$ no. of cavities (1)

Table 4: Cavity Pressure

Cavity pressure	(kgf/cm^2
Lower injection pressure	200-400
Higher injection pressure	400-600

Source: Misumi, (2009)

Herbert Rees, [11] reported that;

Cavity pressure $= (^1/_2 *$ injection pressure) for easy flow materials and (2)

Cavity pressure $= (^1/_3 *$ injection pressure) for viscous materials. (3)

In this design, Polypropylene material of easy flow characteristics is chosen, hence, from table 3.7, a cavity pressure of 600kgf/cm^2 is chosen for a worst case scenario.

Cavity pressure $= \frac{1}{2} * 600 = 300\text{kgf/cm}^2 = 29{,}420.04Pa$

Therefore, clamping tonnage required $= 0.0552 * 29420.04 * 1 = 1623.99\text{N}$
clamping tonnage required $= 1623.99\text{N} = 15.93\text{tons}{\sim}16\text{tons}$

Taking a factor of safety of 1.3 (30% of actual tonnage) in this design, we have a
tonnage $= 4.8$ tons$\sim$5tons

Therefore, an injection machine of a clamping tonnage of 21 tons is selected, It is suggested that Mathmann 30T injection machine is selected.

ANALYSIS AND RESULTS

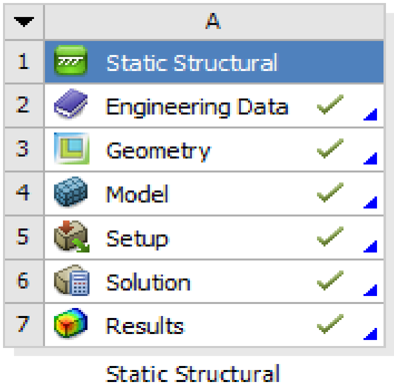

Fig-3: flow diagram of the structural analysis of the Ansys workbench 14.0

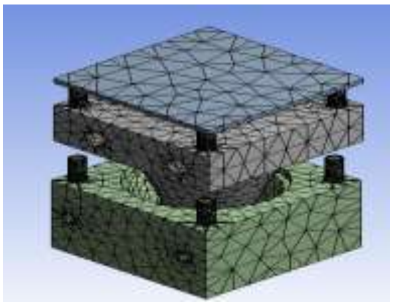

Fig-4: Fine size meshing of the isometric view of the cavity and core mould

The mesh was achieved when the geometry of the model was imported into the Ansys workbench 14.0 environment, where the material for the mould was formulated in the engineering data and assigned in the geometry. The mesh was performed in the model of the static structural with a triangular surface mesher and fine size mesh was selected for the meshing. An edge length of $5.e^{-004}m$, with a statistics of; nodes 136975 and elements 79840 were achieved.

Table 5: Simulation conditions of structural analysis of the untreated injection mould

Density	7800 kg/m^3
Young's modulus	205 (GPa)
Yield strength (elastic limit)	508 (MPa)
Poisson Ratio	0.28
Clamping force	1826.2N
Injection pressure	29420Pa

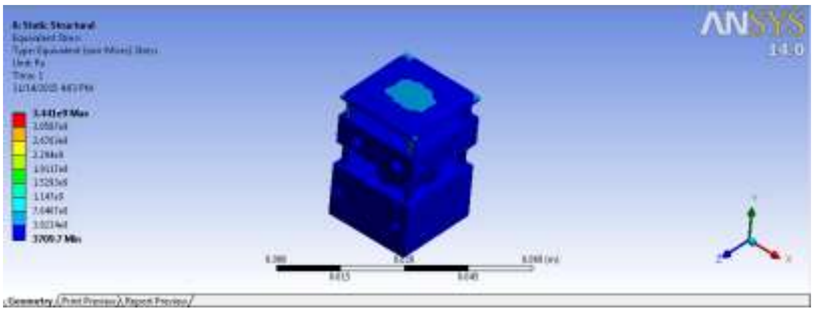

Fig-5: Equivalent von-mises of the static analysis of the un-treated injection mould

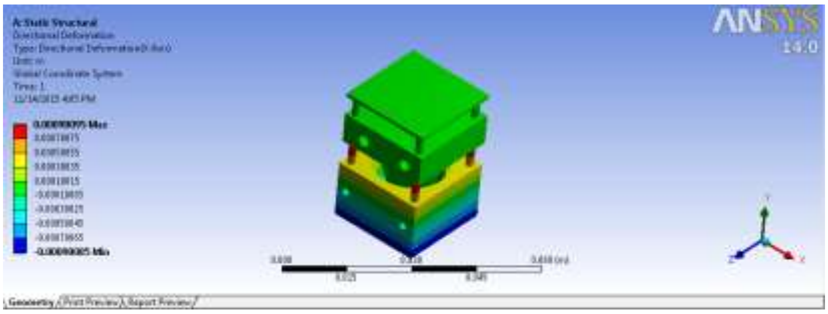

Fig-6: Directional deformation of the static analysis of the un-treated injection mould

Table 6: simulation condition for the static structural analysis of the treated mould material

Density	7900	Kg/m^3
Clamping force	1826.2	N
Injection pressure	29420	Pa
Poisson's ratio	0.291	
Young's modulus	218	Gpa
Yield strength	810	MPa

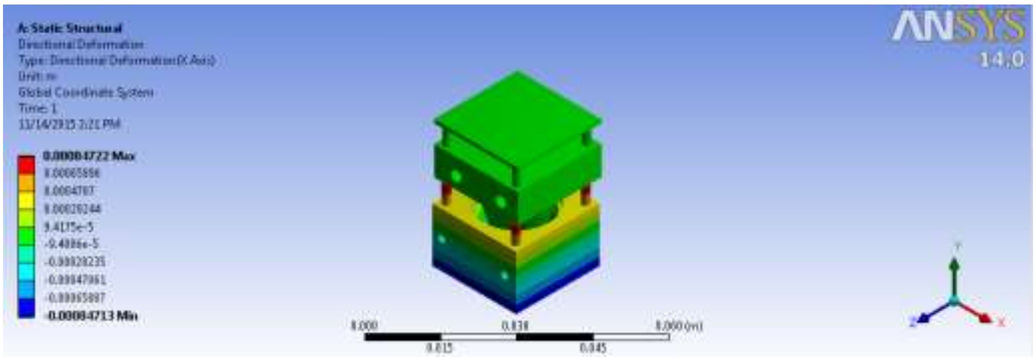

Fig-7: Directional deformation of the static analysis of the treated injection mould

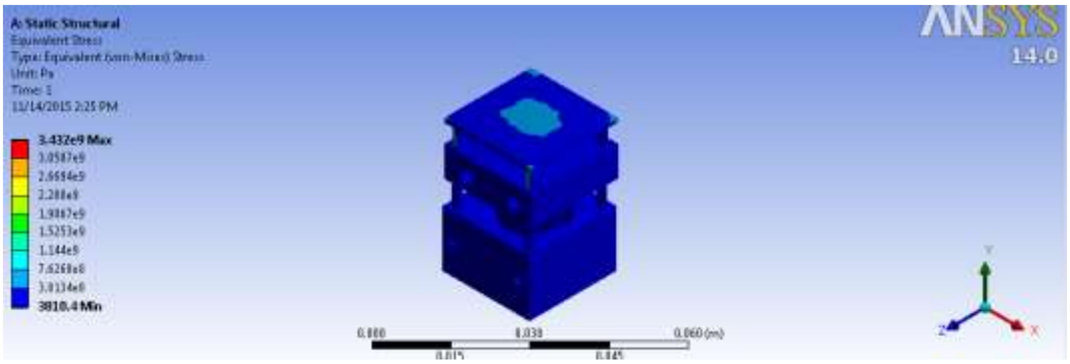

Fig-8: equivalent Von mises of the static analysis of the treated injection mould

DISCUSSION

Accordingly,

1. It was observed that the maximum deformation obtained from figure 6 for the untreated MCS mould is higher than the maximum deformation of the treated MCS mould of figure 7, this was as a result of the yield strength of the treated MCS which is presented in table 2.3 is higher than the yield strength of the un-treated MCS mould which is found in table 2.2. Therefore, the higher the strength of a material, the lesser its response to deformation.

2. The process of banging/clamping, impact almost the same stress on the mould both before and after heat treatment, but comparing the yield strength of the material before and after heat treatment is an indication that, the yield strength of the material

after heat treatment in table 2.3, which is 810Mpa will last long than that before heat treatment which is 508Mpa in table 2.2.

3. The equivalent von-mises stress of the static analysis of the un-treated injection mould of Figure 5 is 344.1MPa, when compared to the yield strength of the untreated mould found in table 2.2 which is 508MPa, and as such the mould may not last long in operation.

4. While, the equivalent von-mises stress of the static analysis of the treated injection mould of Figure 8 is 34.432MPa, when compared to the yield strength of the treated mould found in table 2.3 which is 810MPa, it was found that, the mould would performed more better in reliability and durability in operation.

CONCLUSION

A material for mould construction was developed from medium carbon steel which is readily available in our country; hence costly acquisition of imported materials for mould production can be avoided. As received medium carbon steel material was analysed (structural analysis) for mould usage and results presented, on the other hand, same medium carbon steel material was heat treated at a temperature of 850°C, 900 °C and 950 °C respectively and was allowed to cool inside water (quenchant) for a period of 40 minutes. The heat treated medium carbon steel was analysed (structural analysis) for mould application, results were also presented.

The maximum equivalent von –mises stress and directional deformation of the structural analysis of the mould material before heat treatment were $3.441*10^9$Pa and $9.0095*10^{-4}$m, While, the maximum equivalent von –mises stress and directional deformation of the structural analysis after heat treatment were $3.432*10^9$Pa and $8.4722*10^{-4}$m respectively.

Accordingly:

1. The results obtained during the analyses of the material (MCS) after heat treatment were better off compared to the un-treated material.
2. Comparing the impact of the clamping force on the mould behaviour during operation both before and after heat treatment, show that the heat treated mould would perform far better.
3. The mechanical properties of the heat treated MCS shown in table 2.3 were also better off compared to the mechanical properties of the un- treated MCS shown in table 2.2

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