Comparison of Cooling Performance Between High Thermal Conductivity Steel (HTCS 150) and Hot Work Tool Steel (SKD 61) Insert for Experimental Tool Using Finite Element Analysis

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Abstract. In hot stamping, the tool cooling system plays an important role in optimizing the process cycle time as well as maintaining the tool temperature distribution. Since the chilled water is forced to circulate through the cooling channels, there is a need to find the optimal parameters of the cooling channels that will cool down the tool efficiently. In this research paper, the cooling channel parameters that significantly influence the tool cooling performance such as size of the cooling holes, distance between the cooling holes and distance between the cooling holes and the tool surface contour are analyzed using the finite element method for both static and thermal analysis. Finally the cooling performance of two types of materials is compared based on the optimized cooling channel parameters.

Introduction

Hot stamping is a special forming technique developed for forming hardened steel sheet materials. In general, this technique combine the process of forming and heat treatment of the blank (made of hardened steel) into a single operation using specially designed stamping tool which is capable of forming the blank into a shape and cool down the blank rapidly to a predetermined temperature. Currently, there are two variants of hot stamping namely, direct and indirect method Fig.1. The main difference between these two methods is the application of cold pre-formed part prior to actual forming. This pre-forming operation often is required by a part that has complicated shape where a pre-formed shape will ease the material flow into the die during the final forming or the calibration operation [1].

During the process, the sheet material is cut into a pre-determined shape called a blank and then heated to the austenization temperature of approximately 900 - 950°C inside the furnace to alter the microstructure of the blank from a mixture of ferrite and pearlite to the austenitic phase. Immediately after leaving the furnace, it is quickly transferred to a forming tool and forming of the blank will take place, where the tool will forced the blank to deform according to the tool contour and simultaneously quench the formed blank as the tool dwells at bottom death (closed position)for a few second. This allows the blank cool down rapidly at least at a rate of 27^0C/s to a temperature where the austenitic is fully transformed into martensitic phase at less than 200^0C.After that, the formed blank leaves the tool ready for the next operation which is laser cutting to trim out the excess material [2].

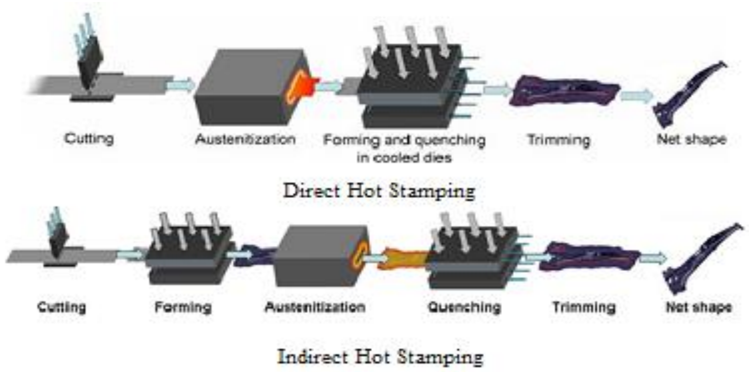

Fig. 1. Difference between the two variations of hot stamping process[2].

Since the process requires the tool to cool down the blank rapidly, a cooling system must be integrated into the tool. This cooling system must be capable of lowering the tool temperature to accelerate the blank cooling rate as well as sinking away the heat to the cooling fluid as fast as possible [3]. Thus the cooling systems play an important role in reducing the process cycle time where efficient cooling will not only reduce the blank cooling time but also recover the initial tool temperature in the shortest time period [4]. In the tool cooling system, a liquid cooling medium, such as water is forced to circulate in the cooling channels machined inside the tool and sink away the heat through the heat exchanger. According to common practice, in order to have a high cooling efficiency of the blank and tools, the cooling channel need to be positioned as close as possible to the tool contour. However to avoid tool failure such as deformation and cracks, the cooling channel must be far enough to withstand the high forming load during the forming process. Here an optimal distance must be obtained for a high cooling efficiency. The cooling efficiency can be improved by analyzing the cooling channel parameters such as the size of the cooling channel, distance between cooling channels and the distance of the cooling channel to the tool contour as shown in Fig. 2 below [5].

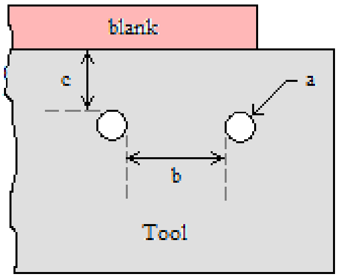

Fig. 2. Cooling holes parameter; a-hole diameter, b-distance between cooling holes, c-distance to tool contour

Another critical aspect of the tool cooling system is the tool material itself. Here the tool material must be able to satisfy two main criteria's; capable of high working temperature to withstand the high forming load as well as the blank temperature and having high thermal conductivity property to sink away the heat as fast as possible [3]. According to industrial practice, most tools makers prefer the high thermal conductivity tool steel material (HTCS 150) as the material for the tool insert. As a comparison, the thermal conductivity of SKD 61 is around 25 W/m^2K at 20°C whereas HTCS 150 is about 66 W/m^2K at 20°C. However due to material cost, a few research have been use hot work tool steel (SKD 61) as a tool insert material. In this paper the cooling performance of high thermal conductivity tool steel material

(HTCS 150) and hot work tool steel (SKD 61) is also compared based on the optimized cooling channel parameters.

Finite Element Analysis of Cooling Parameters

In order to study the cooling performance of the tool material, the actual process of hot stamping in a laboratory scale experiment is replicated where the process is simplified into a simple compression of flat square blank in contact with the tool as shown in Fig. 3a. While in the finite element analysis (Solid Works COSMOS software), the 3D model of the tool and the blank is simplified by modeling only the lower half and half thickness of the blank to reduce the number of element as well reducing the iteration time as shown in Fig. 3b.

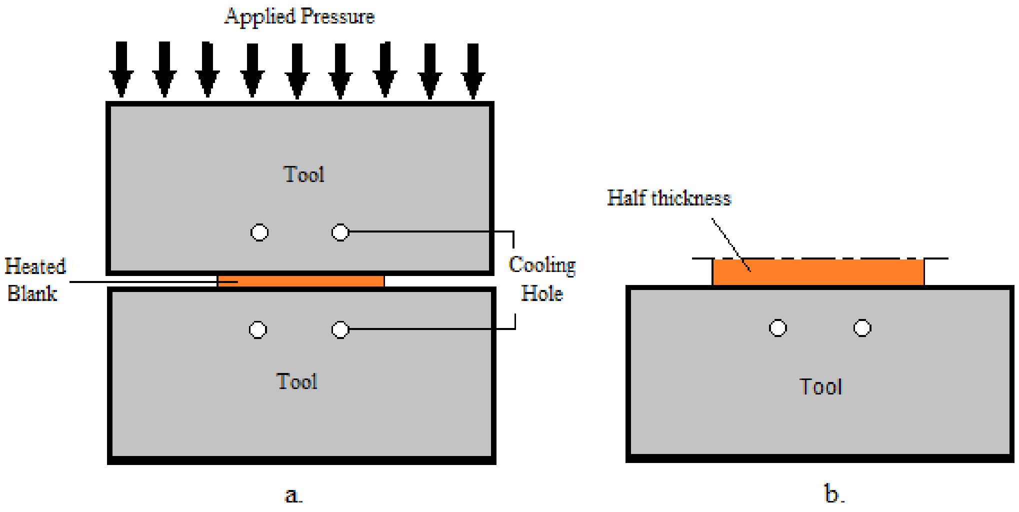

Fig. 3. a) Simplified hot stamping process condition, b) Simplified model of the tool and half thickness of the blank for finite element analysis

In this study, the cooling channel parameters of both materials are optimized using finite element analysis and later compared. The finite element analysis consists of two main analyses; static and the thermal analysis. The purpose of static analysis is to study the deformation of the tool as a result of the distance *c* of the cooling hole to the tool contour, under the forming pressure of 35 MPa. While in thermal analysis, the cooling characteristics of the tool is analyzed as the blank comes into contact with the tool surface. The tool initial temperature is set at 20°C, while the thermal contact resistance between the tool and blank surface is given by 1.25×10^{-4} m^2K/W[6] . The heat convection coefficient at cooling hole surface is constant at 4877.4 W/m^2K based on the calculated minimum flow rate to achieved turbulent flow inside the cooling hole. In both analyses, a numbers of combinations of distance between cooling channel (b) ranging from 6.0 to 12.0 mm and distance to tool contour (c) ranging from 4.0 to 10.0mm are examined with the size of the cooling channel kept constant at 8.0mm.

The thermal analyses are carried out with transient and thermal boundary conditions. The total time for the analyses is based on the actual hot stamping process condition. Since the accuracy of the finite element analysis is greatly dependent on the input parameters, so all the material properties, thermal properties and its temperature parameters such as: thermal conductivity, specific heat and density are taken into account in the thermal analysis. These values are obtained from literature and manufacturers catalogues [7-9].

Result and Discussion

As mentioned earlier, finite element analysis is used to compare the tool cooling performance between high thermal conductivity tool steel material (HTCS 150) and hot work tool steel (SKD 61) based on the optimized cooling channel parameters. In the static analysis, the value of the maximum von Mises stress on the tool for all cooling channel parameter combination and both materials did not exceed the yield strength of the tool material. In addition, the maximum von Misses stress on the tool seems to decrease with increasing values of distance b and c as shown in Table 1.

Table 1: Result of maximum von Mises stress (MPa) on tool insert.

b, (mm) / c, (mm)	6.0	8.0	10.0	12.0
4.0	77.7	72.7	65.8	62.4
	74.6	70.0	62.9	60.1
6.0	70.4	65.2	61.8	**56.0**
	68.1	62.8	59.0	**54.3**
8.0	63.8	61.6	**56.5**	**52.2**
	61.6	59.7	**54.0**	**50.4**
10.0	57.7	**56.1**	**52.7**	**49.1**
	55.8	**54.2**	**50.9**	**47.4**

HTCS 150	SKD61

From the static analysis result, a cooling channel parameters of (8.0,8.0,10.0), (8.0,10.0,8.0), (8.0,10.0,10.0), (8.0,12.0,6.0), (8.0,12.0,8.0) and (8.0,12.0,10.0) are selected for thermal analysis based on the value of von Mises stress less than 60MPa. While in thermal analysis, the cooling performance for both tool materials with the selected cooling channel parameter is compare by analyzing the temperature changes over time as shown in Fig. 4 below. The plotted tool temperatures are directly taken from the thermal analysis result and this temperature is based on the center node at the tool surface in contact with the blank.

According to the thermal analysis result, in general the tool surface temperature seems to increase slightly with increasing of distance to the tool surface, c from 4.0 to 10.0mm. While with the increasing of distance between cooling channels, b from 6.0 to 12.0mm there are no significant changes to the tool surface temperature. Specifically for SKD 61 material, the maximum tool surface temperature reached a range of 233-237°C and the final temperature ranging from 59-64°C while the tool cooling rate ranges from 18-18.7°C/s. Meanwhile for HTCS 150, for all combination of the cooling channel parameters, the maximum tool surface temperature reaches a range of 169-170°C, final temperature ranging from 37-40°Cand the tool cooling rate shows a slight variations from 13 to 14°C/s. In addition, based on the thermal analysis the combination cooling channel parameter of a=8.0, b=12.0, and c= 6.0 gave the lowest final tool surface temperature for both types of materials.

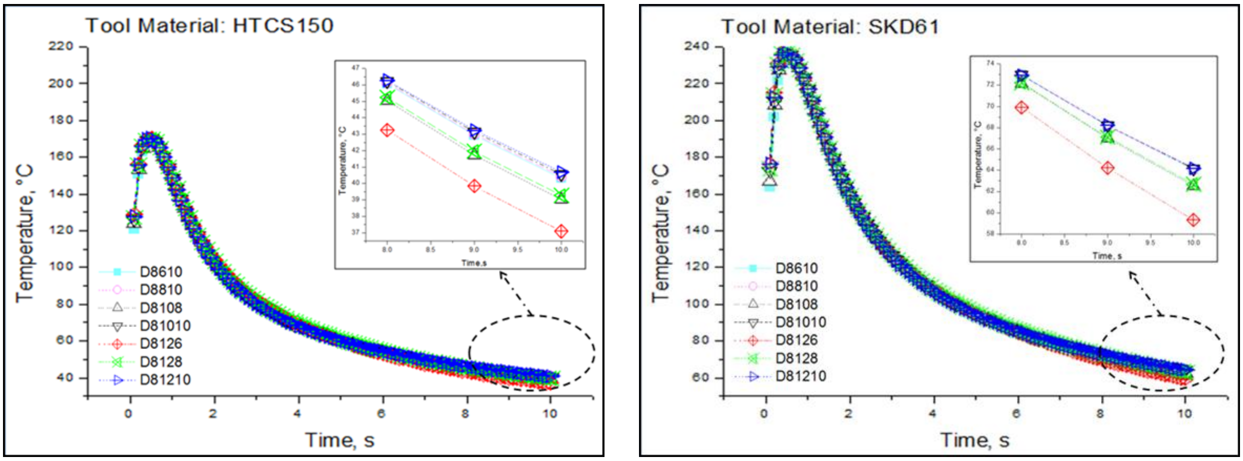

Fig. 4. Graph of temperature changes over time, a) High Thermal Conductivity Steel b) Hot Work Tool Steel

Based on the thermal analysis Fig. 5, the SKD 61 has a higher cooling rate compared to HTCS 150. This is due to the higher maximum tool surface temperature reached by SKD 61. But in term of maximum tool surface temperature and the final tool temperature, HTCS 150 performs better where the maximum and final tool surface temperature for SKD 61 is 34% and 59% higher than HTCS 150. The material with higher thermal conductivity performs better due to lower heat resistance to conduct the heat. In other words, the heat is capable of flowing from the tool surface in contact with the blank to the cooling channel surface faster as shown in Fig. 6. Consequently, the tool is capable of returning to it's initial temperature faster and indirectly reducing the process cycle time. Beside that, due to the lower heat resistance this has resulted in a lower temperature of the tool surfaceThis will reduce the tendency of the tool surface to wearoff during the process.

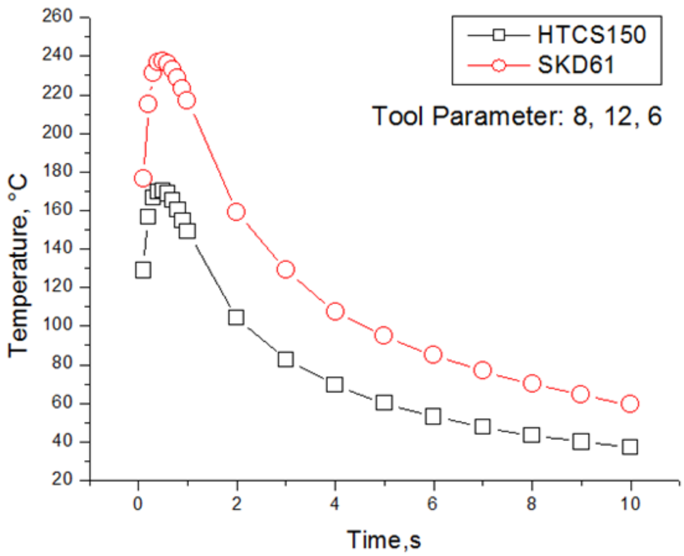

Fig. 5 Comparison of tool cooling performance between HTCS 150 and SKD 61materials with same cooling channel parameter.

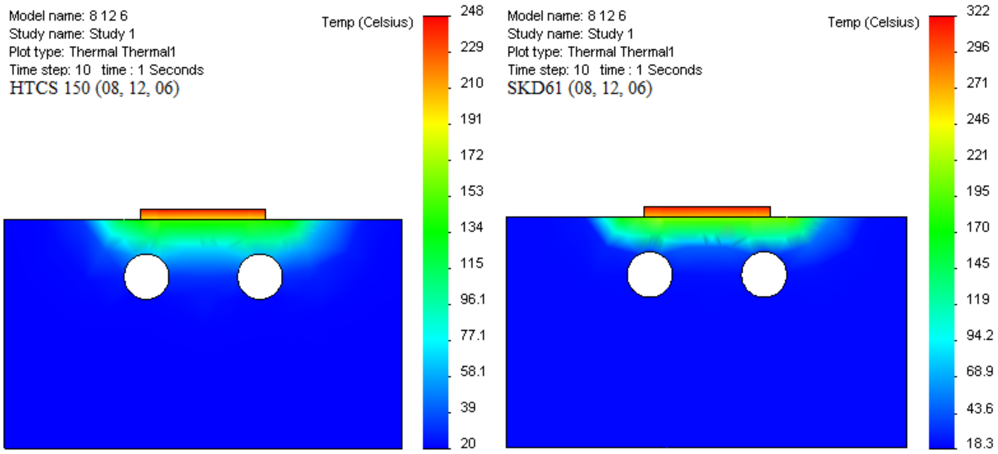

Fig. 6 Effect of heat resistance in the tool material shows on tool cross section at 1.0 second for HTCS 150 and SKD 61tool material.

Conclusion

In this research paper, the optimum cooling channel parameters have been investigated through static and thermal analysis as well as comparing the cooling performance between high thermal conductivity tool steel material (HTCS 150) and hot work tool steel (SKD 61) using Solidwork Cosmos simulation software based on actual experimental condition. It was found that the cooling channel parameters and type of tool materials have a significant influence on the tool cooling performance. Further research will be conducted to study the quenching ability of boron steel blank as well analyze the actual tool cooling performance based on optimized cooling channel parameters.

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