The Effect of Thermal Coefficients on Temperature Condition of the Blank in FE Analysis of Warm Hydro mechanical Deep Drawing Process

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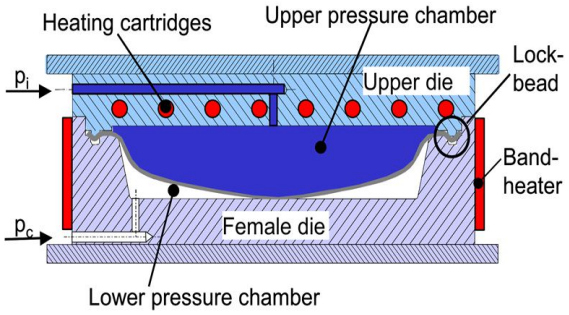
***Abstract*—A challenge to conduct the most accurate FE simulations in Warm Hydromechanical Deep Drawing (WHDD) process is to predict temperature condition of the blank which was held between the heated dies and cooled punch. This is possible by knowing effects of thermal coefficients in the FE analysis of WHDD process and modeling of the heat transfer between the blank and tools accurately. In this study effects of thermal coefficients on the temperature condition of the blank in the FE analysis of WHDD to conduct accurate FE simulations of the process. So, it can be possible to predict deformation behavior of the materials accurately and determining the proper forming conditions in less time and shorting development time.**

***Index Terms*—Warm hydroforming, Finite Element Analysis, Sheet metal forming.**

I. INTRODUCTION *(HEADING 1)*

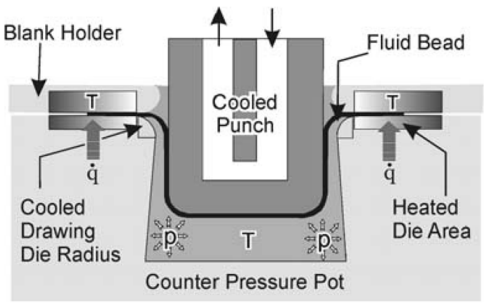
Warm hydroforming is an innovative forming technology in which sheet metals or tube materials are formed by pressurized fluid at warm forming temperatures. Hydroforming process is implemented to overcome low formability issue of lightweight materials. It is also well known that the formability of materials increase with temperature [1]. So, warm forming is an alternative way of forming the materials with low formability. It was reported that warm forming temperatures are in the range of 0.3 to 0.5 times of the melting temperature of the material [2]. Warm hydroforming ensures an additional formability increase in hydroforming and warm forming and it also acts decreasing the necessary fluid pressure and closing force in hydroforming and decreasing the forming temperature in warm forming [3]. In addition, this process offers part consolidation, reduction of manufacturing steps, mass reduction and cost reduction [4].

Warm sheet hydroforming has two types as in hydroforming, depending on whether punch or die is being used as tool. When the die is used, the sheet metal blank is formed by heated fluid after the blank is clamped between the die and blank holder and is heated to forming temperature. In this process, generally, all areas of the sheet metal blank are heated to same temperature [5]. But when the punch is used, the sheet metal blank is formed by a cooled punch and pressurized fluid having low temperatures while the flange of the sheet is heated between the blank holder and die [6] (Figure 1). Thus, in the second process named as warm hydromechanical deep drawing (WHDD), the sheet should have a temperature gradient in order to achieve a successful forming. In WHDD, high temperature in the flange region, in which most of the plastic deformation occurs, induces decreasing the flow stress and increasing the ductility of the material. Low temperature in punch wall region induces increase in material strength providing additional resistance to drawing force [7].



a)

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b)

Fig. 1. a) Warm hydroforming with die (Siegert and Jager, 2004a), b) Warm hydromechanical deep drawing (Groche et al., 2002)

Finite Element Analysis (FEA) is used to predict deformation behavior of the materials in forming processes. So the proper forming conditions are determined to be less time consuming and development time is shortened by the FEA. Reliability of FEA for forming processes is highly affected by variety of factors including accuracy of geometric and material models, reasonability of assumptions and simplifications, element type, size and solution algorithm [8]. The accuracy of the FEA of warm hydroforming also depends on the accuracy of the temperature condition of the blank. There are three different approaches in modeling of the temperature condition of the blank. One of them is isothermal approach in which no heat transfer between the tooling and materials exists and temperature assigned directly to the blank. In warm hydroforming with die, this method can give accurate results but since the blank has a temperature gradient in WHDD process, the accuracy of this method is poor. An alternative method was proposed by Choi et al. [8] named as adaptive-isothermal FEA module developed and validated by comparing with the fully coupled thermomechanical FEA method. In adaptive-isothermal FEA, the temperature distribution of the blank was determined by checking its position at each time step and assigning the temperature levels of adjacent tooling and hydraulic medium to the blank material. Although the method gives more accurate results compared to the isothermal FEA, the accuracy of this method is less than the fully coupled thermomechanical FEA in which the heat transfer between the tools (die and blank holder) and blank is modeled. So, the best way of modeling temperature condition of the blank in WHDD process is fully coupled thermomechanical FEA while it takes very long time and needs great amount of resources. In order to conduct the fully coupled thermomechanical FEA with high accuracy, temperature condition of the blank (TCB) should be calculated precisely and this depends on the use of proper thermal coefficients.

In this study, the effect of the thermal coefficients on the temperature condition of the blank in FEA of WHDD process was investigated. In order to obtain the most accurate TCB, the most convenient thermal coefficients were determined.

II. FEA OF WHDD PROCESS

In order to ensure a proper and rational TCB in FEA of WHDD, different thermal coefficients were evaluated in the FEA. A real comparison of the TCB could not be performed as it was not possible to measure the temperature distribution of the blank during WHDD. So the accuracy of the FEA was decided by comparing the center of the blank with the punch and the flange of the blank with tools. FEA's were performed in Ls-Dyna commercial FEA package. The temperature values of 180, 50 and 20 °C were assigned for the tools, punch and blank respectively in the FE modeling of WHDD process. The analysis were conducted as implicitly and forming time in the analysis was used close to experiments. In order to ensure heat transfer between the tools and blank was performed exactly and the blank was allowed to have the temperature of the tools at a particular time. This time was determined as 15 seconds with trial and error. In the meantime the punch and tools were in contact with the blank. FE model of the process is shown in Figure 1. The model consists of four main parts namely blank, die or counter pressure chamber, blank holder and punch. While the blank was considered as elastic-plastic, the other parts were modeled as rigid parts. The diameter of the blank was set to 100 mm in all simulations. For meshing process, quadrilateral and triangle (only for punch) element types were used. Fully integrated 8-node shell elements were applied to all parts while the blank and tools were modeled with 7 and 5 integration point elements, respectively. Other details of the FE model can be found in the study of [9].

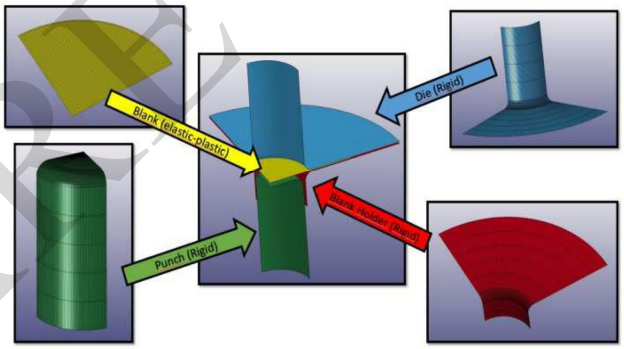


Fig. 2. FE model for hydromechanical deep drawing process (Acar et al. 2014)

After the FE model was constructed, the thermal coefficients acting on the temperature condition of the blank were applied in different values and the effects of the coefficients were revealed and the most appropriate values for accurate temperature distribution were determined. Depending on surface conditions, the gap between the tool and blank affects the heat transfer significantly. Heat transfer is affected from the heat transfer coefficient h in LS-DYNA and h is defined as follows:

$$h=\begin{cases} HTC & (0 \leqslant l_{gap} \leqslant GCRIT) \\ CF/\, l_{gap} & (GCRIT \leqslant l_{gap} \leqslant GMAX) \\ 0 & (GMAX \leqslant l_{gap}) \end{cases}$$

Here, HTC is the heat transfer conductance, CF is the thermal conductivity of the fluid between the two sliding surfaces and l_{gap} is the distance between the tool and the blank. GCRIT is the critical gap distance under which h is constant. GMAX is the maximum gap above which no thermal contact is assumed [10]. In addition to HTC and CF, thermal conductivity (TC) and heat capacity of the blank and tools (HC) were changed in FE simulations as shown in Table 1 and

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consequently 12 FE simulations were conducted. As seen in Table 1, the same thermal coefficient values were used in each simulation except for the bold written parameters. After the FE simulations terminated, the temperature distribution of the blank was obtained through a line from center to flange of the blank prior to the starting of the punch displacement (before forming) and after the punch displacement finished (after forming) and the sheet metal blank was formed. Also these temperature distributions were compared with each other and tool temperatures. Consequently, the effect and appropriate values of the thermal coefficients were determined.

Table 1. Thermal coefficients used in FE simulations

		HTC ($W/m^2.K$)	CF (W/m.K)	HC (J/kg.K)	TC (W/m.K)	GCRİT (m)
1	HTC, Simulation 1	**28**	10	Tools=420 Blank=900	Tools=50 Blank=147	0.005
2	HTC, Simulation 2	**1400**	10	Tools=420 Blank=900	Tools=50 Blank=147	0.005
3	HTC, Simulation 3	**2000**	10	Tools=420 Blank=900	Tools=50 Blank=147	0.005
4	CF, Simulation 1	2000	**10**	Tools=420 Blank=900	Tools=50 Blank=147	0.005
5	CF, Simulation 2	2000	**140**	Tools=420 Blank=900	Tools=50 Blank=147	0.005
6	HC, Simulation 1	2000	10	Tools=4200 **Blank=180**	Tools=50 Blank=147	0.005
7	HC, Simulation 2	2000	10	Tools=4200 **Blank=900**	Tools=50 Blank=147	0.005
8	HC, Simulation 3	2000	10	**Tools=420** Blank=900	Tools=50 Blank=147	0.005
9	TC, Simulation 1	2000	10	Tools=4200 Blank=900	Tools=50 **Blank=147**	0.005
10	TC, Simulation 2	2000	10	Tools=4200 Blank=900	Tools=125 **Blank=33**	0.005
11	TC, Simulation 3	2000	10	Tools=4200 Blank=900	**Tools=50** Blank=147	0.005
12	TC, Simulation 4	2000	10	Tools=4200 Blank=900	**Tools=220** Blank=147	0.005

III. Results and Discussion

The effect of the HTC on the temperature distribution of the blank through a path from center to flange of the blank (0 to 53 mm) was shown in Fig.1. It was realized that when the HTC was taken as 28 W/m2.K, the flange of the blank could not reach to the tools temperature. But when the HTC was taken as 1400 and 2000 W/m2.K, at the beginning of the forming (before forming), the center of the blank was heated to a value above the punch temperature and the flange of the blank reached to the die temperature. After the forming process finished, the base of the part, which is in contact with the punch base, reached to the punch temperature and the flange of the part reached nearly to 150 °C because the blank wrapped the cooled punch. Consequently a temperature gradient occurred between the center and flange of the blank. Here, as the results were near, when the HTC values of 1400 and 2000 W/m2.K were used in the FEA, it was concluded that using of 1400 W/m2.K is convenient in the FEA of the WHDD process as used in Choi et al. (2007).

The effect of CF is seen in Fig. 4. Here, it was obviously noticed that the CF did not affect the temperature distribution of the blank. It was concluded that since there is wrinkling in

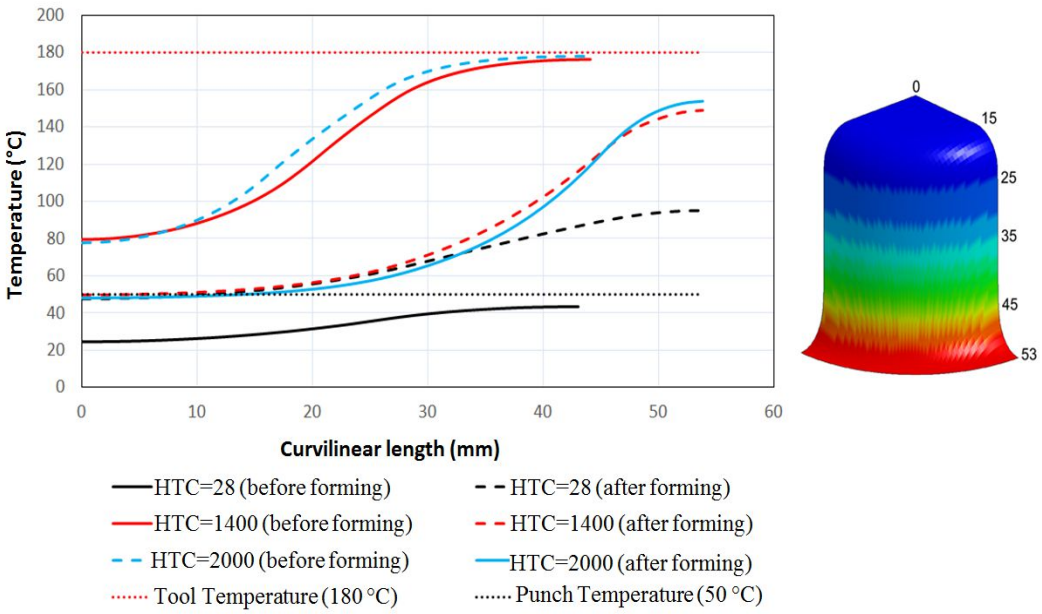


Fig. 3. Effect of heat transfer coefficient (HTC) on temperature distribution of the blank

the flange region of the blank, the gap occurred between the blank and tools due to the wrinkling is smaller than the GCRIT value which was set as 50 µm in all simulations. In this case, it can be said that the heat transfer between the tools and blank is only characterized by HTC.

was understood that as the temperature of the tools was constant through the forming process the heat capacity of the tools was not effective. For the aluminum sheet material, as the heat capacity of 900 J/kg.K is given at the catalogues, this HC value was considered appropriate for the FEA of WHDD of

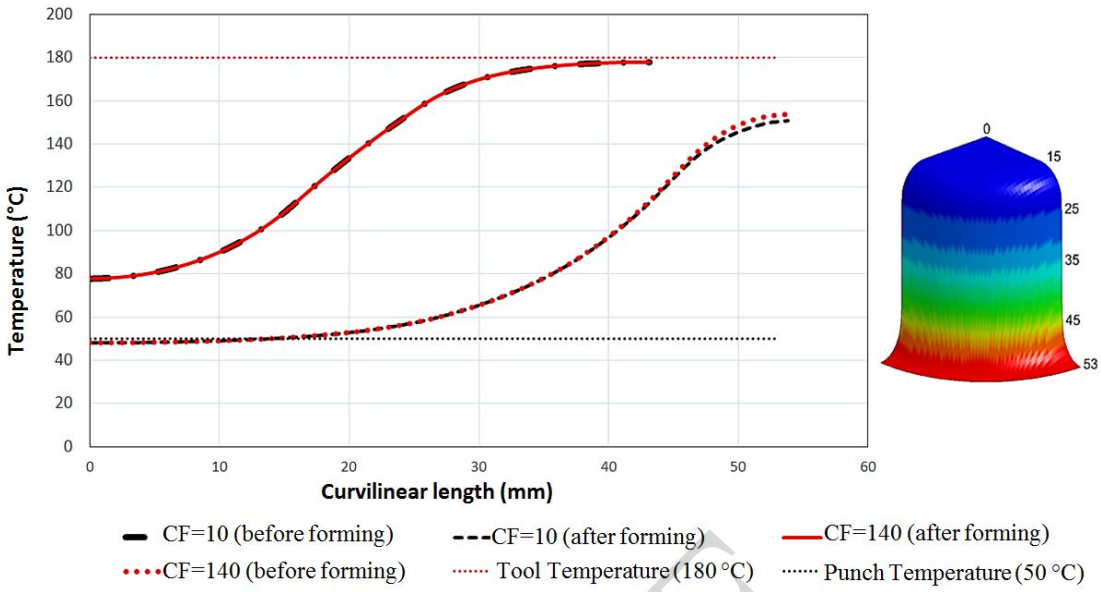


Fig. 4. Effect of thermal conductivity of the fluid between the two sliding surfaces (CF) on temperature distribution of the blank

The effect of HC is shown in Fig. 5. In the simulations, when the heat capacity of the steel material used for the tools was set 420 and 4200 J/kg.K, any difference between the temperature distributions was not observed. So it was understood that the heat capacity of the tool materials did not affect the temperature condition of the blank. While the values of 180 and 900 J/kg.K for the blank material AA 5754 did not affect the temperature distribution of the blank at the beginning of the forming, it was observed that there was an apparent difference at the end of forming. Referring to these results, it

AA 5754.

The effect of thermal conductivity (TC) on temperature distribution is demonstrated in Fig. 6. The values of 33 and 147 W/m.K affected the temperature distribution too much. When the TC of 33 W/m.K was used, as the heat transferred to the center of the blank less than the value of 147 W/m.K, there was an appreciable difference between the center and flange region of the blank at the beginning of the forming. Because of the same reason, when the value of 147 W/m.K is used, the flange of the blank is warmer at the end of the forming. As this

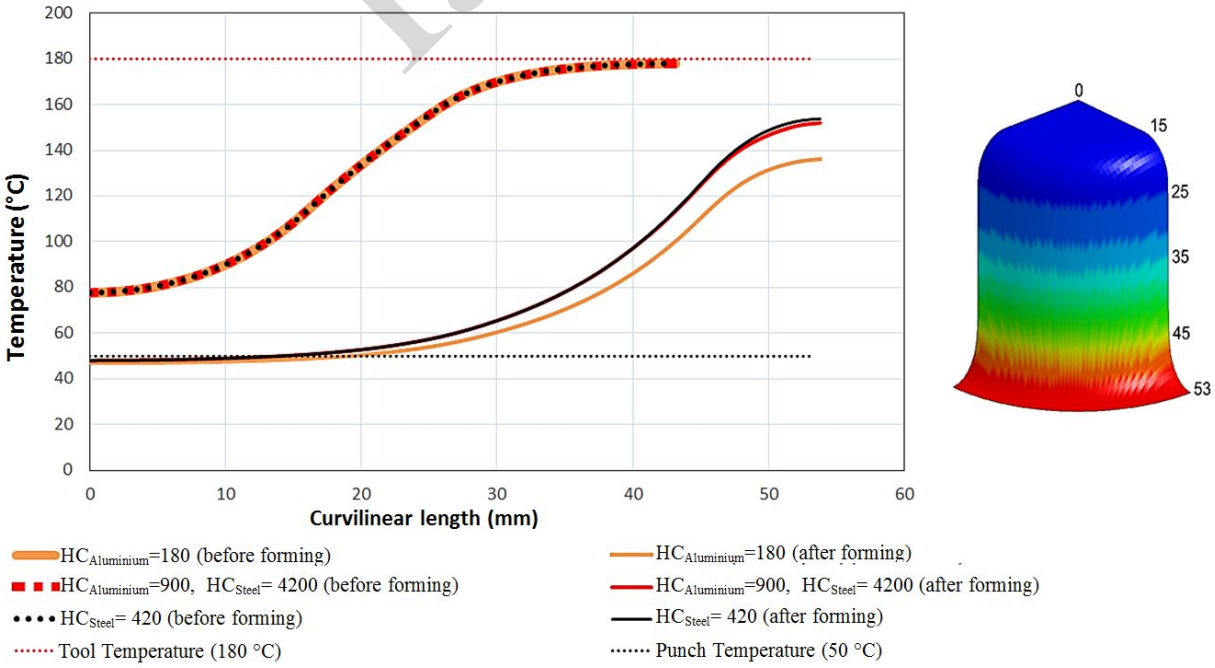


Fig. 5. Effect of heat capacity (HC) of aluminum and steel to temperature distribution of the blank

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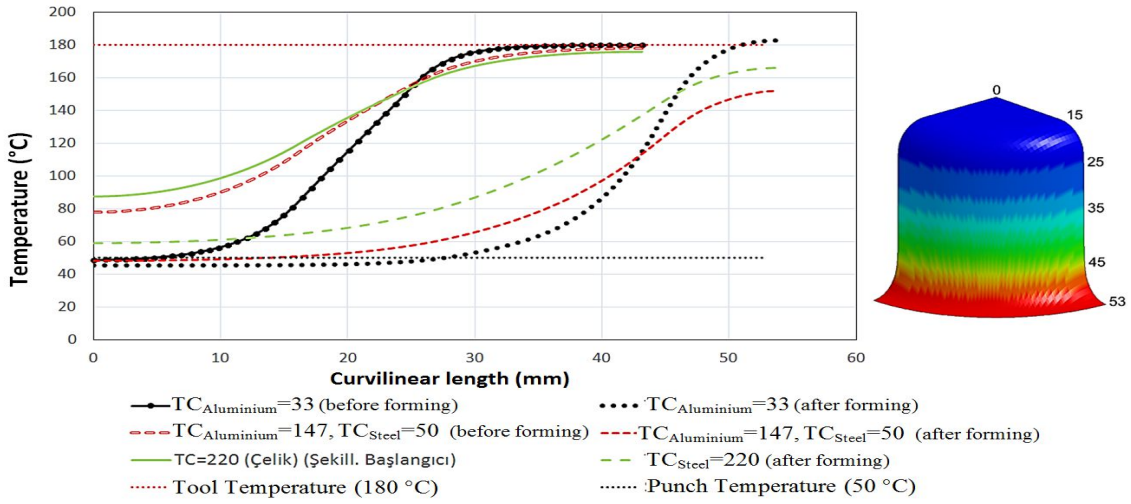


Fig. 6. Effect of thermal conductivity (TC) of the aluminum and steel on temperature distribution of the blank

situation is not realistic, the value of 147 W/m.K considered more convenient. Although the TC of the steel was not as effective as the TC of aluminum, it changed the temperature distribution of the blank. As the TC of the steel is used as 50 W/m.K in most of the studies, this value was accepted as convenient for the FEA of WHDD process.

IV. Conlusions

In this study, the effect of the thermal coefficients on the temperature condition of the blank in FEA of WHDD process was investigated. In order to obtain the most accurate temperature condition of the blank, the most convenient thermal coefficients were determined by conducting FEA of the WHDD process and comparing the temperature distribution of the blank with the temperatures of the tools. It was concluded that while the heat transfer coefficient and thermal conductivity of the blank and tool materials affected to temperature distribution of the blank considerably, thermal conductivity of fluid between sliding surfaces and heat capacity of the tool material was not effective.

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