FEM and multi-objective optimization of B-pillar with tailored propertie

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Keywords: Hot stamping; tailored tempering process; tensile strength; ductility; gradient performance

Abstract: At present, the traditional high-strength hot stamping parts cannot play the role of buffering energy absorption due to insufficient ductility, and cannot meet the current requirements of automotive safety. By heating the hot stamping die and changing the cooling rate, the hot forming parts with gradient performance are obtained. It is a new hot stamping process based on the traditional hot stamping process. In this paper, the B-pillar is used as the research object, and the Ls-dyna simulation software is used to optimize the hot-stamping parameters of the B-pillar gradient performance based on the mode Frontier optimization platform. The temperatures of upper and lower die, sheet initial temperature, and dwell time are input as process variables, and the final temperature of hot stamped component, sheet thickness, and thinning rate are selected to be objective functions to obtain more accurate process parameters. It is suggested that the initial temperature of sheet metal is 930℃, the temperature of heated upper and lower die is 500℃, the temperature of the unheated lower and upper die is 30℃, and the dwell time is 20s. Finally, the optimized process parameters are used to simulate the tailored tempering process of B-pillar to verify its feasibility.

1. Numerical modeling

In this paper, the studied high strength steel belongs to boron steel specialized for tailored tempering process. The blank material is the 22MnB5 boron steel, provided in 1.8 mm thick sheets. The die is divided into a heating and a cooling zone. With the different die temperatures, the cooling rates differ in different regions. Therefore, different mechanical properties can be achieved in different zones throughout the specimen .Dividing the die into a heating zone and a cooling zone (die partition) is one of the methods to get tailored properties, as shown in Fig. 1.

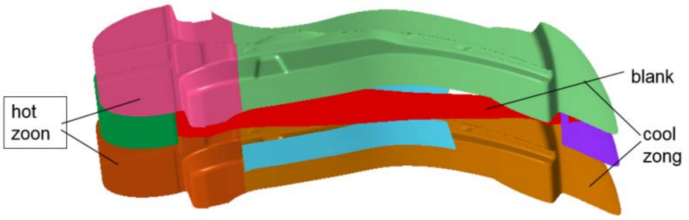
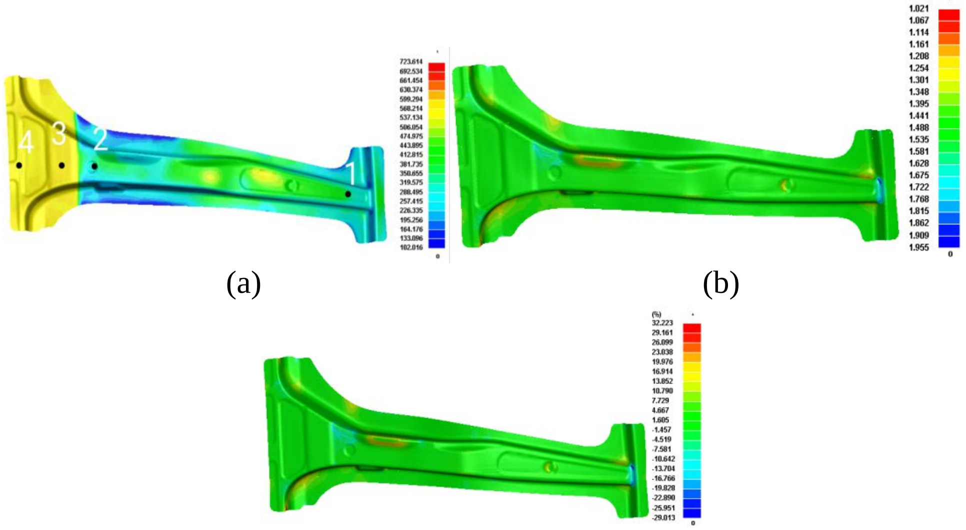


Fig. 1 FE model of the application case described

When the hot blank is quenched in a die, its thermal resistance mainly relies on temperature difference during the heat exchange process between the blank and the die, thus affecting the cooling rate of the blank. The most obvious parameters are selected as the research object[2]. The parameters used in this method are shown in Table1: The temperature in heating zone (upper tool and lower tool) is 550℃. The temperature in cooling zone (upper tool and lower tool) is 30℃. The Blank heating temperature is 900℃, and the temperature holding time is 15s. Using ls-dyna software for simulation, the temperature distribution, thickness distribution, and thinning rate distribution are shown in Fig. 2[3].

Table1 tailored tempering process initial parameters

name	Temperature in heating zone/℃	Temperature in cooling zone/℃	Blank heating temperature/℃	Temperature holding time/s
Value	550	30	900	15



(a) (b)

(c)

(a) temperature distribution(b) thickness distribution(c)thinning rate distribution

Fig. 2 Analysis results of thermo-mechanical

It can be seen the distribution from the Fig. 2. The minimum thickness of the sheet material is 1.7 mm, and the minimum thinning rate is 18% .The temperature distribution of the formed part has a clear tailored properties. The CCT diagram of elements at location 1,2,3,4, .it can be seen from the CCT diagram shown in Fig.3 that the location 3 deviates from the bainite region and is closer to the martensite region after quenching. The location 2 did not reach the formation of martensite, location 4 just reached the bainite region, and only location 1 reached the martensite region in line with the target[4]. Although a hot-formed part with a tailored properties distribution is obtained, the martensite and bainite formation regions are not idealized. So it is difficult to ensure the uniform production of martensite with high tensile strength on the same hot-pressed formed part and the bainite with better elongation requires optimization of the hot stamping process with performance gradient distribution at a later stage.

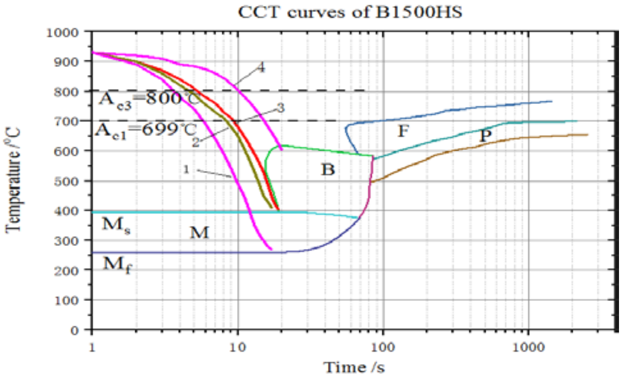


Fig. 3 CCT diagram before B1500HS optimization

2. Process optimization

2.1. Multiobjective optimization

Optimization analyses is achievable through integration with multiple calculation tools and explicable by effective post- processing tools. The role of the optimization algorithm is to identify the solutions which lie on the trade-off Pareto Frontier. These solutions all have the characteristic that none of the objectives can be improved without prejudicing another. The use of mathematical and statistical tools to approximate, to analyze and to simulate complex real world systems is widely applied in many scientific domains. These kinds of interpolation and regres- sion methodologies are also known as Response Surface Methods (RSMs), now becoming common even in engineering [1–3].

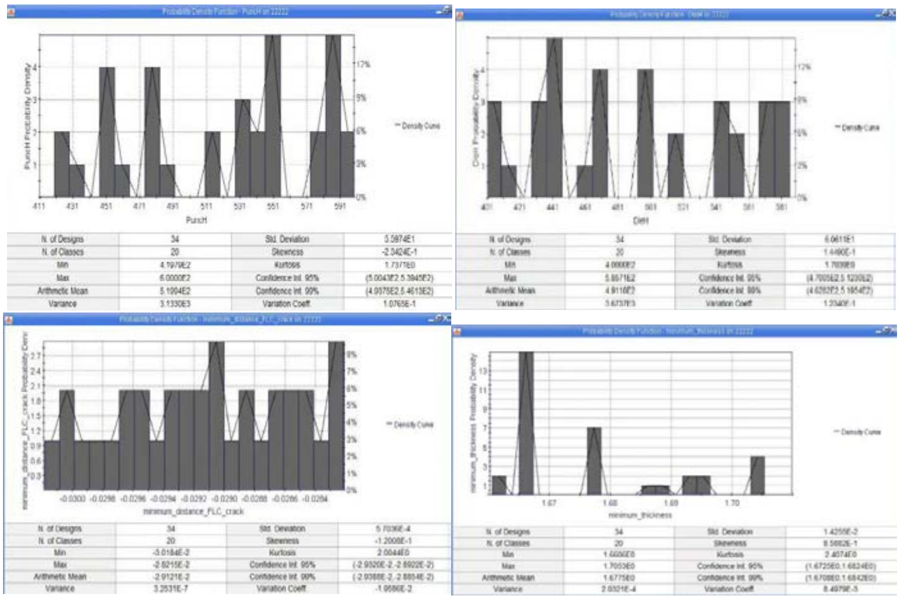
Once data have been obtained, whether from an optimization or DoE (Design of Experiment), or from data importation, the user can turn to the extensive post-processing to analyze the results. The software (modeFrontier) offers a wide-ranging toolbox, allow -ing the user to perform sophisticated statistical analysis and data visualization. Does can serve as the starting point for a subsequent optimization process, or as a database for response surface (RS) training, or for checking the response sensitivity of a candidate solution.

2.2. Results and discussion

Based on the modeFrontier platform, the optimal design and analysis of the tailored tempering process is performed. Based on the initial temperature of the sheet, the temperature of the high-temperature die (upper tool and lower tool), the temperature of the low-temperature die (upper tool and lower tool), and the holding time as the input variables for this optimization, the sheet thinning rate, thickness, and final temperature of the sheet are taken as the objective functions of the optimal design. First we set up the input variables, define the limits and discretized the variable step number between designs as shown in Table 2. When the objective function, input variables, and constraints are determined, the most important parameters are identified and selected by performing experimental design (DOE) analysis and screening by calling modeFrontie, and the calculation is performed by the MOGA-II algorithm to obtain the gradient performance [14]. The optimal parameters of the distributed tailored tempering process, and the histogram of the optimized input variables are shown in Fig. 4.

Table2 Optimized objective function quality index

Objective function	Blank hng temperature/℃	Temperature in heating zone /℃	Temperature in cooling zone/℃	Holding time /s
Value	[700,1100]	[400,650]	[20,60]	[10,25]



N. of Designs	34	Std. Deviation	5.5974E1
N. of Classes	20	Skewness	-2.3424E-1
Min	4.1979E2	Kurtosis	1.7371E0
Max	6.0000E2	Confidence Int. 95%	(5.0043E2,5.3945E2)
Arithmetic Mean	5.1994E2	Confidence Int. 99%	(4.9375E2,5.4613E2)
Variance	3.1330E3	Variation Coeff	1.0765E-1

N. of Designs	34	Std. Deviation	6.0611E1
N. of Classes	20	Skewness	1.4490E-1
Min	4.0000E2	Kurtosis	1.7039E0
Max	5.8671E2	Confidence Int. 95%	(4.7005E2,5.1230E2)
Arithmetic Mean	4.9116E2	Confidence Int. 99%	(4.6282E2,5.1954E2)
Variance	3.6737E3	Variation Coeff	1.2340E-1

N. of Designs	34	Std. Deviation	5.7036E-4
N. of Classes	20	Skewness	-1.2008E-1
Min	-3.0184E-2	Kurtosis	2.0044E0
Max	-2.8215E-2	Confidence Int. 95%	(-2.9320E-2,-2.8922E-2)
Arithmetic Mean	-2.9121E-2	Confidence Int. 99%	(-2.9388E-2,-2.8854E-2)
Variance	3.2531E-7	Variation Coeff	-1.9586E-2

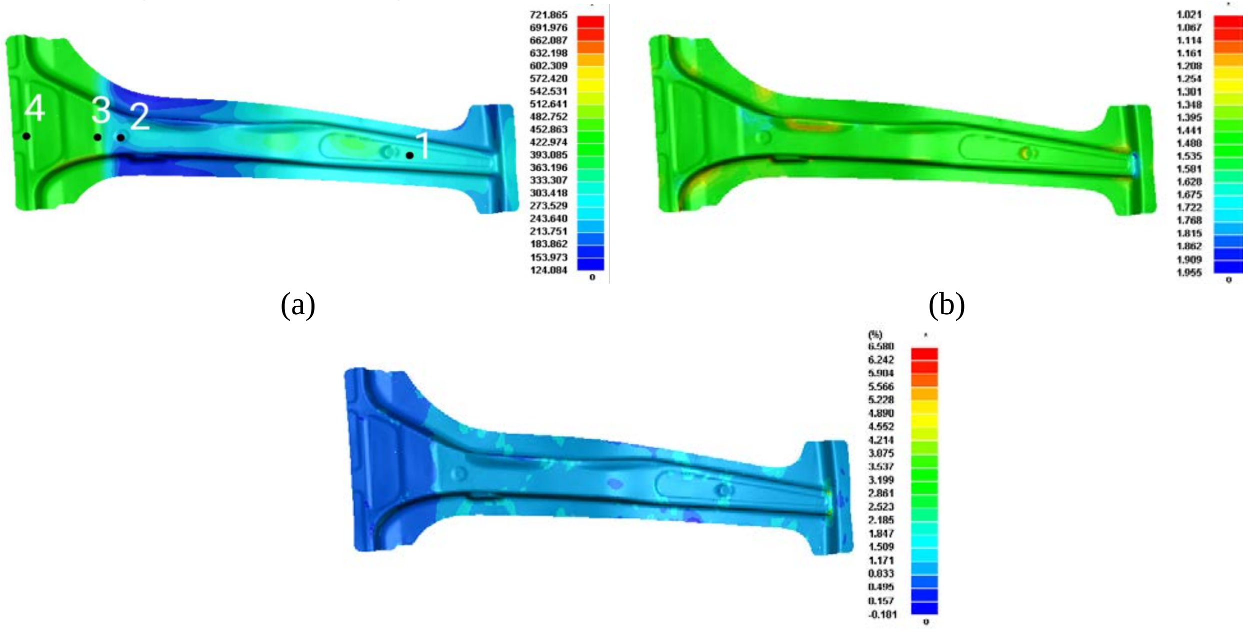
N. of Designs	34	Std. Deviation	1.4255E-2
N. of Classes	20	Skewness	8.5882E-1
Min	1.6606E0	Kurtosis	2.4074E0
Max	1.7053E0	Confidence Int. 95%	(1.6725E0,1.6824E0)
Arithmetic Mean	1.6775E0	Confidence Int. 99%	(1.6708E0,1.6842E0)
Variance	2.0321E-4	Variation Coeff	8.4979E-3

Fig. 4 Histogram distribution after optimization

It can be seen from the optimized result that the temperature in heating zone (upper tool) is 491℃, and the approximation value is 500 ℃.The temperature in cooling (lower tool) is 509℃, the approximation value is 500℃, the minimum thickness reached 1.677 mm, and the gap value was 0.03 mm.

2.3. Comparative Results

Use the optimized parameters as the value of FEM, and simulation with Ls-dyna software. The results before and after the comparison are compared, the optimized result is shown in Fig. 5, and the CCT diagram is shown in Fig. 6.



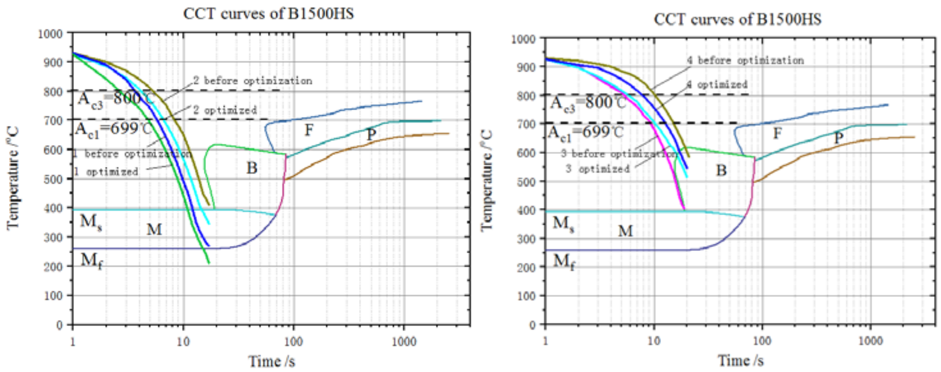
(a)

(b)

(c)

(a)temperature distribution(b) thickness distribution(c)thinning rate distribution

Fig. 5 Analysis results of thermo-mechanical coupling after optimization



(a) Temperature in cooling zone (b) temperature in heating zone

Fig. 6 Comparison curve of plate partition results before and after optimization

According to the comparison of the results before and after the optimization shown in Fig. 5. For the location 3, the bainite region cannot be reached before the optimization, and the curve is closer to the martensite region, after the optimization, the bainite region can be reached to completely generate the bainite. For the location 2 the temperature in cooling, martensite cannot be formed before optimization, and martensite can be completely generated by optimization. Through the simulation of the optimized parameters, the components with tailored properties distribution can be better obtained. Such as B pillar, which needs multi strength in different regions. It is essential to partly achieve softer structure with high ductility, to enhance the crashworthiness and energy absorption of the whole component and thus improving the safety performance. The parameter pairs before and after optimization are shown in Table 3.

Table 3 Comparison of parameters before and after optimization

Variable name	Blank heating temperature/℃	Blank heating temperature(upper tool)/℃	Heating low die temperature(lower tool)/℃	Temperature in cooling zone(upper and lower tool)/℃	Holding time/s
Before optimization	900	550	550	30	15
Optimized	930	500	520	30	20

It can be seen in Table 3 that after the optimization, the blank heating temperature is 930℃, the temperature in heating zone (upper tool) is reduced from the previous 550℃ to 500℃, and the temperature in cooling zone (upper tool and lower tool) is 30℃. the temperature in heating zone (lower tool) is has been reduced from the previous 550 ℃ to 500℃, and the holding time is increased from 15s to 20s. Through optimization, the tailored tempering process parameters with more reasonable and practical performance gradient distribution can be effectively found. After the tailored tempering simulation using the optimized parameters is completed, the tailored tempering parts with better performance gradient distribution can be obtained at the same time. Martensite and bainite can be obtained simultaneously, that is, high tensile strength and good elongation can be obtained simultaneously, which greatly saves time and reduces energy consumption compared with before optimization.

3. Conclusions

1) The multi-objective genetic algorithm can play a nonlinear relationship between the parameters of the tailored tempering process and the quality index of the hot-formed parts to fit the performance gradient distribution. Using the multi-objective genetic algorithm can save optimization time.

2) The ideal parameters for the optimization of the performance gradient tailored tempering process are: the blank heating temperature is 930℃, the temperature in heating zone (upper tool) is 500℃, the temperature in heating zone (lower tool) is 500℃, and the temperature in cooling zone (upper tool and lower tool) is 30℃. The temperature holding time is 20s.

3) Using the tailored tempering process, through specific solution calculations, a better performance gradient distribution hot stamping part can be obtained, which can not only resist deformation but also buffer energy absorption, which can well protect the safety of the occupants and verify the validity of this paper.

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