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Evolution analysis of process-induced residual stress during the manufacture of diesel body

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Abstract

Residual stress is most likely to cause deformation in a diesel body (DB). The traditional independent analysis method is no longer suitable for obtaining the residual stress of multi-process DBs, because the stress is constantly produced and changed during the casting, heat treatment, and cutting processes. Therefore, an evolution analysis method (EAM) is proposed. First, an evolution analysis model of a DB was established. Subsequently, the residual stress of the DB in the casting and heat treatment processes was analysed using ProCAST and ABAQUS. Finally, the material removal of the DB during the machining process was simulated by using ABAQUS. The residual stresses for every process were calculated by coupling inherited and process-induced stresses. Thus, the final stress distribution of the DB was deduced by considering the entire machining process. The evolution analysis of the residual stress is significant for controlling the deformation of the DB.

Keywords: Residual stress; Multi-process; Diesel body; Evolution analysis method; Material removal

Declarations

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Competing interests The authors declare that they have no competing interests.

Data availability All data generated or analyzed during this study were available by emailing to author. (1942537840@qq.com).

Authors contributions Donghao Zhao proposed the main analysis ideas, established the analysis framework, and carried out the stress analysis of the machining process, is the main contributor of the paper. Zhuhua Ai and Yunlong Liu built an analytical model of the diesel body. Xiaoxiang Bai carried out the analysis of the heat treatment process of the diesel body. Guochao Li carried out the stress analysis of the casting process, modified and edited the language of the paper, and put forward some suggestions. Honggen Zhou and Liping Cao helped to read and approve the final manuscript.

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1 Introduction

Diesel bodies (DBs) are the key components of marine diesel engines. Residual stress is most likely to cause deformation in the DB, thus affecting its performance and service life. Therefore, the residual stress should be studied to improve the DB performance. However, the residual stress field is constantly redistributed owing to hot-working and machining processes. Thus, an evolution analysis of the process-induced residual stress during the manufacture of DBs should be performed.

The performance of engineering components manufactured by applying foundry processes is considerably influenced by several defects, one of the most detrimental of which is the residual state of stress. If adjacent regions experience different specific volume variations (owing to cooling at different rates or different phase transformations), stresses can be generated, and beyond the yield limit of the material, a residual stress state exists at room temperature. The analysis of residual stress in the casting process is essential to improve casting technology and casting quality. In the casting process of super duplex stainless steel, the simulation and prediction results of the residual stress can be obtained by conducting a finite element (FE) simulation [1]. The life cycle of the cylinder parts can be increased by improving the casting process of the engine blocks [2]. G Funk et al. [3] performed a continuous numerical simulation of temperature and stress to analyse the residual stress of an engine cylinder block, measured the residual stress, and concluded that the predicted residual stress was consistent with the measured data. D Q Zhang et al. [4] studied the stress states in the casting, shakeout, and heat treatment processes of low-pressure aluminium alloy shell castings. C. Lood et al. [5] used ANSYS to simulate the stress of aluminium alloy castings and analysed and compared the effects of pouring speed and heat conduction coefficient on the stress. Therefore, it is necessary to study the residual stress during the casting process.

The heat treatment process is an effective method for eliminating residual stress and reducing stress concentration during actual industrial production [6]. M. Honarpisheh et al. studied the change in the residual stress of hot-extruded

aluminium-6061 rods during heat treatment [7]. B Huang et al. [8] studied the influence of post-welding heat treatment on the residual stress field and deformation of a 20/0Cr18Ni9 plate by using Simufact Welding software and combining numerical simulations with experiments. Si Young Kwak et al. [9] conducted experiments and numerical analysis on a constant stress bundle to evaluate the influence of residual stress generated in the heat treatment process on the yield behaviour of the products used. To optimise the machining process of the cam to control the residual stress, the heat treatment process was analysed, and the residual stress in the heat treatment process of the cam was studied [10]. The actual effect of treatment parameters on the residual stress can be obtained by studying the residual stress in the process of quenching and heat treatment of aluminium alloy, and the heat treatment process can be optimised [11].

Material removal has a significant impact on the quality, stress, and deformation of the parts. Deng et al. used numerical simulations to analyse the deformation and stress distribution after machining [12]. Meng et al. designed FE simulations of orthogonal cutting based on arbitrary Lagrangian–Eulerian. The milling residual stress of a prestressed workpiece was studied. The results were found to be well-consistent with the FE simulation results [13]. Song et al. established a two-dimensional FE simulation model for titanium-alloy cutting by using an FE software named ABAQUS. The influence and coupling effect of multi-step machining and pre-stress machining on the residual stress distribution of the machined surface were explained [14]. The evolution of the residual stress field during continuous machining was studied by performing FE analysis [15]. Z Zhang et al. investigated the influence of material removal partition on residual stress in high-strength aluminium alloy parts to minimise machining distortion [16]. By combining theoretical analysis and experiments, Guo et al. investigated the redistribution of residual stress during multi-process milling of thin-walled parts [17]. X Cerutti et al. [18,19] successfully predicted the processing deformation caused by the initial residual stress and analysed the influence of the processing sequence on the initial residual stress by simulating the material removal process of the workpiece using the life-and-death element method.

Thus, in previous studies, the main focus was on the stress of one process or several processes without correlation. There is a lack of research on the residual stress of the entire process under coupled multiple processes of the same component. The evolution analysis of the residual stress in multiple processes is necessary because the residual stress is constantly generated and changed during the machining process.

In this study, an evolution analysis method (EAM) is proposed. First, an evolution analysis model of a DB was established. Second, the residual stress of the DB during the casting and heat treatment processes was analysed using ProCAST and ABAQUS. Third, the material removal of the DB during the machining process was simulated by using ABAQUS. Finally, the final stress distribution of the DB was deduced by considering the entire machining process.

2 Evolution analysis model of the residual stress

Residual stress exists in the casting, heat treatment, and machining processes of a DB, and it exhibits different states and evolution laws at each stage. Therefore, it is necessary to study the entire DB process to determine the state of residual stress and evolution rules at each process.

2.1 Modelling strategy

The processing of the DB varies significantly in each stage owing to the different production mechanisms of residual stress. In the casting stage, the residual stress is generated due to the uneven solidification and cooling of molten iron; in the heat treatment stage, it is generated due to the influences of annealing temperature and time; in the machining stage, the residual stress is redistributed due to material removal, and the residual stress changes. Therefore, to ensure the accuracy of the simulation results of hot-working and machining, and to fully utilise the conversion interface and compatibility mode of all types of current software, ProCAST and ABAQUS are selected as the simulation and calculation platforms for the entire process of residual stress evolution in the DB.

First, NX12.0 is used to simplify the diesel engine body and establish the DB FE analysis model. Subsequently, the processes of casting and shakeout are simulated successively by using ProCAST, and the evolution of residual stress is analysed. Third, the DB stress state obtained in the casting process is mounted in ABAQUS to simulate the heat treatment process. Finally, the ABAQUS software is used to simulate machining with the stress state of the DB after heat treatment as the initial state by employing the 'birth and death element method'. Based on these analyses and simulations, the stress state and evolution law of each stage of the DB are obtained, and the stress evolution law of the entire process of the DB and the influence of different process schemes on the stress state of the DB are obtained. The solution process is shown in Figure 1.

Fig. 1 Procedure of EAM

2.2 Geometric modelling and evaluation criterion

The DB selected as the object of the study is shown in Figure 2. The profile length, width, and height are 4200 mm, 1800 mm, and 1400 mm, respectively. There are 16 cylinders, divided into two columns and arranged in a V shape. The main wall thickness is 22–32 mm.

Fig. 2 3D model of the DB

Because the free end of the DB is stable and not easily deformed, the output end exhibits complex stress and is prone to deformation. Therefore, a partial structure of the DB output end is selected to analyse the residual stress evolution of the DB.

According to the principle of the casting and gating system, the design sand box and gating system settings are shown in Figure 3a. To accurately obtain the evolution law of residual stress in subsequent casting, heat treatment, and material removal processes, stress measuring points are selected in each analysis process. The distribution of the measurement points is shown in Figure 3b.

a) Evolution analysis model of DB

b) Data points of residual stress

Fig. 3 Modelling and data point selection

2.3 Finite element meshing

Owing to the large size and complex structure of the DB and the high mesh quality requirement for casting simulation by the ProCAST casting software, HYPERMESH is used for meshing. The DB, sand mould, and gating system are divided into meshes with specific dimensions, as listed in Table 1, with a total of 4.5613 million units. The grid type is a tetrahedral grid, and the results are shown in Figure 4.

Table 1 Grid partition size settings

Parts	Element size/mm
Overall size	20
Up and down the bottom	10
Curved shaft hole	10
Cylinder hole	10
Camshaft hole	10
Gating system	20
Sand mold	100

a) Sandbox mesh

b) Casting and gating system mesh

c) Local mesh of curved shaft hole, camshaft hole, and cylinder hole

Fig. 4 Mesh of the entire model

2.4 Material Properties

The body material is EN-GJS-500-7, and its chemical composition is presented in Table 2. The specific thermophysical and mechanical property parameters are listed in Table 3, where ρ is the density, E is the Young's modulus, μ is the Poisson's ratio, σ_s is the yield strength, H is the enthalpy, K is the thermal conductivity, C_p is the specific heat, and α is the linear expansion coefficient.

Table 2 Chemical composition of EN-GJS-500-7 (mass fraction, %)

Composition	C	Si	Mn	S	P	Mg	Re
Content	3.4~3.8	2.0~2.8	0.3~0.5	≤ 0.03	≤ 0.15	0.03~0.06	0.03~0.05

Table 3 Thermophysical and mechanical property parameters

$T/$ $^{\circ}\text{C}$	$\rho/$ $(\text{kg}\cdot\text{m}^{-3})$	$E/$ (GPa)	μ	$\sigma_s/$ (MPa)	$H/$ $(\text{kJ}\cdot\text{kg}^{-1})$	$K/$ $(\text{W}\cdot\text{m}^{-1}\cdot\text{K}^{-1})$	$C_p/$ $(\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1})$	$\alpha/$ (10^5K^{-1})
0	6687.9	103.4	0.3	589.5	0	21	448	2.05
100	6687.9	103.4	0.3	558.6	28	21	443	2.05
200	6687.9	103.1	0.3	534.8	91	22	461	2.05
400	6687.9	93.13	0.3	360.0	189	23	507	2.04
600	6687.9	73.69	0.3	158.1	310	24	603	2.04

3 Residual stress analysis for the entire machining process

3.1 Residual stress analysis for the casting process

During the solidification process, the DB shrinks. Owing to the uneven thickness of the DB, the cooling speed increase, and thus, the contraction speeds of the different parts of the DB are different, causing mutual obstruction in the cooling process of the DB. This results in deformation and residual stress in the DB. The designed pouring temperature, termination temperature, and pouring time were 1410 °C, 700 °C, and 12 s, respectively. Subsequently, the stress state of the DB during the pouring process was analysed. The residual stress of the DB was generated when it continues to cool in the air after shakeout, and the residual stress that remained at room temperature became the final residual stress of the DB. Based on the casting process, the sand was dropped, stress results of the DB casting process were extracted, sand was removed, and DB was air-cooled to 30 °C.

The casting process of the DB was simulated by using ProCAST, and the results are shown in Figure 5. The stress change curve at each measuring point in the DB during the casting process is shown in Figure 6.

a) Stress results after pouring

b) Stress results after shakeout stage

Fig. 5 Stresses in the casting process

a) Stress results at points 1–3

b) Stress results at points 4–6

Fig. 6 Stress changes at each measuring point during casting

Figure 6 shows that during the casting process, the stresses at points P1, P2, P3, P4, P5, and P6 increase rapidly at first, then decrease, and finally increase as the pouring process progresses. The DB is in the liquid phase at the beginning of casting cooling. Because liquid iron has good feeding and deforming ability, the change in temperature does not cause thermal stress in the DB. During the solidification process, thermal stress is generated in the DB. The rapid decrease in stress occurs because during the solidification process, the DB undergoes a secondary phase change and its volume increases, reducing the mutual obstruction at the thickness of the DB and the obstruction caused by the sand box on the DB, thus decreasing the stress of the DB. Finally, owing to the complete solidification of the DB, the residual stress at the measuring point increases continuously owing to the different cooling rates.

In the shakeout stage, the stress variation at measuring points P1, P2, P3, P4, P5, and P6 exhibits a 'fast declining-increasing-levelling' trend. The trend of residual stress change at each measuring point of the DB after shakeout is same, which first decreases rapidly for a very short time and then gradually increases until the residual stress tends to stabilise. The interaction between the DB before the shakeout and the

sand box produces a considerable amount of elastic stress; after the shakeout of the body outer surface to remove sand box constraints, the elastic stress disappears, stress decreases sharply, stress that is retained is the casting residual stress, and residual stress increases as the temperature drops slowly.

After casting, larger stress values exist in the crankshaft observation window, bottom surface of the DB, curved shaft hole, and cylinder hole surface, whereas the other positions exhibit lower and better stress states.

3.2 Residual stress analysis for heat treatment process

When the entire casting process was simulated, the heat treatment process of the DB was also simulated. The results of the casting simulation in ProCAST were exported, and the shakeout results were imported into ABAQUS by using the compatible conversion interface between ABAQUS and ProCAST to simulate the heat treatment process of the DB. A body heat treatment simulation was performed according to the actual annealing heat treatment process of the body blank. The specific process was as follows: heating to 520 °C, holding for 6 h, furnace cooling at 120 °C, and natural air cooling to 25 °C. The heating and cooling rates of annealing by using the furnace were not less than 50 °C/h.

Thermodynamic coupling analysis using Coupled Temp-Displacement was adopted to simulate the DB heat treatment process, and the residual stress state of the DB after heat treatment was obtained. The results are presented in Figure 7. After the heat treatment, the residual stresses at the positions of the measuring points were determined by using the same process as that in the casting process to obtain the stress change curve before and after the heat treatment at each measuring point, as shown in Figure 8.

Figures 7 and 8 show that after the heat treatment, stresses at the cylinder hole surface, side of the DB, and inner side of the bottom surface are large. After heat treatment of the DB on the basis of casting, the overall stress of the DB measuring point decreases, and the analysis reveals that the average stress elimination at the measuring point reaches 47%. The upper part of the body wall was relatively thin.

Thus, during the annealing process, the temperature changed rapidly, resulting in a relatively large stress field.

a) Stress before heat treatment

b) Stress after heat treatment

Fig. 7 Stress results during heat treatment

Fig. 8 Stress changes before and after heat treatment

The results show that the residual stress of the DB was eliminated significantly, and the stress state of the DB became more stable after annealing.

3.3 Residual stress analysis for material removal process

In the process of machining, as the excess material of the blank is gradually removed, the stress in the cutting layer is gradually released, and the original balance state of the residual stress in the blank is destroyed. To achieve a new stress balance, the initial stress is redistributed, and then a new balance state is reached.

The processing technology was analysed and the key parts of the DB were selected to simulate material removal. Different material removal sequences were designed, and the ABAQUS 'life and death unit' method was used to simulate the processing. A 'life and death unit' allows specific units to be activated or killed during analysis. That is, when a material is removed, the corresponding element is removed. The 'life' or 'death' of an element is not really adding or removing the element but multiplying it with a very small reduction coefficient, so that the mass, damping, element stress, and strain of the corresponding killing element are set to 0. In the machining process of DBs, material removal leads to the release and redistribution of

residual stress, which affects the actual stress state of the DB.

According to this analysis, the residual stress after the heat treatment was considered as the initial residual stress during machining and applied to the DB as a predefined field. On this basis, the material removal process of the DB was simulated, machining simulation of the DB with different material removal sequences was performed, and evolution laws of the residual stress of the DB with different material removal sequences were obtained.

Based on the actual machining conditions and feasibility of the simulation, the processing technology of the DB was analysed. Five key parts of the DB were selected for the machining simulation. Based on the analysis of the DB process, five key positions (① top surface, ② bottom surface, ③ cylinder hole, ④ curved shaft hole and ⑤ camshaft hole) were selected for the removal simulation. The removal plans are listed in Table 4, and the methods are shown in Figure 9.

Fig. 9 Schematic diagram of material removal

Table 4 Material removal plans

Plans	Order of removal
1	①→②→③→④→⑤
2	①→②→③→⑤→④
3	①→②→④→③→⑤
4	①→②→④→⑤→③
5	④→①→②→⑤→③
6	④→①→②→③→⑤

According to processing plans 1–6, the DB was simulated to determine the stress at each measuring point under different schemes and processes. The measuring points in each area were selected according to the aforementioned analysis steps of the DB, and they represented the stress state in the corresponding area of the measuring points. After removal, the stresses at the measuring points in the same removal sequence and in the same region were averaged, and the average value of the stress represented the state of residual stress in the corresponding region. Thus, the residual stress in different regions and under different removal schemes were obtained, as shown in Figure 10.

Fig. 10 Stresses in each area after removal

Figure 10 shows that when the material is removed, the stress in each area is present as a whole; the residual stress in the cylinder hole area is the largest, followed by those in the curved shaft hole and on the top surface, and the residual stress on the bottom surface is the smallest. The maximum stress in the cylinder hole area is 97.4 MPa. The stress in the bottom area is the smallest with a stress value of 30.57 MPa. The minimum stress values in the curved shaft hole and on the top surface are 57.9 and 36 MPa, respectively.

For the cylinder hole, top surface, curved shaft hole, and bottom surface area, different processing and removal sequences have different influences on each area, and different stress states are generated after removal. The stress states before and after the removal of different regions and for different removal sequences were analysed, as shown in Figure 11.

e) Stress change rate at each position

Fig. 11 Stress results in each area

As shown in Figure 11,, for the cylinder hole and top surface area, removal plan.4 (top surface - bottom surface - curved shaft hole - camshaft hole - cylinder hole) and plan.5 (curved shaft hole - top surface - bottom surface - camshaft hole - cylinder hole) exhibit the largest influence on the residual stress at the top surface area of the DB. For the curved shaft hole and bottom surface area, the influences of the removal schemes on the residual stress are similar.

For the cylinder hole, top surface, curved shaft hole, and bottom surface, the rate of change of residual stress under different removal schemes shows that the stress on the top surface is the largest, followed by those at the curved shaft hole and bottom surface, and the stress in the cylinder hole is the smallest. The material removal order has the largest influence on the residual stress at the top surface.

In the machining process, different processes (i.e. removal of different parts) have different effects on the final residual stress state in different regions of the workpiece. The influence of different processes on the residual stress in each area is expressed by the rate of change of stress in each area under different working procedures of the DB. The rate of residual stress change in the cylinder hole, top surface, curved shaft hole, and bottom surface are represented by μ_1 , μ_2 , μ_3 , and μ_4 ,

respectively, as shown in Figure 12.

Fig. 12 Rates of change of residual stress in different areas under different processes

Figure 12 shows that when the top surface is removed, the rate of change of residual stress in each area is as follows: $\mu_2 > \mu_4 > \mu_1 > \mu_3$. This process has the largest effect on the residual stress of the top surface and the smallest effect on that of the curved shaft hole.

When the bottom surface is removed, the rate of change of the residual stress in each area is as follows: $\mu_4 > \mu_2 > \mu_1 > \mu_3$. This process has the largest influence on the bottom residual stress and the smallest influence on the residual stress of the curved shaft hole.

When the cylinder hole is removed, the rate of change of the residual stress in each area is as follows: $\mu_1 > \mu_2 > \mu_3 > \mu_4$. This process has the largest impact on the residual stress of the cylinder hole and the smallest impact on that of the bottom surface.

When the curved shaft hole is removed, the rate of change of the residual stress

in each region is as follows: $\mu_3 > \mu_2 > \mu_1 > \mu_4$. This process has the largest effect on the residual stress of the curved shaft hole and the smallest effect on the bottom surface residual stress.

When the axle hole of the cam is removed, the rate of change of the residual stress in each region is as follows: $\mu_2 > \mu_1 > \mu_3 > \mu_4$. This process has the largest effect on the residual stress on the top surface and the smallest effect on the bottom surface residual stress.

Therefore, it can be concluded that the removal of the top surface and camshaft hole has a significant influence on the top surface residual stress, and the removal of the cylinder hole has the largest influence on the residual stress of the cylinder hole. The removal of the top and bottom surfaces has little influence on the residual stress of the curved shaft hole area, whereas the removal of the cylinder hole, curved shaft hole, and camshaft hole has little influence on the bottom surface residual stress.

4 Conclusions

In this study, an EAM was proposed. The evolution analysis of the residual stress on the DB was performed, and the following conclusions were drawn.

1) During the thermal processing, the DB goes through the casting process to achieve the initial residual stress. After casting, a larger stress exists in the crankshaft observation window, bottom surface of the DB, curved shaft hole, and cylinder hole surface, whereas the other positions exhibit better stress states. During the heat treatment process, the stress of the DB is eliminated and released, and the stress is reduced at a rate of change of 47%, making the stress state more stable.

2) The stress generated during the removal of the DB material interacts with the residual stress. The residual stress is redistributed, and the stress changes. After material removal, the overall stress in each area shows that the residual stress in the cylinder hole area is the largest, followed by those at the curved shaft hole and top surface, and the residual stress at the bottom surface is the smallest.

3) The material removal sequence has the largest influence on the top surface residual stress. For the cylinder hole and top surface area, removal plan.4 (top surface - bottom surface - curved shaft hole - camshaft hole - cylinder hole) and plan.5 (curved shaft hole - top surface - bottom surface - camshaft hole - cylinder hole) have the largest influence on the residual stress. For the curved shaft hole and bottom surface area, the influences of the removal schemes on the residual stress are similar.

4) The removal of the top surface and camshaft hole has a significant influence on the residual stress at the top surface, removal of the cylinder hole has the largest influence on the residual stress of the cylinder hole, removal of the top and bottom surfaces has little influence on the residual stress of the curved shaft hole area, and removal of the cylinder hole, curved shaft hole, and camshaft hole has little influence on the bottom surface residual stress.

Authors contributions Donghao Zhao proposed the main analysis ideas, established the analysis framework, and carried out the stress analysis of the machining process, is the main contributor of the paper. Zhuhua Ai and Yunlong Liu built an analytical model of the diesel body. Xiaoxiang Bai carried out the analysis of the heat treatment process of the diesel body. Guochao Li carried out the stress analysis of the casting process, modified and edited the language of the paper, and put forward some suggestions. Honggen Zhou and Liping Cao helped to read and approve the final manuscript.

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Data availability All data generated or analyzed during this study were available by emailing to author. (1942537840@qq.com).

Declarations

Competing interests The authors declare that they have no competing interests.

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References

- [1] Palumbo, G., Piccininni, A. & Guglielmi, P (2020) Prediction of the residual state of stress in a superduplex stainless steel produced by sand casting (using a coupled thermo-mechanical approach). *Int J Adv Manuf Technol* 107: 3011–3022. <https://doi.org/10.1007/s00170-020-05213-0>.
- [2] Farzaneh Farhang Mehr, Steve Cockcroft & Daan Maijer (2020) A fully-coupled thermal-stress model to predict the behavior of the casting-chill interface in an engine block sand casting process. *Int J Heat Mass Transfer*. <https://doi.org/10.1016/j.ijheatmasstransfer.2020.119490>.
- [3] G. Funk, J.R. Boehmer & F.N. Fett (1994) A coupled FDM/FEM model for the continuous casting process. *Int. J. of Computer Applications in Technology*(3/4/5/6). <https://doi.org/10.1504/IJCAT.1994.062525>.
- [4] D Q Zhang, J X Zhou, T Chen. (2015) Heat transfer and stress evolution behaviors of an aluminum alloy low pressure shell casting. *IOP Conf. Series: Materials Science and Engineering* 84. <https://doi.org/10.1088/1757-899X/84/1/012041>.
- [5] Epp Jérémy, Surm Holger, Hirsch Thomas & Hoffmann Franz (2010) Residual stress relaxation during heating of bearing rings produced in two different manufacturing chains. *Journal of Materials Processing Tech* (4), <https://doi.org/10.1016/j.jmatprotec.2010.11.022>.
- [6] Kim, JS., Yoo, JH. & Oh, YJ (2015) A study on residual stress mitigation of the HDPE pipe for various annealing conditions. *J Mech Sci Technol* 29, 1065–1073. <https://doi.org/10.1007/s12206-015-0218-7>.
- [7] M. Honarpisheh, F. Nazari & M. A. Haghighi (2020). Annealing Heat Treatment Effect on the Residual Stresses in Hot-Extruded Aluminum Alloy Rods with High Cross-Sectional Reduction. *Strength of Materials*(12), <https://doi.org/10.1007/s11223-020-00177-8>.
- [8] Yujia Xie, Jia Zhuang, Bensheng Huang, ... & Guangwen Li. (2020) Effect of different welding parameters on residual stress and deformation of 20/0Cr18Ni9

dissimilar metal arc-welding joint. Journal of Adhesion Science and Technology(15).
<https://doi.org/10.1080/01694243.2020.1715670>.

[9]Si Young Kwak & Ho Young Hwang.(2018).Effect of heat treatment residual stress on stress behavior of constant stress beam. Journal of Computational Design and Engineering(1), <https://doi.org/10.1016/j.jcde.2017.07.001>.

[10]Li, G., Xu, H., Zhou, H. et al (2019) Experimental study of residual stresses of Cam produced by heat treatment and grinding processes. Int J Adv Manuf Technol 100, 1355–1362. <https://doi.org/10.1007/s00170-018-2756-5>.

[11]Ba, K., Levesque, J., Gakwaya, A. et al (2021) Residual stress investigation of quenched and artificially aged aluminum alloy 7175. Int J Adv Manuf Technol. <https://doi.org/10.1007/s00170-021-07520-6>.

[12]Deng Jie,Zhou Shi Jie,Gao Han Jun,Lin Ming Hui & Li Xin.(2021).Numerical Simulation Investigation on Machining Deformation of Aviation Thin-Walled Parts Caused by Residual Stress. Materials Science Forum({4}), <https://doi.org/10.4028/WWW.SCIENTIFIC.NET/MSF.1032.186>.

[13]Meng, L., Khan, A.M., Zhang, H. et al (2020) Research on surface residual stresses generated by milling Ti6Al4V alloy under different pre-stresses. Int J Adv Manuf Technol 107, 2597–2608. <https://doi.org/10.1007/s00170-020-05165-5>.

[14]Song, X., Li, A., Lv, M. et al (2019) Finite element simulation study on pre-stress multi-step cutting of Ti-6Al-4V titanium alloy. Int J Adv Manuf Technol 104, 2761–2771. <https://doi.org/10.1007/s00170-019-04122-1>.

[15]Ma, Y., Zhang, J., Feng, P. et al (2018) Study on the evolution of residual stress in successive machining process. Int J Adv Manuf Technol 96, 1025–1034. <https://doi.org/10.1007/s00170-017-1542-0>.

[16]Zhang, Z., Li, L., Yang, Y. et al (2014) Machining distortion minimization for the manufacturing of aeronautical structure. Int J Adv Manuf Technol 73, 1765–1773. <https://doi.org/10.1007/s00170-014-5994-1>.

[17]Guo, M., Jiang, X., Ye, Y. *et al*. Investigation of redistribution mechanism of residual stress during multi-process milling of thin-walled parts. Int J Adv Manuf Technol **103**, 1459–1466 (2019). <https://doi.org/10.1007/s00170-019-03640-2>.

[18] Cerutti, X., Mocellin, K (2016) Influence of the machining sequence on the residual stress redistribution and machining quality: analysis and improvement using numerical simulations. *Int J Adv Manuf Technol* 83, 489–503. <https://doi.org/10.1007/s00170-015-7521-4>.

[19] Cerutti, X., Arsene, S. & Mocellin, K (2016) Prediction of machining quality due to the initial residual stress redistribution of aerospace structural parts made of low-density aluminium alloy rolled plates. *Int J Mater Form* 9, 677–690. <https://doi.org/10.1007/s12289-015-1254-7>.