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Research on cross wedge rolling forming technology of railway axles

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Abstract. This paper introduces a new forming method of railway axles: the square bloom is forged into a round axle billet by fast forging machine, then the round billet is rolled into the rough axle by the cross-wedge rolling machine. In order to prove the feasibility of this method, we have done an experimental trial of the technology on making scale-down Chinese railway freight axles with the scale ratio 1:1.4. The test result shows that the new method can double the productivity compared with the single forging method, save about 9% materials and improve shape accuracy of rough axle. Microstructure and mechanical properties of the axles formed by the new method have been tested and the test results show that the yield strength is greater than 345Mpa, the tensile strength is greater than 610Mpa, and the grain size reaches grade 8, which meets the standard requirements；The transverse and longitudinal impact toughness is greater than 21J, and the cross-sectional hardness distribution is uniform；The fatigue toughness test shows that the KQ value of the journal and shaft body in the deformation area of cross wedge rolling is slightly larger than that of the wheel seat，which indicates that the CWR process has no negative effect on fracture toughness of axles.

1. Introduction

Cross-wedge rolling (CWR) is an advanced plastic forming technology, characterized by continuous deformation in a small localized area of work piece, for producing finished-form work pieces, particularly suitable for making stepped axles or rotationally symmetrical parts. The CWR technology has been widely used in the production of semi-finished axles & shafts of motor vehicles, tractors, motorcycles, internal-combustion engines, etc. and hundreds of different kinds of semi-finished components has been made by the CWR process in the world. Theoretically, the CWR technique can be supposed to be applied to form railway axles, which are typical of stepped shafts. Railway axles are so far mainly made by open die forging process, which is very beneficial to improving structural compactness of products, but is low in efficiency and leads to low degree of dimensional accuracy. This paper introduces a compound forming technology: the square bloom is forged into a round axle billet by fast forging machine, then the round billet is rolled into the final axle by the cross-wedge rolling machine. This technology allows to ensure high structural compactness, improve the productivity, increase the shape accuracy of semi-finished axles to save raw material and reduce machining costs. In order to assess the feasibility of this technology, we have performed an experimental trial of the technology on scale-down axles and tested the quality of these axles.

2. Trial production of axle

The RE2B-type axles are used for Chinese railway freight car and made of LZ50. The scaled-down (the scale ratio 1:1.4) version of RE2B-type axles was made with the compound forming technology because of no CWR machine in the world for the full-scale railway axles, and the drawing of the scaled-down axles can be seen as figure 1. The forming processes are as follows: I. The square rolled bloom (□230mm×□230mm) is cut to length to provide an amount of material needed for a single axle; II. The segments are heated to 1200℃ in an annular furnace(φ10m); III. The hot segments are forged into round axle billets by 10MN fast forging machine; IV, Rough axles are formed with a cross-wedge rolling machine (H1400 type). roll rotation speed 2-5 r/ min, wedge flood mold exhibition is 7 ° - 10 °.

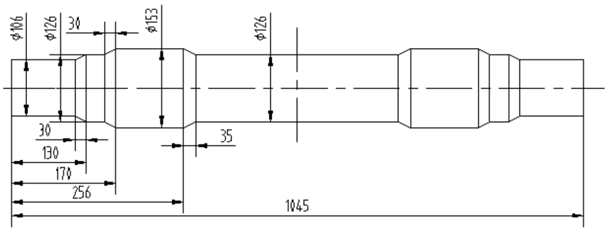


Figure 1. The drawing of the scaled-down axles.

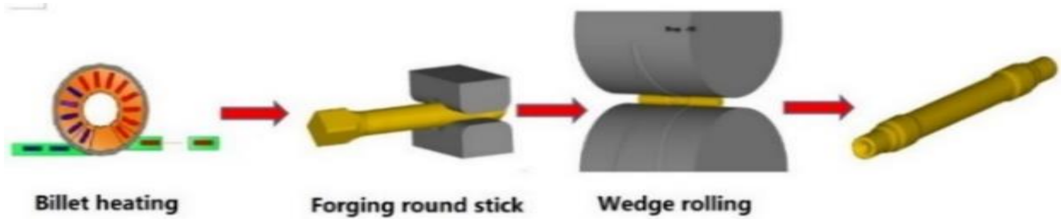


Figure 2. The process flow chart.

Figure 3. Round axle billet forged by 10MN fast forging machine.

Figure 4. The rough axle formed with a H1400 type CWR.

Figure 5. The Round axles.

15 axles have been made by this compound forming technology. For forming an axle, 3-4 minutes are needed in the fast forging machine, and about 30 seconds are needed in the cross-wedge rolling machine.

Less than 4 minutes is enough for forming each rough axle by the compound technology, because forging and cross-wedge rolling can be performed on different axles simultaneously during batch production. It takes 8-10 minutes to produce an axle by forging alone, so the new method can double the productivity.

3. Shape accuracy analysis

Surface quality of the rough axles has been individually checked. The surfaces are without any lumps, cracks, laps, dents or other defects. 10 axles were measured, and the diameters can be seen as figure 6.

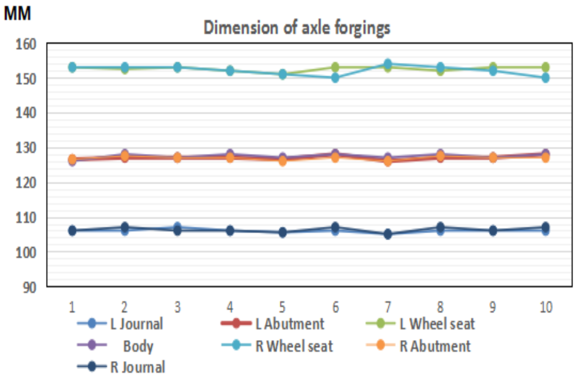


Figure 6. Diameters of parts of the axles.

The measurements shows that there is a difference of less than 2mm in diameter of journal, abutment or axle body separately, and there is a difference of less than 5mm in longitudinal dimension, and the curvature of the axles is within 2mm. For rough axles formed by this technology, one-sided margin is allowed to be within 5mm, while one-sided margin is currently set in the range of 7.5-9mm for rough axles which are formed with the single forging method in Taiyuan Heavy Industry Company. Taking axles of freight cars on Chinese railways as an example, the new method can save 9% of raw materials. So it is proved that the compound forming technology not only allows much higher shape accuracy, but also to save raw material.

4. Full analysis of properties

For fully investigating the effect of the compound forming processes on axle quality, the analyses of macrostructure and metal flow have been performed on the axles in the as-rolled condition; the test of comprehensive mechanical characteristics (including homogeneity and fatigue characteristic) has been carried out on the axles after heat treatment; UT and MT have been conducted on the axles after machining process.

4.1. Analyses of macrostructure and metal flow

Macrostructure test can clearly show structural compactness and macroscopic defects of axle. Test pieces have been taken from different parts of axle according to figure 7. And hot etching tests (industrial hydrochloric acid ($HCl:H_2O=1:1$); etching temperature of 70-80 Celsius degree; etching time of 15 minutes) were carried out on these slices. Rating has been performed according to GB/T1979-2001 "the standard diagrams for macrostructure defects of structural steel". Analysis of metal flow has be carried out on the longitudinal section of axle.

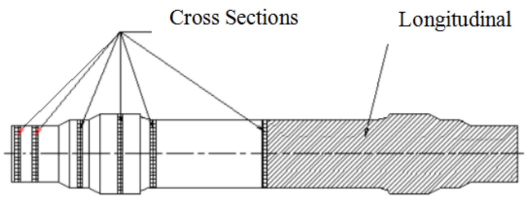
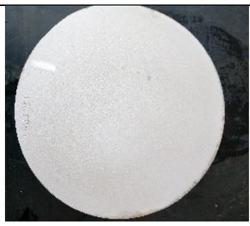
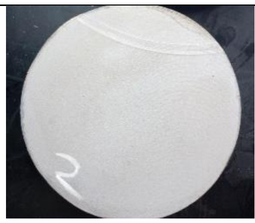
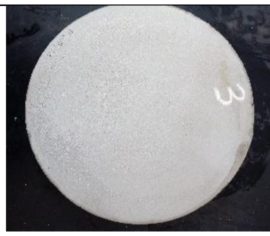
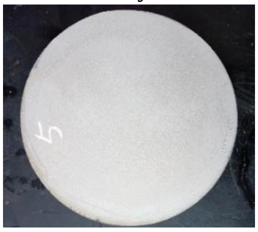
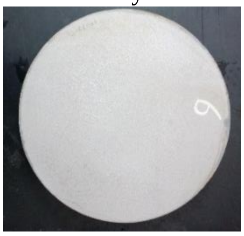


Figure 7. The position of the test piece.

Figure 8. Longitudinal slice for metal flow analysis.

Results demonstrate that macrostructure characteristics completely satisfy the relevant technical requirements. There is free from shrinkage cavity, lamination, a crack, which is visible to the unaided eyes on all the cross sections whose locations in an axle can be seen as figure 7. Figure 8 shows that there are no defects such as porosity, cavity, cracking, and lamination, and the structural compactness is good. The level rating of shrinkage porosity is Level 0.5, shown in table 1.

Table 1. Macrostructure test on cross sections.

Position	Journal 1	Journal 2	Abutment
Macrostructure			
Level	0.5	0.5	0.5
Position	Wheel seat	Body 1	Body 2
Macrostructure			
Level	0.5	0.5	0.5

4.2. Test of comprehensive mechanical characteristics.
According to “TB/T 2445-1999 Technical Specifications of LZ50 Steel Axles and billet for Rolling Stocks”[1], the axles were normalized twice and then tempered. After heat treatment, the comprehensive mechanical characteristics have been examined on these axles.

4.2.1. Tensile test. Four tensile specimens were taken at mid-radius from each part of axle (journal, wheel seat and axle body). Tensile tests were carried out in accordance with GB/T 228. Grain size tests were performed at undeformed ends of the tensile specimens according to ISO643. The test results are shown in table 2.
Tensile test results show that the tensile characteristics of journal, wheel seat and axle body meet the requirements, and the grain sizes are very small and the level of it is 8.

Table 2. Tensile characteristics and grain size.

Sampling Position	ReL(MPa）	Rm（MPa）	A(%）	Z%	Grain size
Achieved	≥345	≥610	≥20	≥37	≥6
Journal- 1	372	724	24.5	49	8
Journal- 2	366	706	21.0	49	8
Journal- 3	372	716	23	49	8
Journal- 4	372	718	24	51	8
Axle body-1	362	705	24.0	49	8
Axle body -2	366	715	22.5	50	8
Axle body -3	342	693	24	48	8
Axle body -4	363	696	26	51	8
Wheel seat-1	350	708	24.5	48	8
Wheel seat-2	361	704	24	49	8
Wheel seat -3	354	704	24.0	49	8

Wheel seat -4	370	714	23.5	50	8

4.2.2. Impact test characteristics. In order to assess the impact strength characteristics of the axles, Charpy impact tests at room temperature have been carried out in accordance with GB/T 229. Six longitudinal test pieces and six transverse test pieces from each part of the axle were taken, and the sampling positions are shown in figure 9. Each of the specimens had a U-notch with depth of 5mm. The test results are shown in figure 10, 11.

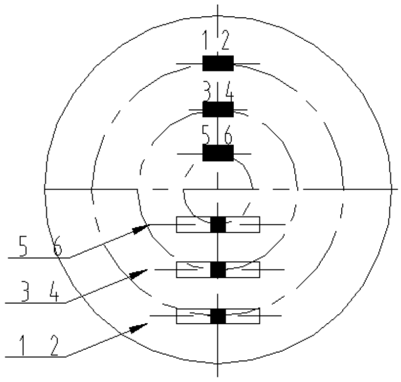


Figure 9. The sampling positions of impact test pieces.

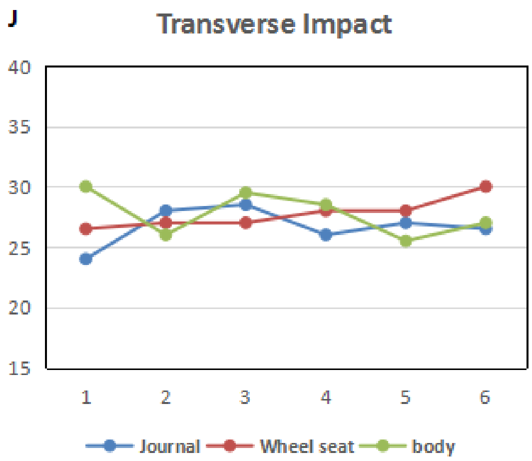


Figure 10. Results of transverse impact tests.

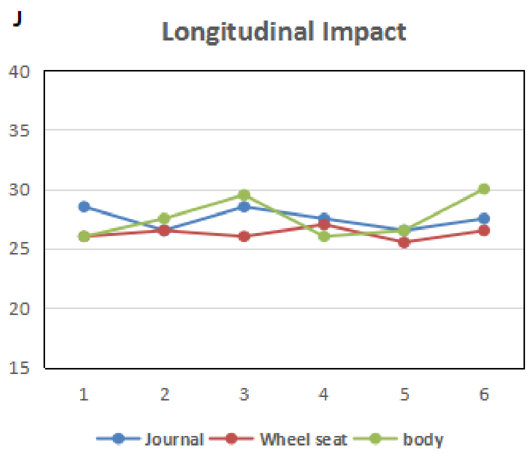


Figure 11. Results of longitudinal impact tests.

The test results show that the impact strength over the entire axle varies slightly, the difference of values is almost within 5J. The parts (journal and axle body) where large deformation occurred during the CWR process differ insignificantly from the wheel seat where almost no deformation occurred during the CWR process in impact strength.

4.2.3. Hardness homogeneity. In order to assess the effect of CWR process on hardness of axle, the hardness measurements have been carried out at those points (shown in figure 12) on the 3 cross-sectional slices taken from axle journal, wheel seat and axle body. And the tests have been performed according to GB/T 231.1. The test results are shown in figure 13.

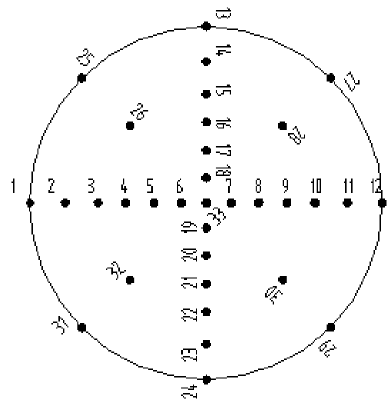


Figure 12. Points for hardness test.

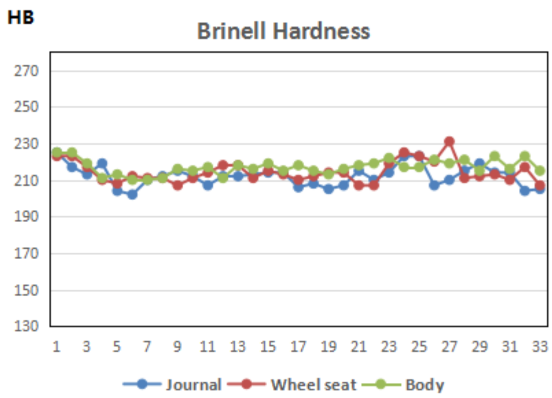


Figure 13. Results of the hardness tests.

The test results indicate that the hardness distribution of three parts (journal, axle body and wheel seat) is broadly consistent, and the hardness values of each test piece vary slightly and the difference is within 15HB, though during the CWR process large deformation occurred on the parts (journal and axle body) while almost no deformation occurred on the wheel seat.

4.3. Fracture toughness test

In order to assess the effect of the CWR process on the fatigue characteristics of near surface part of the axles, fracture toughness tests have been carried out according to ASTM E399 on specimens which were taken from the journal, wheel seat and axle body. The chevron notches of specimens were oriented towards the axle surface. The test results are shown in table 3.

Table 3. Results of fracture toughness tests.

Sampling Positon	B	W	p_{max}	P_Q	K_Q
Journal	30.02	59.92	60.61	53.88	76.1
Wheel seat	30.04	59.9	64.41	55.85	75.7
Axle body-1	30.01	59.93	69.46	57.52	77.9
Axle body-2	30.03	60.02	67.66	56.48	76.8

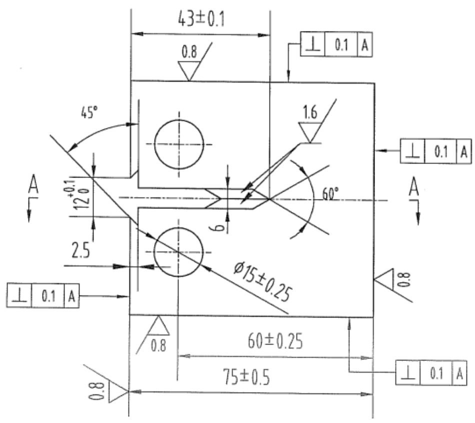


Figure 14. The specimen for fracture toughness test.

The test results show that all the KQ values are between 76.1 and 77.9 and the KQ value of the wheel seat (where almost no deformation occurred during the CWR process) differs slightly from the KQ values of journal & axle body, The KQ value of the journal and shaft body is slightly larger than that of the wheel seat, which indicates that the CWR process has no negative effect on fracture toughness of axles.

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4.4. Surface integrity and internal integrity

After machining process, surface integrity inspection has been performed on ten of the axles with a magnetic particle inspection equipment according to “TB/T 1619 Magnetic Particle Testing of Axle for Rolling Stock” and no surface defect was found. Radial and longitudinal ultrasonic inspection has been carried out with portable ultrasonic flaw detector KW-4C according to “TB/T 1618 Ultrasound Acceptance Testing of Axle for Rolling Stock”. Results show that the back face reflection is no less than 90%, and no defect (≥ Φ1.5mm) is found. The results of surface integrity inspection and internal integrity inspection of the 10 axles meet the relevant requirements.

5. Conclusion

The scale-down Chinese freight axles for rolling stock have been successfully manufactured by the compound forming processes (forging square bloom with fast forging machine and then cross-wedge rolling the round axle billet into rough axle with high shape accuracy). The whole forming processes can be completed within 4 minutes, which greatly improves the forming efficiency.

The rough axle formed by this method can have higher shape accuracy, and the one-sided margin is allowed to be controlled within 5mm. Compared with the single forging method, this compound forming method can improve material utilization.

The results of macrostructure tests on cross sections and metal flow examination on longitudinal slices show that the axles formed by the compound forming technology have good structural compactness and there are no defects such as shrinkage cavity. The mechanical characteristic tests on the axles after heat treatment demonstrate that all the properties of axles meet the relevant requirements, and the CWR process has no negative effect on impact strength, hardness distribution, fatigue characteristic, etc. Internal integrity and surface integrity of the axles have been respectively verified by UT inspection and magnetic particle testing.

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