UDC 547.918

DOI: 10.15372/KhUR20180502

Behavior and Strengthening Mechanism of Modified SiCp in Gray Cast Iron

CHUNFENG WANG[1,2], QINGYAN LIANG[2], GUILIN LIU[1], MEILING CHEN[1], and HONG GAO[1]

[1]*School of Material Science and Engineering, Dalian Jiaotong University, Dalian (China)*

E-mail: wangchunfeng821@163.com

[2]*Guangxi Yuchai Machinery Co., Ltd., Yulin (China)*

Abstract

Several studies have shown that the mechanical properties, corrosion resistance, and wear resistance of cast alloys, such as gray iron, ductile iron, aluminum bronze, and stainless steel, can be considerably enhanced by adding modified micro and nano SiC particles (SiCp). However, the distribution of SiCp in the melt can still be improved. Investigating the morphology and interaction mechanism of these particles is insufficient. In this study, the distribution and mechanism of HT250 in melt are studied by adding different amounts of modified SiCp. Results show that the microstructure of gray cast iron can be refined, and its tensile strength can be improved by the addition of modified SiCp. The improvement increases with the increase in the amount of added SiCp. Kinetic analysis shows that the mismatch between SiC and graphite is 8.1, and the size of SiC decreases after its addition to the melt. SiC satisfies the nuclei size condition of graphite and austenite precipitation and serves as the pinning particle that hinders the movement of the grain boundary. The addition of SiC to gray cast iron is crucial in fine grain strengthening because of these behavioral characteristics.

Key words: modified SiC particles, fine grain strengthening, gray cast iron, tensile strength

INTRODUCTION

Grain refinement is the only method that can improve material strength and toughness simultaneously, but the method and application of adding second-phase particles with a micro-nanometer size to refine the grain remain rare. In 2002, V. A. Poluboyarov proposed the addition of trace second-phase particles to improve the mechanical properties, corrosion resistance, and abrasion resistance of materials. In literature [1], the effects of various additional particles on the performance of 110G13L steel were studied. Dalian Jiaotong University also accomplished substantial research in this field, and literature [2–7] conducted special research on improving the wear resistance and mechanical properties of materials, such as ductile iron, gray iron, aluminum bronze, and stainless steel, by adding SiC particles. Although research progress has been achieved in terms of improving the material properties of different additional particles, research on the distribution and mechanism of action of additional second-phase particles in the matrix is insufficient. This study focuses on the distribution and mechanism of additional modified SiCp in the melt.

EXPERIMENTAL

Modified SiCp was prepared through the mechanization method, and the particle size distribution curve of SiC was detected with an LS-POP (6) laser particle size analyzer of Euramerican gram, as shown in Fig. 1.

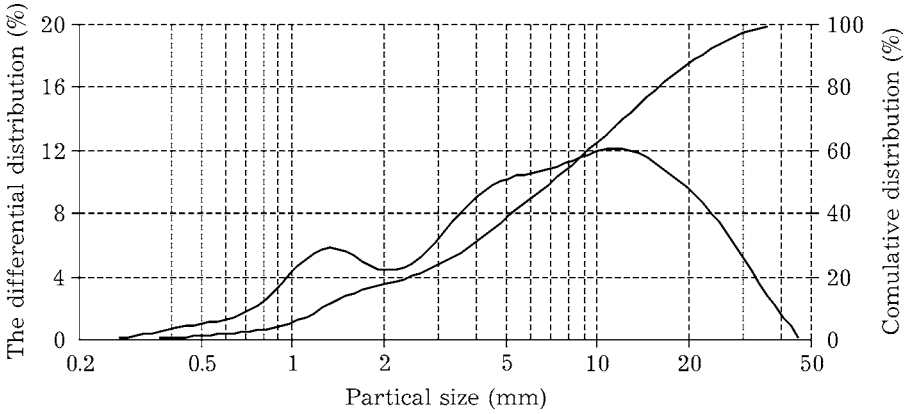

Fig. 1. Particle size distribution curve of SiCp. $D_3 = 0.76$ μm, $D_{25} = 3.15$ μm, $D_{50} = 7.07$ μm, $D_{90} = 21.78$ μm, $D_{97} = 29.33$ μm.

When an intermediate-frequency melting furnace was used to smelt an HT250 iron solution according to the materials in Table 1, silicon calcium and barium inoculant were selected for inoculation treatment. Modified SiCp was added at 0.00, 0.05, 0.10, 0.15 and 0.20 mass % to cast the test rod with diameter 30 mm.

Phase analysis before and after SiCp modification was performed using an Empyrean-type PW1710 X-ray diffractometer. Three test bars were obtained for each pouring scheme to examine tensile properties at room temperature with a CMT5205 microcomputer-controlled electronic universal testing machine. After the tensile samples were sampled, the graphite morphology and eutectic groups were observed by ZEISS Axio Observer Dlm inverted metallographic microscope, and the SEM observation

TABLE 1

Target composition of molten iron

Elements	C	Si (Original)	Si (Final)	Mn	P	S
Target (mass %)	3.15–3.25	1.75–1.85	1.9–2.0	0.75–0.85	≤0.06	0.06–0.1

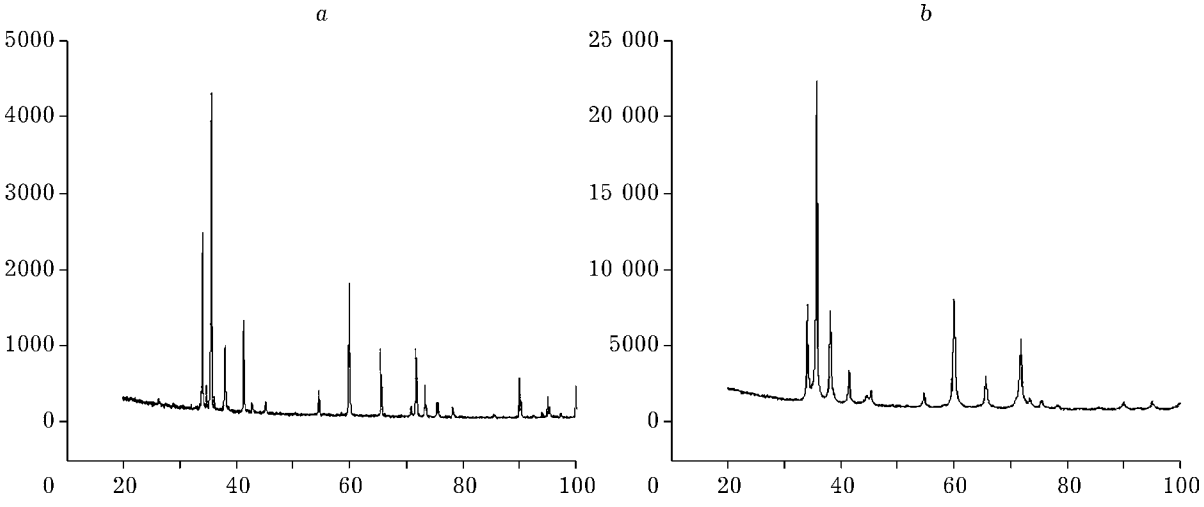

Fig. 2. XRD results: SiC_p before (*a*) and after (*b*) modification.

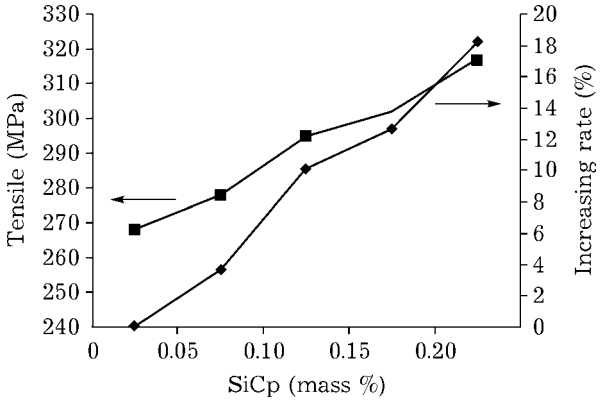

Fig. 3. Normal temperature stretching curves of different modified SiCp addition amounts.

was conducted by FEI QUANTA FEG250 scanning electron microscope and EDS analysis was conducted by OXFORD.

RESULTS AND DISCUSSION

XRD results of raw materials

The X-ray diffraction results before and after SiC modification are shown in Fig. 2. The spectrum lines of SiC widened after modification, which indicates that SiC had lattice distortion and was in a high energy state; thus, it reacted easily.

Tensile properties

The tensile strength test results at room temperature are shown in Fig. 3. After adding modified SiCp, the tensile strength of gray iron continuously increased as the amount of SiCp was increased. When the added amount of modified SiCp was 0.20 mass %, the tensile strength increased by 18.28 %.

Microstructural evaluation

The graphite morphology and eutectic group detection results of the sample are shown in Figs. 4, 5. Figure 6 illustrates the relationship between graphite length and grain size under different modified SiCp addition amounts. Figures 4–6 indicate that after adding modified SiCp, graphite became short and passivated at the tip. The number of eutectic groups increased, and the

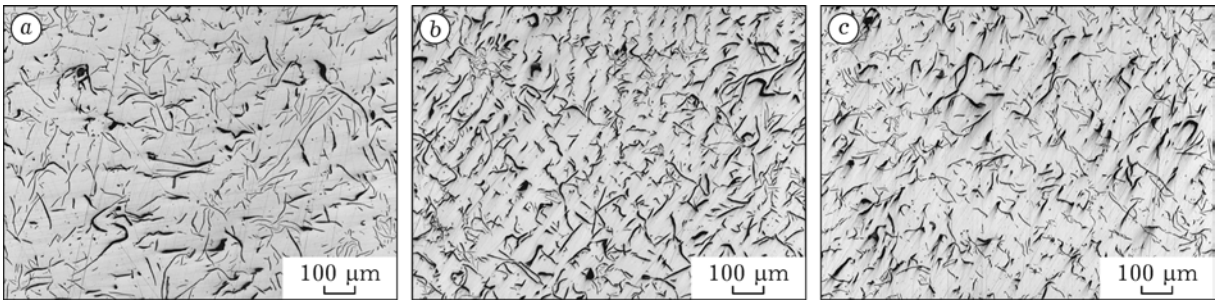

Fig. 4. Different amounts of modified SiCp in graphite morphology (mass %): 0 (*a*), 0.10 (*b*), and 0.20 (*c*).

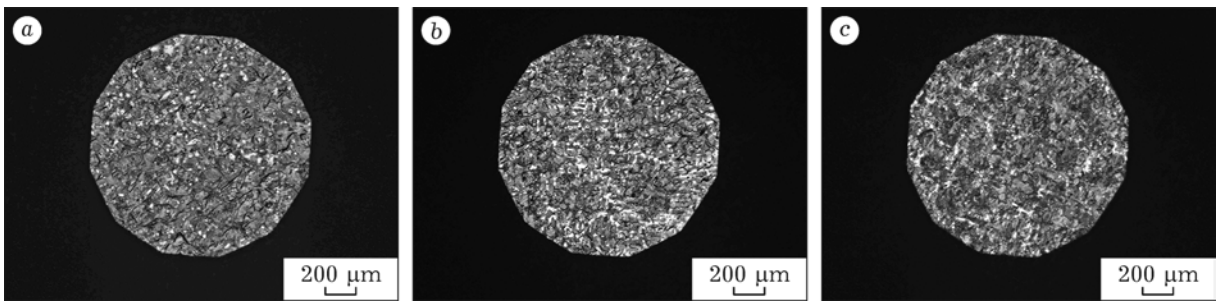

Fig. 5. Different amounts of SiCp added to the eutectic group: 0 (*a*), 0.10 (*b*), and 0.20 (*c*).

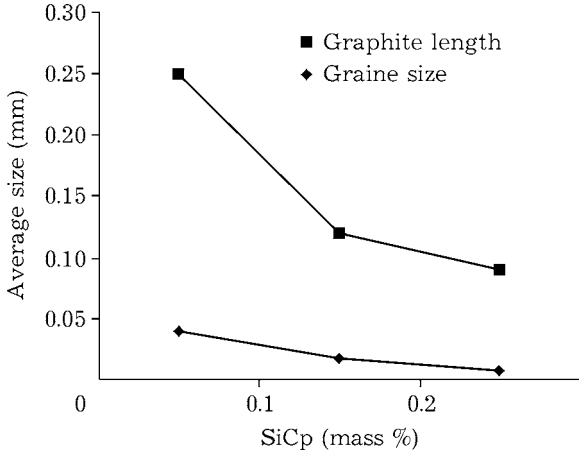

Fig. 6. Graphite lengths and grain sizes of different modified SiCp additions.

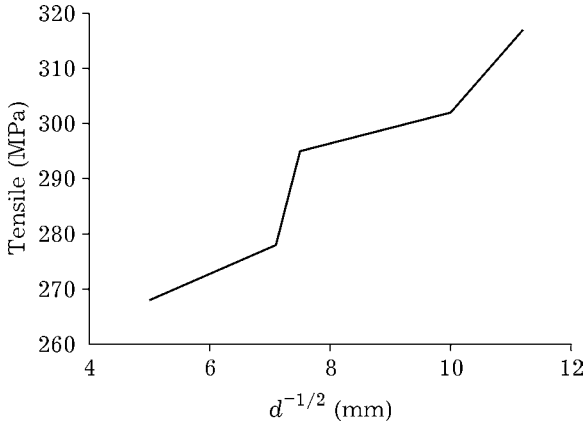

Fig. 7. Relationship between grain size and tensile strength of modified SiCp.

grain size decreased. The effect improved as the amount of added SiCp increased.

Figure 7 shows the relationship between the 0.5 square of grain size (d) and the tensile strength under the addition of different modified SiCp. Tensile strength is a function of $d^{-1/2}$, which is in line with the Hall–Petch formula used to determine the fine grain reinforcement of ordinary grain materials.

The distribution and morphology of SiCp in cast iron are shown in Figs. 8, 9. The black particles are SiC, and the gray ones are MnS. The SiC particles are in the pearlite clusters and at the boundary. Table 2 presents the SiCp particle size distribution determined *via* SEM in the random cross section. SiC particles with a size of 1–2 μm were the largest and accounted for a proportion of 52.08 %. No particles with a size of more than 5 μm were observed. Compared with the SiCp particle size distribution before the addition in Fig. 1, the original ratio of 90 % was found in the SiC particle with an average diameter of 21.78 μm. Therefore, the SiC size of large particles decreased when SiC was added to the cast iron solution, which indicates that SiC reacted in the cast iron solution.

Element	Percentage by mass	Atomic percent
C K	16.91	41.69
Si K	27.24	28.71
Fe K	55.84	29.60
Total	100.00	100.00

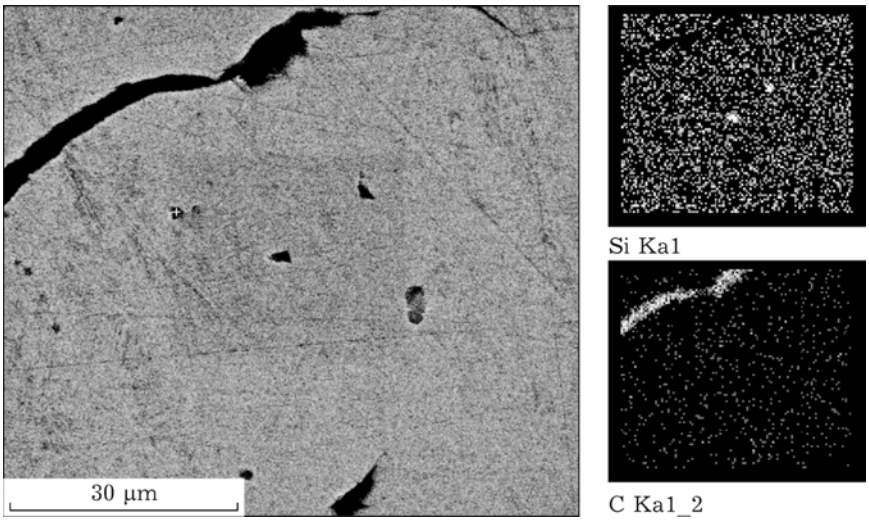

Fig. 8. EDS and plane scanning of SiCp.

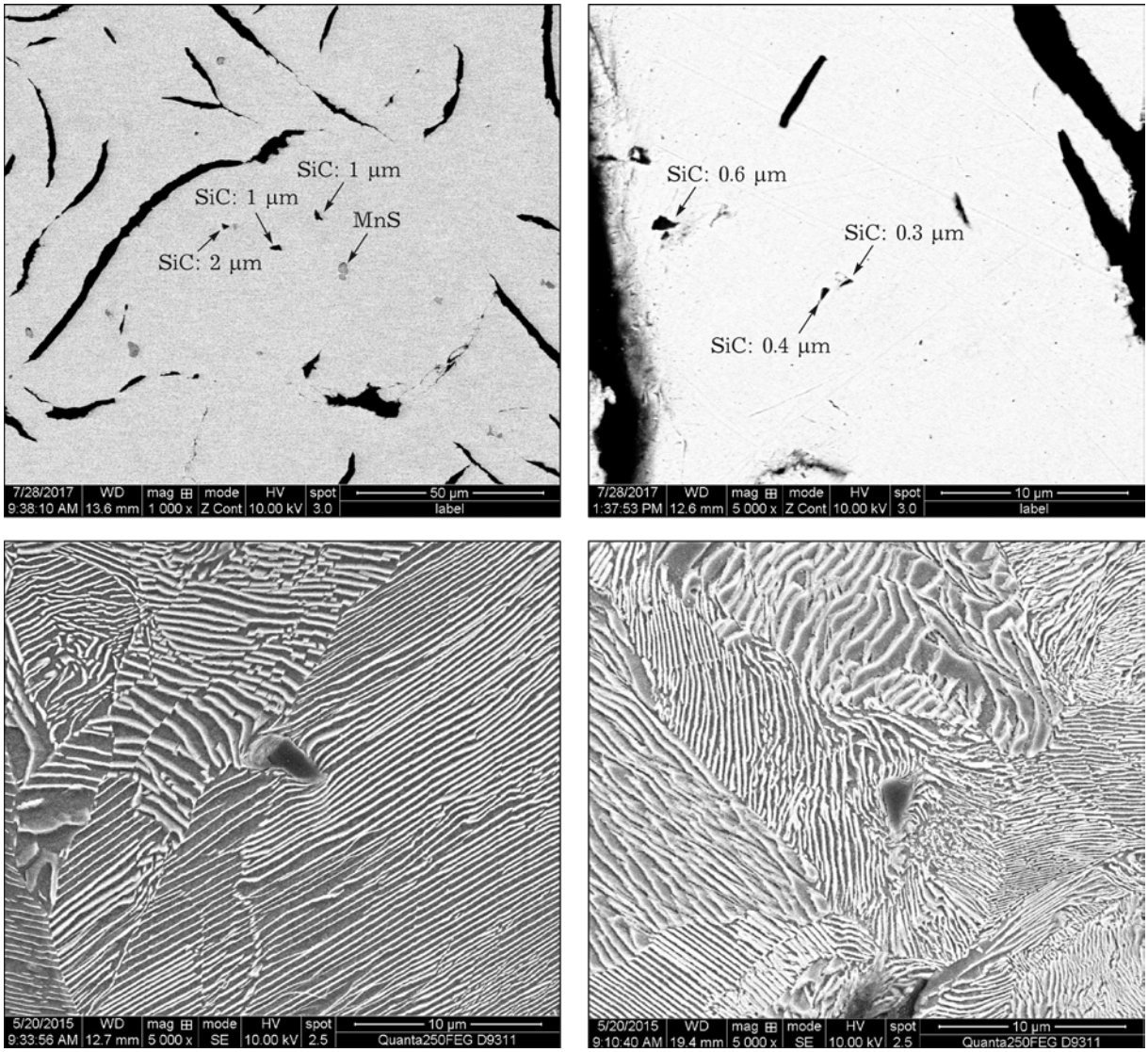

Fig. 9. Distribution and size of SiCp.

SiC in the standard state does not decompose at the melting temperature of cast iron, but in molten iron, carbon and silicon dissolve.

$$[Si] + [C] = SiC_{(S)} \quad (1)$$

$$\Delta G^0 = 3887 + 92.4T \quad (2)$$

SiC could be decomposed into Si and C in molten iron because $\Delta G^0 >> 0$. The reaction was unable to move to the right spontaneously, indicating that the SiC particles observed in Figs. 8, 9 were an external entry rather than an internal reaction formation. In addition, SiC was unstable in molten iron, especially after modification, and in a high energy state, as shown in Fig. 2, which made the reaction easy.

$$SiC + Fe = FeSi + C \quad (3)$$

$$\Delta G^0 = 9900 - 9.14T \quad (4)$$

When $T > 1083$ K, the reaction could occur spontaneously to the right and took place in molten iron at the melting temperature of molten iron [9]. The size of SiC particles decreased gradually because of reactions (1) and (3) in molten iron. The mismatch between SiC and graphite was calculated to be 8.1 %. As shown in Table 3, SiC could nucleate graphite. Some

TABLE 2

Size distribution of SiCp in SEM

SiC size range (μm)	<1	1–2	3–5	>5
Quantity	10	25	13	0
Proportion (%)	20.83	52.08	27.08	0

TABLE 3

Relationship between lattice matching mismatch and nucleation capability [10]

Mismatch degree (δ, %)	<6	6–12	>12
Nuclear capacity	Strongest nuclear capacity	Physical nuclear capability	Weak nuclear capacity

references [10, 11] show that the size of heterostructure is less than 5 μm (generally 0.4–2 μm), which can promote the precipitation of graphite. As shown in Fig. 9 and Table 2, the size of SiC particles after the reactionconformed to the conditions. The distribution of SiCp dispersion, which pinned the grain boundary, is depicted in Fig. 9. The C produced by reaction (3) made the C element in molten iron unevenly distributed. The local C element was too high, the "carbon peak" appeared in the microzone, and the precipitated graphite was non-equilibrium graphite [12], which is the best nuclei of graphite precipitation. These reasons show that the number of eutectic clusters increased, the grain was refined, and improved effects were achieved with the increase in the amount of modified SiCp (see Table 3).

CONCLUSIONS

The distribution and mechanism of modified SiCp in HT250 were studied in this work. The following conclusions were obtained.

1. The addition of modified SiCp refined the grains of HT250 and increased the tensile strength. The effects mproved with the increase in the addition amount. When the amount of added SiCp was 0.20 mass %, the tensile strength increased by 18.28 mass %.

2. The tensile properties of gray cast iron strengthened by modified SiCp were in accordance with the Hall–Petch formula. It belonged to fine grain strengthening.

3. The mismatch degree of SiC and graphite was 8.1 %, indicating the tangible nuclear capability of SiC. SiC decreased in size after the reaction in cast iron solution, which satisfied the size requirement of the graphite heteromorphic crystal nucleus. Moreover, SiC diffusion distribution, as a binding particle that impedes grain boundary movement, refined the grain.

4. The reaction of SiC in molten iron produced nonequilibrium graphite as the nucleation nuclei of graphite during solidification, particularly when the modified SiC was in a high energy state.

REFERENCES

1 Poluboyarov V. A., Korotaeva Z. A., Zhdanok A. A., Kuznetzov V. A. // Eng.&Technol. 2016. Vol. 9. P. 117.
2 Chen Mei-ling, Li Jianwei, Gao Hong // Mater. Introduction. 2006. Vol. 20. P. 214.
3 Gao Hong, Li Jianwei, Chen Meiling *et al.* // Lubrication and Seal. 2007. No. 4. P. 47.
4 Li Jian-wei, Chen Mei-ling, Gao Hong //Foundry. 2007. No. 1. P. 68.
5 Li Jianwei, Chen Meiling, Gao Hong // Mechanical Eng. Mater. 2006. Vol. 30, No. 12. P. 56.
6 Chen Meiling, Kang Lei, Yang Jun *et al.* // Foundry. 2008. Vol. 4. P. 330.
7 Kang Lei. Dalian Jiaotong University. Dalian, 2008.
8 Liu Yuandong. Dalian Jiaotong University. Dalian, 2008.
9 Li Xiaolin. Shenyang University, 2009.
10 Zhou Jiyang. Colour Metallography of Cast Iron. Beijing: Mechanical Industry Press, 2007.
11 Li Chuanshi // Modern Cast Iron. 2015. P. 74.
12 Zhang Wenhe, Ding Jun, Nie Fulong // Modern Cast Iron. 2009. Vol. 58. P. 279.