Texturing Parameters and Characteristics of Multi-head CO_2 Laser Surface Texturing

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Abstract

Cold-rolled steel sheets with specially designed surface topographies are widely in applications in car and fabrication industry. Laser texturing is a novel technique used to texture the cold roller surface to produce high quality steel sheets with good formability and image clarity. Principle of multi-head CO_2 laser surface texturing technique using polygon scanner for beam modulation is introduced. Texturing parameters and their influence are investigated. The obtained craters are of volcano shape with diameter of 120~230μm, depth of 7~21μm and bump height of 5~17μm. The surface average roughness Ra is in the range of 1.03~5.86μm. The textured surface is abrasive resistant and prolongs the roller service life.

Keywords: CO_2 laser texturing, Texturing parameters, Roughness, Mill roller

1. Introduction

With an aim to increase the texturing efficiency to meet the industrial needs and improve the quality of roller surface texturing, Laser texturing is proposed to texture the cold roller surface to produce high quality steel sheets with good formability and image clarity. In recent years, the surface texture of steel sheets with defined topographies plays an important role for automotive applications. Laser texturing is an emerging texturing technique, using high repetition rate and high energy pulses to rapidly melt a small area of surface (Minamida, 1990, pp.30-34; Du, 2005, pp.456-461; Wan, 2008, pp.3251-3256). and produce deterministic craters on the surface of mill roller (Steinhofl, 1996, pp.355-361). The crater profile is repeatable and can be controlled by the processing parameters. The obtained craters act as micro reservoirs for lubricants and traps for wear debris, enhancing formability and significantly improve the visual characteristics of the finished product (Izhak, 2005, pp.248-253; Liu, 2009, pp. 805-810).

Traditionally, laser texturing of mill roller is using a rotating chopper for beam modulation and the output pulse rate is 10 kHz (Wan, 2008, pp.309-314). Texturing a roller with length of 1800mm and radius of 300mm will cost 132 minutes. In order to meet the industrial requirements and improve the surface quality of a textured roller by CO_2 laser processing, a novel CO_2 laser texturing system using polygon scanner for beam modulating is proposed (Zhou, 2009, pp.607-610). The output pulse frequency of each texturing head can be up to 30 kHz. With several heads texturing simultaneously, its efficiency can be compared to EDT (Electrical Discharge Texturing) (Simão, 1994, pp.207-214) without having roughness fluctuation and decreasing image clarity when textured in low Ra (average roughness) value (Scheers, 1998, pp.647-656).

To achieve more appropriate surface topographies, microstructure and mechanical properties, experiments and analysis on the area of multi-head laser textured surface are conducted. In this study, the heat transfer characteristics and the fluid motion induced by convection in the crater melting pool are discussed. Experiments are conducted to examine the texturing parameters and their influence on textured surface. The relationship between the elliptical ratio and off-focus distance is investigated. Roughness and microscopy tests are conducted to examine the textured surface. This work will be of practical significance to the promotion of multi-head CO_2 laser surface texturing technique.

2. Experimental method and procedure

Fig. 1(a) illustrates a sketch of the principle of using a polygon scanner for beam modulation. A continuous laser beam is reflected into a face of a rotating polygon scanner and then reflected and spread into different spatial directions by scanning of polygon scanner. When delivered to the texturing heads, each head sequentially receives only a certain amount of the continuous beam and pulse beam outputs are obtained afterwards. As a result of symmetrical design, each amount of energy received by a texturing head can be exactly the same and hence high repetition rate pulses with identical energy are generated. As the design is symmetrical, only one of the texturing heads is selected to analyze the texturing parameters and the experimental setup is illustrated in Fig.1(b). The roller material is 5Cr15MoV and its chemical composition is in Table 1. The untextured roller surface roughness was 0.8μm and no surface coating treatment is done with the roller beforehand to increase the absorbance. A continuous CO_2 laser beam with average power up to 3000W is used and the output beam mode is TEM_{01} mode. The beam diameter of TEM_{01} mode output is 18mm and full beam divergence angle is 0.75mrad. The revolving speed of mill roller is 50rpm, and the corresponding rotating speed of polygon scanner driven by an electric motor is 8000rpm, producing output pulse rep-rate of 10 kHz. Negative off-focus laser radiation is used and the off focus distance is 0.29mm. The diameter of focal spot is 0.15mm and the focal spot energy density is up to 8.5×10^6 W/mm^2. An argon gas of 12L/min at angle of 45° is used to blow the melting liquid out of center of the textured crater to form boundary rims.

An optical microscopy (M-400-H1) is used to observe the textured specimen and a surface roughness tester (Mitutoyo SJ-301) is used to test the uniformity of surface roughness along the roller surface.

3. Results and discussion

3.1 Evaluation of the textured surface and its roughness.

Fig. 2 illustrates obtained textured craters with different spot density. Approximately round craters can be obtained and they are distributed evenly in a helical pattern on the mill roll surface. Fig. 3 shows the profile of the textured craters. The obtained craters are of volcano shape with diameter of 120~230μm, depth of 7~21μm and bump height of 5~17μm, respectively. Higher power density generates deeper crater because of surface evaporation and evaporation recoil pressure.

The surface roughness is mainly determined by laser texturing laser power. Fig. 4 illustrates the relationship of surface average roughness and laser power output and the obtained surface roughness is in the range of 1.03~5.86μm. A polynomial is used to fit experimental results. It is clear that the fitting plot suggests a laser threshold power of 1000W where the injection of laser pulse energy is compensated by the heat conduction and reflection. The roughness fluctuation along the roller length is illustrated in Fig. 5. For each measurement, 5 different places in one circle of the roller surface are tested to determine the average Ra along the roller. Tests are taken every 400mm along the roller surface and the average Ra is 2.32μm, with Ra fluctuation of 0.5um as a result of deterministic surface topography. The uniformity is within the tolerance of practical applications.

3.2 Analysis of approximately round craters.

Typically, craters obtained by laser texturing using traditional chopper modulation are elliptical, whose spot density can be only 4-9 spot/mm^2 (Zhu, 2000, pp.68-70). The obtained textured crater (in Fig. 2) are approximately round as a result of synchronization between focal spot displacement induced by beam scanning and movement of roller surface which is shown in Fig. 1(b). The roller is revolving with a circumferential velocity V_2. During one pulse duration, the roller surface moves from position a to position b while the corresponding pulse beam is moving from a' to b' on the focusing mirror M_3 with speed V_1 as the scanning beam is not fixed on M_3. By selection of a proper off-focus distance l_2, every single pulse beam will interact with the same surface area during its processing duration. The influence of off-focus distance l_2 on elliptical ratio (the ratio between long axis and short axis of ellipse) of a textured crater is illustrated in Fig. 6. A small impact zone and approximately round textured craters could be obtained when off-focus distance is set to 0.29mm.

3.3 Microscopy test results of textured surface.

Fig.7 shows the microstructure of the textured crater. Fig. 7 (a) shows a top view of a textured crater in 400× magnification. The microstructure in the molten pool is mainly cellular and dendritic. Fig. 7 (b) shows a sectional view of the molten organization in the center of crater in 640× magnification. The temperature of the center radiated directly by the laser is relatively high while cooling rate is relatively low, while the middle region of laser melting zone is sited in the molten pool center with its temperature gradient and cooling rate between that of the pool surface and the bottom. The convection is obvious and the fine microstructure is obtained. Fig. 7 (c) shows the organization of the substrate in 640× magnification. The crystal becomes larger and changes from cellular to particle. For the heat affect zone of substrate, austenite will convert to martensite gradually during the cooling period and the microstructure mainly consists of residual austenite and martensite whose content will be increased with the increasing laser power. Hence the obtained textured surface has a higher hardness than the untreated surface and is more abrasive resistant. The bump hardness can reach up to HV900 and significantly prolong the roller service time.

4. Conclusions

In this paper, heat transfer and convection process are simulated and their characteristics are discussed. The fluid motion in the melting pool of craters is mainly induced by Marangoni force and the convection current speed varies from 0.03 to 1m/s. The obtained craters are of volcano shape with diameter of 120~230μm, depth of 7~21μm and bump height of 5~17μm. Approximately round textured craters can be obtained when the off-focus distance is set to be 0.29mm and the elliptical ratio could be controlled by adjust of off-focus distance. Roller surface Ra could be textured into the range of 1.03~5.86μm and its surface roughness is uniform along the roller length. The hardness of textured surface is about HV900 and abrasive resistant, which prolongs the roller service life.

References

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Table 1. Chemical composition [wt. %] of 5Cr15MoV

C	Si	Mn	P	S	Cr	Mo	V
0.45-0.55	1.00	1.00	0.045	0.015	12.00-15.00	0.5-0.8	0.1-0.2

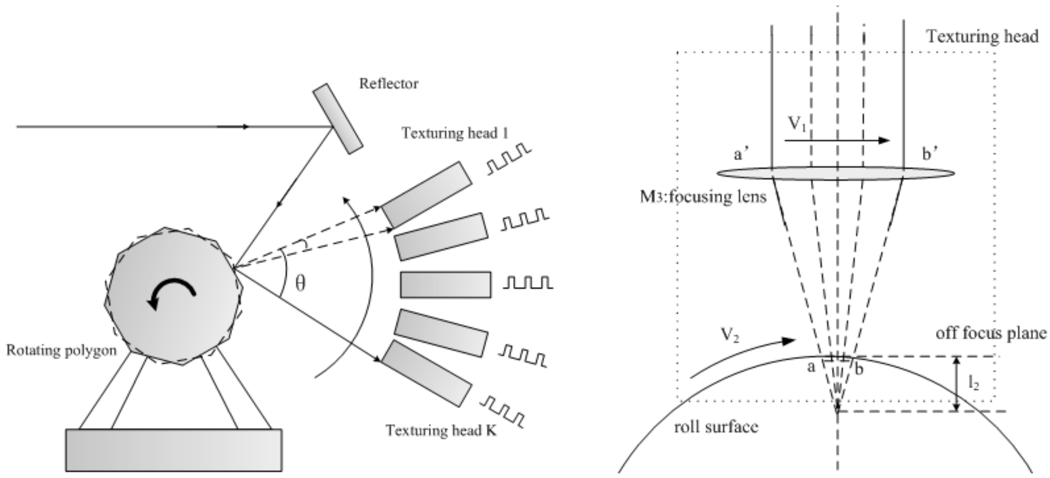
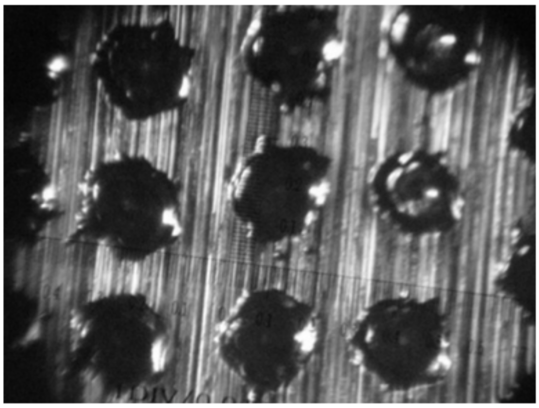
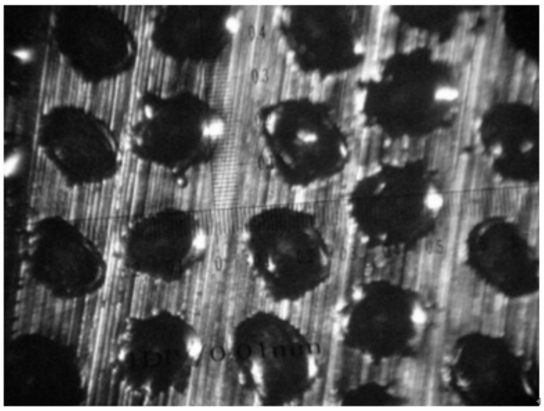


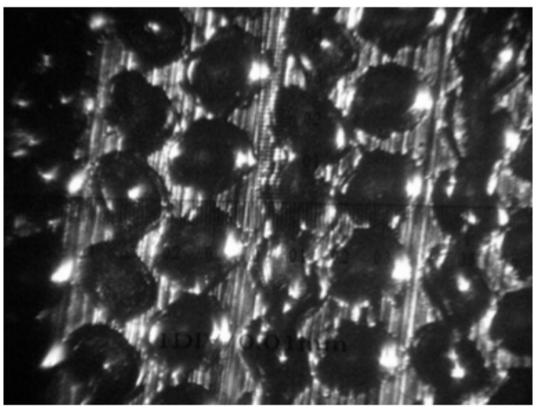
Figure 1. (a) Sketch of principle of beam modulation and (b) schematic diagram of one of the laser texturing heads



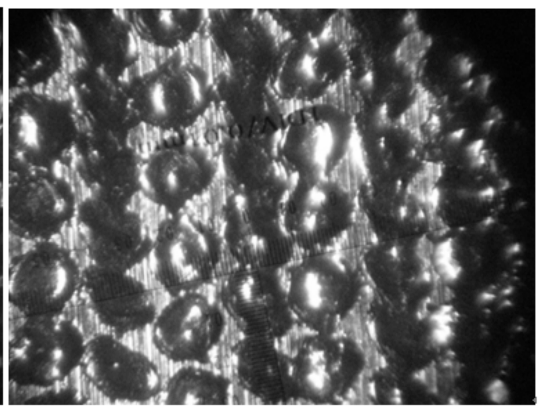
(a) 3×3 spot/mm^2



(b) 4×4 spot/mm^2



(c) 5×5 spot/mm^2



(d) 6×6 spot/mm^2

Figure 2. Textured craters with different spot density

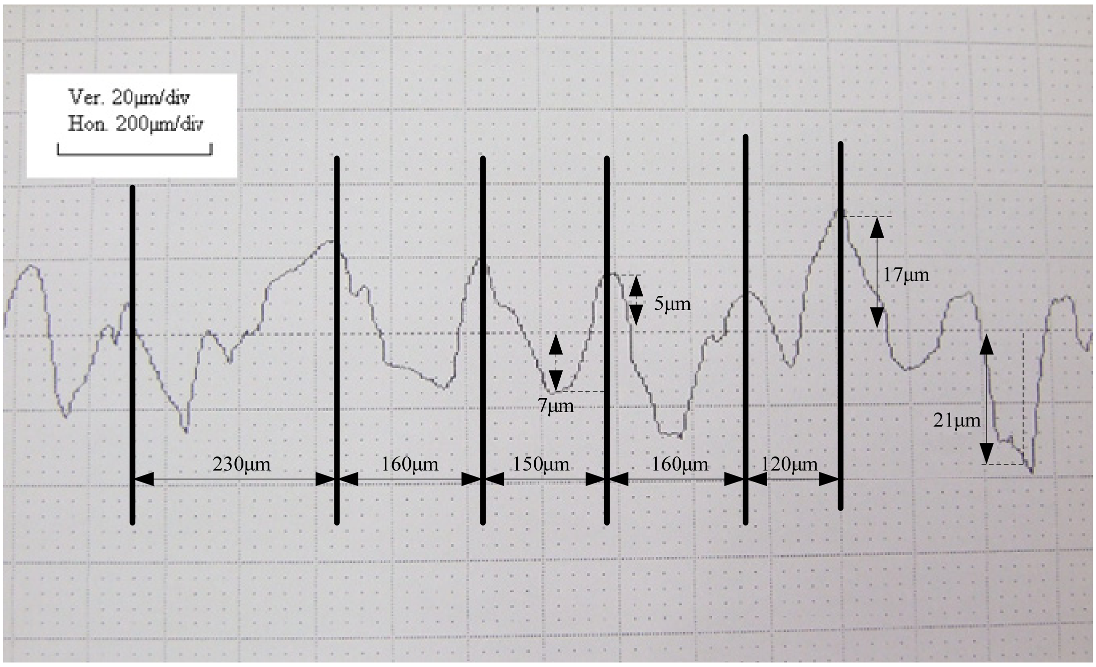


Figure 3. Profile curve of the textured surface

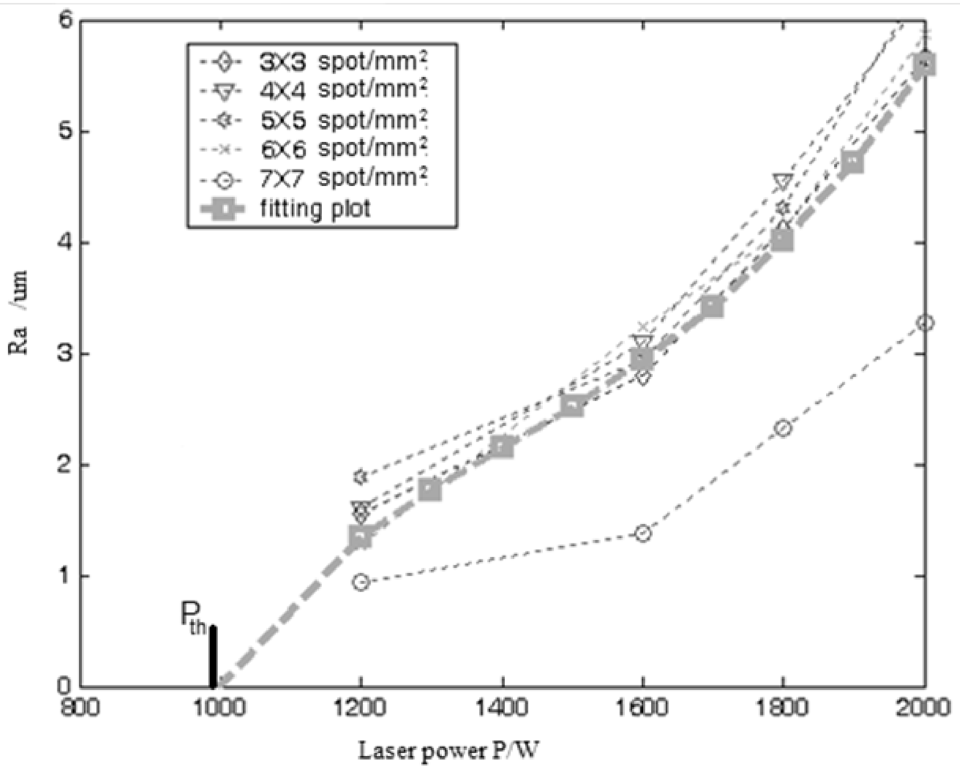


Figure 4. Roughness graph of textured surface at different spot density

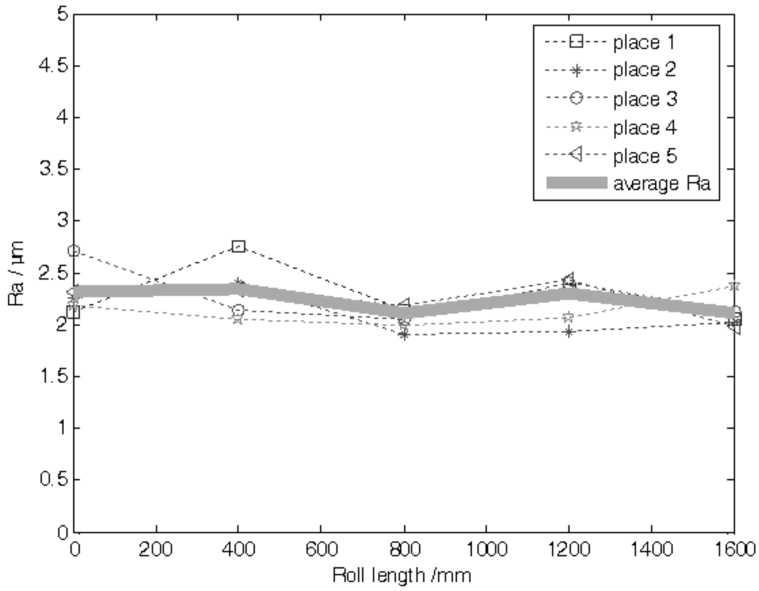


Figure 5. Ra changes along the roller surface

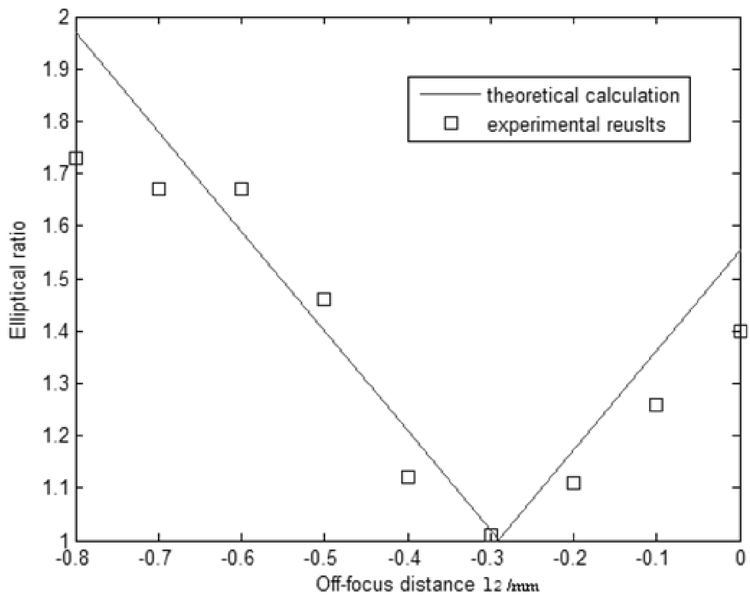


Figure 6. Elliptical ratio changes versus off-focus distance l_2

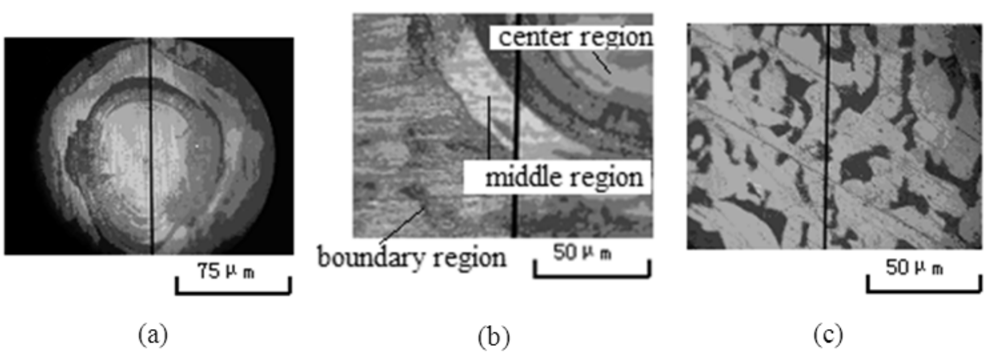


Figure 7. Microscopic photograph of a textured crater sample: (a) a textured crater; (b) molten organization in the center of crater; (c) substrate organization.