INTRODUCTION
This study deals with the influence of laser heat treatment for carbon steel AISI 1045 on chip controllability in turning. In turning at automated machining line, fine chip controllability is required. Irregular continuous chip gets caught in chuck and work material and causes damage of not only finished surface but also cutting tool and machine tool. To avoid these troubles, there are some methods such as adapting steels containing such as MnS and Pb[1], which has brittle as a work material and breaking chip by a breaker piece so on.

In this case, some problems still remain in degradation of mechanical strength and/or corrosion resistance of materials, deterioration of environment and such additives are often expensive. There have been ideas by surface treatment using electrical discharge and laser beam, but these ideas have no practical use. In this study, turning test was conducted for the purpose to clarify influence of heat treatment by laser beam scanning for work material surface on chip controllability. Turning of heat treated carbon steel by a diode laser with carbide and ceramics insert is conducted in CNC lathe and the influence of heat treatment for work material on chip form is investigated experimentally.

EXPERIMENTAL PROCEDURE
The work materials used in this study is a carbon steel AISI 1045 which is widely used in machine components and has good thermal processability. The work material is normalized after hot forging in such a way that it is heated to 850°C for 5 hours and allowed to cool freely in air to room temperature.

The conditions of laser heat treatment are shown in TABLE 1. The direct diode CW-laser (808 nm wavelength) is irradiated on the work surface having the rectangular spot of 2.5 x 0.1 mm. The average laser power and laser scan rate are 120 W and 126 mm/min, respectively. The optical absorbance of carbon steel at 808 nm is approximately 40%.

A diode laser is irradiated linearly in the longitudinal direction on the cylindrical work material surface as shown in FIGURE 1(a), so that the in-situ selective laser heat treatment is carried out. Then the turning test is executed with the CNC lathe as shown in FIGURE 1 (b).

The cutting conditions are summarized in TABLE 2. The tools used in this experiment are cemented carbide P30 and ceramics insert.
FIGURE 2 shows the appearance of the cutting tool and breaker piece. These tools have the same shape as ISO SNMN120408. The breaker piece is ISO CBS-4M. A carbide breaker-piece is fixed to an accurate position on the indexable insert for clamp type holder as shown in the figure. The thickness and wedge angle of the breaker-piece are 2.5 mm and 45°, respectively.

The cutting speed is changed from 100 to 250 m/min and feed rate is changed from 0.10 to 0.20 mm/rev. Only the depth of cut is kept constant 0.4 mm.

TABLE 1. Experimental conditions in laser heat treatment process

<table>
<thead>
<tr>
<th>Semiconductor Laser (CW)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave length : $\lambda$</td>
<td>808 nm</td>
</tr>
<tr>
<td>Average power : Q</td>
<td>120 W</td>
</tr>
<tr>
<td>Scan rate :</td>
<td>126 mm/min</td>
</tr>
<tr>
<td>Spot size :</td>
<td>0.1 mm $\times$ 2.5mm</td>
</tr>
</tbody>
</table>

Table 2. Cutting conditions

| Work : AISI1045 (normalized) $\varphi$70mm (~60mm) |
| Tool : Carbide tool P30, TiC-Al$_2$O$_3$ ceramics insert (SNMN120408) |
| Tool holder : CSMNR2020 (Mitsubishi material) |
| Cutting speed : $v$         | 100~250 m/min |
| Depth of cut : $d$          | 0.4 mm |
| Feed rate : $f$             | 0.1-0.2 mm/rev |
| Coolant : dry               |  |

FIGURE 3 shows the cross section of AISI 1045 after linear laser heat treatment. The specimen is etched by a 3% Nital solution for 5 seconds at room temperature. As is obvious in the figure, a clear semicircle heat affected layer is observed, where the martensitic structure is formed in the ferrite-pearlite mother phase. The maximum hardness in this hardened layer is approximately 600HV.

The influence of laser power and scanning rate on the depth and width of heat affected zone are shown in Fig.3. The output laser power is 120 W and the laser scanning rate is 126 mm/min, the width of heat affected zone $W$ is considerably larger than the laser spot width (0.1 mm). The heat affected area is approximately 0.5 mm width and 0.2 mm depth.

FIGURE 4 shows the chip form generated in turning laser heat treated and non-laser heat treated carbon steel AISI 1045 with the carbide P30 insert. In the case of non-laser heat treated carbon steel, the chip breakability is poor at the higher cutting speed and lower feed rate [2]. On the other hand, in the case of laser heat treated carbon steel, the chip is broken at any cutting condition.

FIGURE 5 shows the chip form generated in turning laser heat treated and non-laser heat treated carbon steel with the ceramic insert. Same as the case of turning non-laser heat treatment, the chip is broken at any cutting condition.
Work material; AISI 1045, V=100-250m/min, d=0.4mm, f=0.1-0.2mm/rev

*FIGURE 4.* Chip form generated in turning laser heat treated and non-laser heat treated carbon steel with the carbide P30 insert.

Work material; AISI 1045, V=100-250m/min, d=0.4mm, f=0.1-0.2mm/rev

*FIGURE 5.* Chip form generated in turning laser heat treated and non-laser heat treated carbon steel with the ceramic insert.

treated carbon steel with carbide P30 insert, the chip breakability is poor at the higher cutting speed and lower feed rate. In the case of laser heat treated carbon steel, the chip breakability is better than that in turning non-heat treated carbon steel with ceramic insert, but poorer than that in turning laser heat treated carbon steel with carbide P30 insert.

*FIGURE 6* shows the cross section of chip generated in turning heat treated carbon steel AISI 1045 with the carbide P30 insert. In the
typical continuous chip structure, the deformed heat affected zone is observed. In turning, the bending moment is induced in the chip by chip flow and weight itself. Thus the local fracture occurs due to the higher brittleness and lower fracture strength of heat affected zone and the chip is broken easily.

FIGURE 7 shows the influence of cutting temperature on chip thickness. The cutting temperature is increasing with increase of cutting speed. The measured chip thickness is decreasing with increase of cutting temperature. As for chip thickness, the thinner chip is difficult to be broken. In turning with ceramics insert, the thickness is thinner than that in turning with carbide insert at the same cutting temperature. This indicates that the affinity of ceramics insert for carbon steel is lower than that of carbide insert. Then, the chip in turning with ceramics insert is more difficult to be broken than that in turning with carbide insert.

Consequently, the surface modification by selective laser heat treatment is one of the most effective methods in chip control in turning of carbon steel.

CONCLUSIONS

In this study, for the purpose of chip control in turning, a direct diode laser is irradiated linearly in the longitudinal direction on the cylindrical work material surface. The influences of laser irradiation on the chip geometry. The main results obtained are as follows.

[1] A direct diode laser (DDL) is available for as an in-situ heat treatment device in turning of carbon steel. By selective laser irradiation, a clear semicircle heat affected layer having the hardness 600HV is formed, where the martensitic structure is observed in the ferrite-pearlite mother phase.

[2] The continuous chip is broken in the heat affected zone during cutting due to higher brittleness so that broken chips have spiral form and their length are approximately equal to those generated by less than 10 revolution cutting.

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