TREATMENT OF ULTRA FINE-GRAINED STEELS USING THE STRAD METHOD

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Abstract

The purpose of this process is to achieve grain refinement through shearing transformation and plastic deformation after recrystallization resulting in ultra-fine-grained (UFG) steels which feature higher tensile strength combined with good formability. The structure is composed of tempered martensite, ferritical grain with size of several micrometres, or hundreds of nanometres and ultra-fine-grained cementite. The STRAD method can easily be used as continuous process in production.

Keywords: ultra fine-grained steel, shearing transformation, recrystallization

1. INTRODUCTION

Deformation refinement, nucleation and growth of grains during heat treatment are the essential steps in the STRAD technology. The process is shaped particularly by chemical composition, optimum temperatures and heat treatment duration depending on grain size and growth rate linked to the deformation level. The technology is fit for steels which have undergone peritectic reaction.

To ensure an effective processing all the above mentioned process parameters must be harmonized taking into account their interactions.

To accomplish a successful process the following three issues must be handled:

- diffusion-free shearing transformation,
- plastic deformation,
- recrystallization.

2. DIFFUSION-FREE SHEARING TRANSFORMATION

The transformation depends particularly on: austenitization temperature/time and cooling rate/method.

2.1 Austenitization temperature and time

The standard general rules must be applied so that the grain size growth is minimized during heating.

2.2 Cooling rate and method

In this case the procedure is more difficult. Because typically steels with carbon content below 0.2 % are processed the Ms temperature is about 500 °C – see Fig. 1 [1]. For that reason acicular tempered martensite is always formed. If the initial structures of the STRAD process are to be modified the hardening condition must be studied.
3. PLASTIC DEFORMATION

If applying the STRAD method the following must be handled:
- deformation level before shearing transformation,
- deformation level before recrystallization.

3.1 Deformation level before shearing transformation

This deformation affects particularly the grain size after transformation and values of parameters influencing the transformation including initial conditions for the following processes. The basic criterion is the position in plastic deformation process in terms of whether the texture in the formed material is generated or not with respect to the grain size.

3.2 Deformation level before recrystallization

In this case the maximum plastic deformation and forming method to which the tempered material can be subjected and what will be the impact on the basic recrystallization parameters must be known. The initial approximation and determination of general rules can be based on Fig. 2 [2] although this diagram provides information only for grain size over 10 μm and recrystallization temperature over 500 °C. The above indicates for grain size below 10 μm the classic recrystallization technology cannot be applied and about 500 °C recrystallization temperature should be selected at optimum heating time.

4. RECRYSTALLIZATION

Recrystallization is the key process of the STRAD method. It must be controlled so that its duration is as short as possible. The following dependencies must be known to be able to accomplish successful recrystallization:
4.1 Dependence of recrystallization temperature on carbon content

The mathematical relation between recrystallization temperature and carbon content of steel can be determined using Fig. 3 [3]. If line \( Ac_{cm} \) is extended it intersects the temperature axis at 406 °C for pure iron. Since the line extension is located below \( Ac_1 \) it represents 100 % probability of ferrite nucleation. The line therefore determines the initial depending on carbon content. Because the line intersects also the point of 731 °C temperature at 0.8 % carbon content the mathematical expression is as follows:

\[
TR = 406.25 \times \% C + 406,
\]

where \( TR \) – initial recrystallization temperature and

\[\% C\] – carbon content in mass %.

For carbon content higher than 0.2 % the curve replacement by line can be considered but for low-carbon steel the calculated values correspond to actual recrystallization temperatures. In production practice the recrystallization is not used to restore the material formability after cold forming of steel with carbon content higher than 0.25 % when patenting is applied.

4.2 Dependence of recrystallization time on temperature

For the ultra-fine-grained structure the recrystallization start time is important. It can be determined from Fig. 4 [4] provided the dependence of recrystallization start time at different annealing temperatures for pure iron is similar to that for steel with up to 0.2 % carbon content. The extension of line 1 intersects axis \( \ln t \) at 0 value, i.e. \( \ln t = 0 \) for \( T = 1,000 \) °K; the dependence can be described by general equation of line \( \ln t \), where \( K \) – gradient of line, \( \ln t \) – natural logarithm of recrystallization start time, \( T \) – temperature [°K]. If introducing the values from the diagram the following is the result:

\[
\ln t = 2.7 \times \frac{10^4}{T} - 27
\]
4.3 Dependence of recrystallization temperature on deformation level

It is generally known that the higher the forming rate the higher the number of areas fit for the inception of nuclei which means a higher number of nuclei and finer crystals are found after recrystallization. However, the final post-recrystallization grain size depends predominantly on grain size of the original structure (the finer the better) and forming method. At the same tensile or pressure forming the recrystallized structure after pressure forming is coarser than after tensile forming. The basic dependence of recrystallization temperature on deformation rate for iron is shown on Fig. 5 [1] which indicates that the more intense metal forming the higher increase of the internal energy of the metal and the lower the temperature at which the recrystallization starts. The figure also indicates the effect of a deformation exceeding 70 % on the recrystallization temperature is negligible. The recrystallization temperature depending on deformation level can be calculated using the following empirical formula:

\[ T_R = \frac{731}{\mu^{0.151}} \]

where: \( T_R \) – recrystallization temperature and cross sectional deformation (area reduction).
The wire was drawn using four dies to 12.5 mm diameter with 60.9 % total reduction. The wire sample was then hardened in water with 870 °C temperature and again drawn using four dies to remove scales to 7.8 mm diameter with 61 % total reduction. After that the sample was subjected to recrystallization annealing at 530 °C temperature in laboratory furnace for 12 minutes. The descaled sample was again drawn using four dies to 5.5 mm diameter with 50.3 % total reduction. The sample processed this way using the STRAD method was subjected to tensile tests and metallographic examinations. The tensile test results are provided in Table 2.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>( R_{p0.2} ) (MPa)</th>
<th>( R_m ) (MPa)</th>
<th>A (%)</th>
<th>Z (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>903</td>
<td>907</td>
<td>10,4</td>
<td>59,4</td>
</tr>
<tr>
<td>2</td>
<td>879</td>
<td>934</td>
<td>14,4</td>
<td>67,9</td>
</tr>
<tr>
<td>3</td>
<td>777</td>
<td>889</td>
<td>13,6</td>
<td>64,0</td>
</tr>
<tr>
<td>4</td>
<td>856</td>
<td>904</td>
<td>10,4</td>
<td>59,7</td>
</tr>
</tbody>
</table>

The metallographic examination showed the grain size as illustrated by see Fig. 6 indicating the value of 790 nm was achieved.

**Fig. 6** 5.5 mm diameter – 0.00079 mm

6. CONCLUSIONS

The experimental verification of the STRAD process showed the described method can be applied to improve the qualitative properties of steel and can be classified as an SPD method. The specified mechanical properties prove the wire with 0.085 % carbon content processed this way corresponds to patented wire with 0.42 % carbon content. The described method can be further developed using induction heating significantly reducing the heat treatment times which will enable additional improvement of qualitative properties of steel and make it possible to perform the processing as continuous process. If magnetic and electrical field is used in the processing then the STRAD method forms a basis for development of research of steel with hyperstructure, so-called structured carbon steel and enables theoretical research of graphen steel where cementite is replaced by graphen. This method opens new possibilities in the field of business economics. Significantly reduces the manufacturing cost of the product and may significantly increase the firm's competitiveness on the world market.
REFERENCES


