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Process Redesign to Improve Metal Fracture in Blanking Operation of Fe410 Low Carbon Steel

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Abstract:
Blanking is a metal fabricating process, during which a metal workpiece is removed from the primary metal strip or sheet when it is punched. The removed workpiece is called blank. The blanking process forces a metal punch into a die that shears the part from the primary metal strip or sheet. A die cut edge normally has four attributes – burnish, burr, fracture & rollover. Metal fracture is formed due to non-uniform grain flow and grain size in the Hot Rolled Structural Steel. Increased variation in micro-hardness also causes metal fracture during shaving process. To improve the surface smoothness there are many types of manufacturing process used in day to day life like use of progressive tooling, laser cutting, wire cutting, machining of surface etc. But these process are only suitable where cost is not a major factor for the part produced. If the required volume is very high then progressive tooling is beneficial, for intermediate volume where cost plays an important role in we will go with conventional tooling (i.e. Simple Punch and Die Method). In this project the metal part is heated above the recrystallization temperature and annealed to study and improve the surface smoothness of sheared part.

***Key Word**:Blanking, Metal Fracture, Annealing*

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I. Introduction

Fe410 Structural Steel Plate is used in seawater application, chemical process, gas process, marine application because of its resistive property. Hot rolled steel are used for medium and high tensile structural purposes. This Fe410 structural steel is blanked to required shape and profile by means of blanking process. Tool to die clearance plays a major role in surface smoothness of sheared surface alongside material property. In continuous process industries this clearance is maintained at 8% of steel plate thickness. By reducing this clearance the metal fracture will be reduced whereas tool wear rate will increase proportionally. So frequent regrinding of tool required which will interrupt the continuous process, increased process time and cost.

1.1 Heat Treatment Process:

Heat treatment is the process of metals being controlled by heating and cooling to change the physical and mechanical behavior of metals. Often it is used to increase a material's strength, ductility, and formability. Also, it can be used to improve the machining of metal that can be used in the machines. The success heat treatment process involves three basic steps: heating, soaking, and cooling. Figure 1.1 shows the steps of heat treatment.

Stage-1: Heating the metal slowly to ensure a uniform temperature.
Stage-2: Soaking the metal at a given temperature.
Stage-3: Cooling the metal to room temperature.

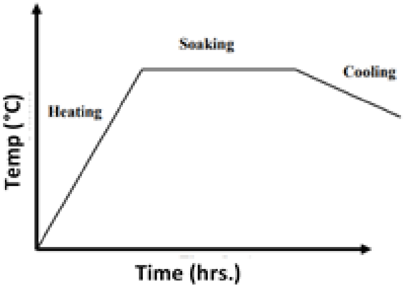


Fig. 1.1 Heat Treatment process

1.2 Literature Survey:

There are several articles in the literature dealing with carbon steel heat treatment, including those listed below:

Dahiwade et al, (2014) studied the effect of hardness of steel by Annealing and Normalizing during hot Rolling Processes. Annealing primarily is the process of heating a metal which is in a metastable or distortion structural state, to a temperature which will remove the instability or distortion and then cooling it (usually at a slow rate) to the room temperature structure which was stable and strain free. Normalizing or air quenching consists in heating steel to about 40-500ºC above its upper critical temperature and if necessary, holding it at that temperature for a short time and then cooling in still air at room temperature. The hardness of steel sample after normalizing is higher than found in annealing because the cooling rate is faster in normalizing and not in annealing. Also the microstructure of normalized sample of steel contains finer grain.

Morris, (2001) investigated the influence of grain size on the mechanical properties of steel. Many of the important mechanical properties of steel, including yield strength and hardness, the ductile-brittle transition temperature and susceptibility to environmental embrittlement can be improved by refining the grain size. The improvement can often be quantified in a constitutive relation that was an appropriate variant on the familiar Hall-Petch relation: the quantitative improvement in properties varies with d-1/2, where d is the grain size. Nonetheless, there was considerable uncertainty regarding the detailed mechanism of the grain size effect, and appropriate definition of "grain size". Each particular mechanism of strengthening and fracture suggests its own appropriate definition of the "effective grain size" as compared with annealed steel structure.

Akinlabi et al, (2013) experimented on the microstructural development during Mechanical Forming of Steel Sheets. Metal forming was used synonymously with deformation, a process during which an object gets changed due to the applied force. These changes can either be reversible or irreversible depending on the type of material; size and geometry of the object and the magnitude of the applied force to the object. The microstructural evaluations showed that the applied loads employed caused an increase in the magnitude of the grain sizes in each loaded specimen. Furthermore, the increase in the grain size of the microstructure was observed to be directly proportional to the loads applied. In addition, the micro hardness values of the cross sections investigated were found to increase with the applied loads. Hence, the grain size growth and the hardness were linearly dependent on the applied loads, and this implies that there was a correlation between the applied loads and the resulting microstructure of the material and the hardness of the material.

Vinod Kumar et al, (2012) Optimized Hot Rolling and Annealing Process of Low Ni Stainless Steel Using Simulation Studies. Processing of low Ni Stainless Steel poses a serious problem during rolling both in roughing and finishing stands owing to high load. This is primarily attributed to high work hardening rate due to low Ni and high Mn in such steels. An increase in temperature to bring down the rolling load deteriorates the surface quality. In addition to this, high hardness in the cold rolled and annealed product possess problem during further forming operation. To overcome these problems, simulation studies were carried out using Gleeble Thermo-mechanical Simulator

a) To determine flow stress under different hot rolling conditions
b) To simulate continuous strip annealing process to optimize annealing parameters to bring down the hardness.

It was observed that the flow stress increases gradually with a decrease in temperature till 1050ºC and thereafter, at a significantly high rate. It was further observed that continuous dynamic recovery occurred at 1050–1150℃ which gradually diminished and resulted in work hardening at lower temperatures. In view of this, rolling schedule was modified which led to smooth rolling without any over-load problem. It was also found based on simulation studies that the hardness was minimum in the temperature range of 950-975℃, however, no/little recrystallization occurred at these temperatures. A fully recrystallized grain with significant drop in hardness was observed at 1050℃.

1.3 Research Gap:

From the literature review it was clear that due to hot rolling process original grains were elongated grain flow was not uniformly distributed along the metal as shown in Figure 1.2. Also the mechanical properties and fracture micro mechanisms are affected by hot rolling process.

Annealing the part above recrystallization temperature will effect grain regrowth within the elongated grains to produce uniform grain size as shown below in Figure 1.3. This will relieve stress, increase ductility and toughness of the raw material. Annealed part when manufactured through redesigned manufacturing process will considerably reduce metal fracture.

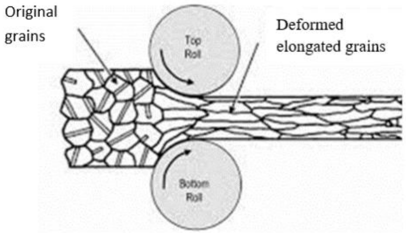


Fig. 1.2 Grain deformation during hot rolling process

Annealing refers to a heat treatment in which a material is exposed to an elevated temperature for an extended period and then slowly cooled to meet desired properties.

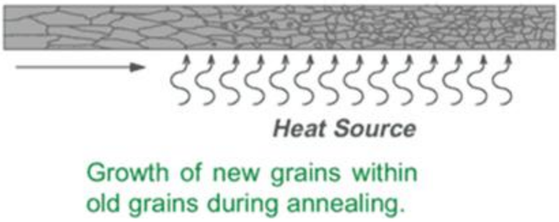


Fig. 1.3 Effect of annealing on grain structure

II. Methodology

2.1 Mechanical Properties of Fe410

The mechanical properties of Fe410 structural steel is given below

Yield strength	250 MPa Min
Tensile strength	410 MPa Min
Elongation	23%

2,2 Chemical Properties of Fe410

The Chemical properties of Fe410 structural steel is given below

Carbon	0.23 Max
Silicon	0.40
Magnesium	1.50
Nitrogen	0.012 Max
Phosphorus	0.045 Max
Sulphur	0.045 Max

2.3 Microstructure of Fe410

Micro examination of the specimen revealed grains with ferrite and pearlite shown in figure 2.1. This structure confirms that the material is low carbon alloy steel from iron carbon phase diagram (figure 2.2).

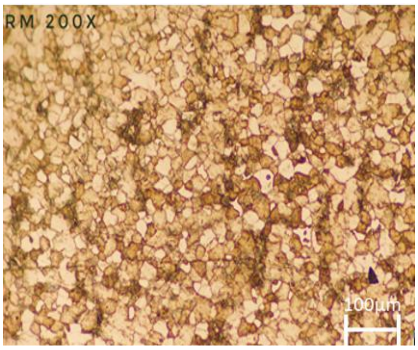


Fig. 2.1 Microstructure of Fe410

Grain size of the specimen is found to be 5 to 6

Micro hardness of the specimen was found to be 99 - 107 HV0.1.

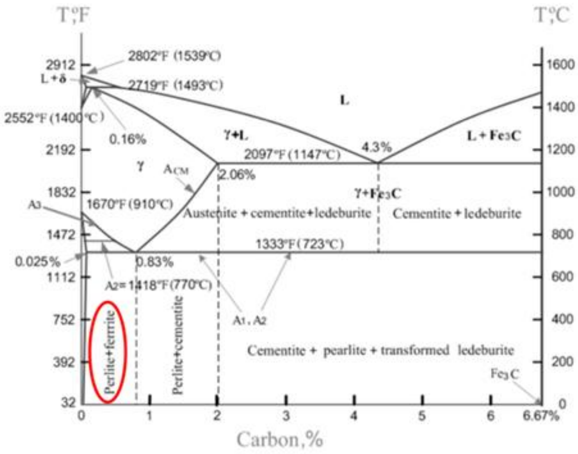


Fig. 2.2 Iron carbon phase diagram

2.4 Recrystallization Temperature:

Annealing the material to an elevated temperature above recrystallization zone for an extended period of time results in grain regrowth. The material is furnace cooled to maintain its properties.

Liquidus Temperature $= 1537 - [(8*Si) + (5*Mn) + (30*P) + (25*S) + (1.5*C) + (2*Mo) + (4*Ni)]$

$= 1537 - [(8*0.4) + (5*1.5) + (30*0.045) + (25*0.045) + (1.5*0.23) + (2*0) + (4*0)]$

Liquidus Temperature = 1524°C

Recrystallization Temp. = Liquidus Temperature / 2

= 1524/2

Recrystallization Temperature = 762°C (Approx.)

Recrystallization Temperature for Fe410 is between 750°C and 800°C

Annealing soak time is calculated as 1 hour per half an inch thickness of the specimen. Part to be annealed above recrystallization temperature to obtain optimum results.

III. Experimentation

3.1 Trial Matrix for Microstructure Refinement:

Annealing of specimen was done with four different temperature above its recrystallization temperature to study the effect on microstructure. As recrystallization temperature for IS2062 Fe410 lies between 750ºC and 800ºC. Specimen was annealed at 800ºC, 850ºC, 900ºC and 950ºC for 1 hour. After soaking time the specimen is allowed to cool in furnace till it reaches room temperature.

Table 3.1 Trial matrix for microstructure refinement

TRIAL ID	ANNEALING TEMPERATURE	SOAKING TIME	COOLING METHOD
T1	800°C	1 Hr	FURNACE COOLING
T2	850°C	1 Hr	FURNACE COOLING
T3	900°C	1 Hr	FURNACE COOLING
T4	950°C	1 Hr	FURNACE COOLING

Specimen was made from the billet strip for this experimentation purpose. Dimension of the specimen 55 X 50 X 6 mm (as shown in figure 3.1)

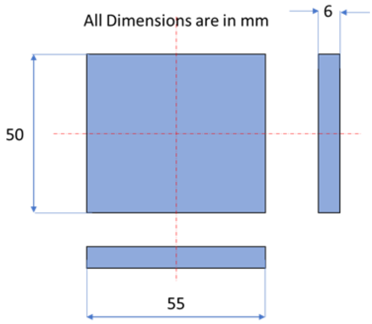


Fig. 3.1 Specimen dimensions

3.1.1 Annealing at 800ºC:

Specimen was annealed at 800ºC. Muffle furnace used for annealing has a capacity of ΔT = 10°C/min.

Microstructure examination of the specimen revealed ferrite grains with small amount of pearlite shown in figure 3.2

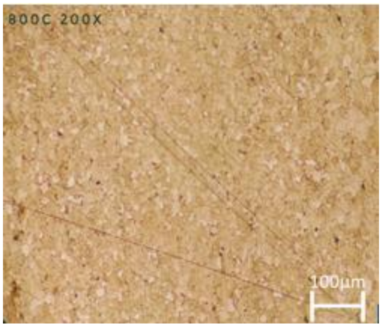


Fig. 3.2 Microstructure of 800ºC Annealed specimen

Grain size of the specimen is found to be 6 to 7

Micro hardness of the specimen was found to be 104 - 111 HV0.1.

3.1.2 Annealing at 850ºC:

When specimen was annealed at 850ºC, microstructure examination of the specimen revealed ferrite grains with small amount of pearlite as shown in figure 3.3. Pearlite grains at 850ºC specimen was little bit more than 800ºC, this was due to grain regrowth during annealing.

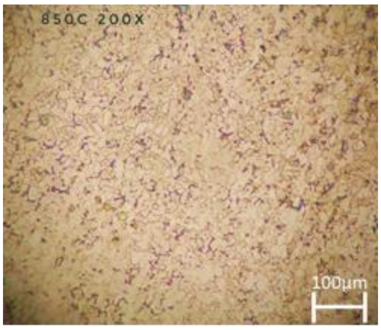


Fig. 3.3 Microstructure of 850ºC Annealed specimen

Grain size of the specimen is found to be 6 to 7

Micro hardness of the specimen was found to be 104 - 109 HV0.1.

3.1.3 Annealing at 900ºC:

When specimen was annealed at 900ºC, microstructure examination of the specimen revealed ferrite grains with small amount of pearlite found as shown in figure 3.4.

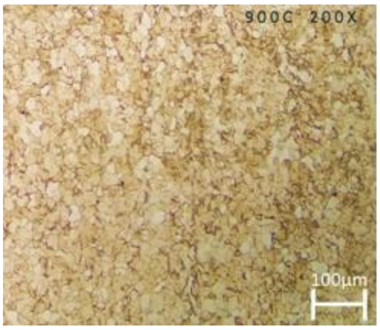


Fig. 3.4 Microstructure of 900ºC Annealed specimen

Grain size of the specimen is found to be 6 to 7

Micro hardness of the specimen was found to be 109 - 110 HV0.1.

Micro hardness values shows, that the grain refinement reduces the hardness variation and Grain flow is found to be linear.

3.1.4 Annealing at 950ºC:

When specimen was annealed at 950ºC, microstructure examination of the specimen revealed ferrite and pearlite grains observed as shown in figure 3.5.

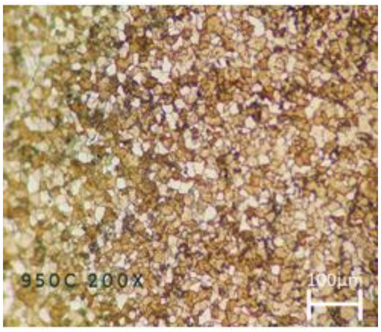


Fig. 3.5 Microstructure of 950ºC annealed specimen

Grain size of the specimen is found to be 6 to 7

Micro hardness of the specimen was found to be 107 - 109 HV0.1.

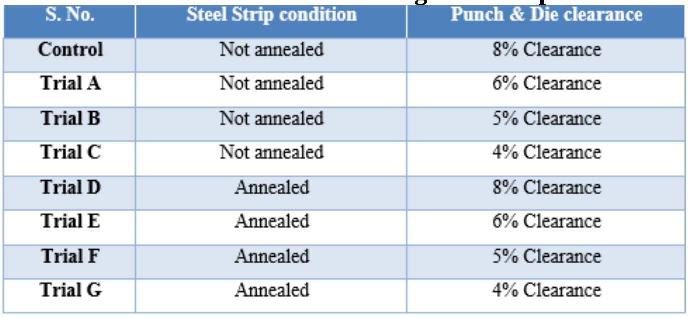
Micro hardness values shows that grain refinement reduces variation of hardness in the material. Hence annealing at 950ºC is found to be optimum with linear grain flow.

3.2 Trial Matrix for Annealed Steel Strip versus various Punch-Die Clearance:

As per Tool Design, Nominal Clearance between Die and Punch for shaving operation was 8% of the Sheet Thickness.

To study the effect of change in clearance between die & punch, following experimentation was done with different punch & die clearance as shown in table 3.2

Table 3.2 Trial matrix for regular steel plate

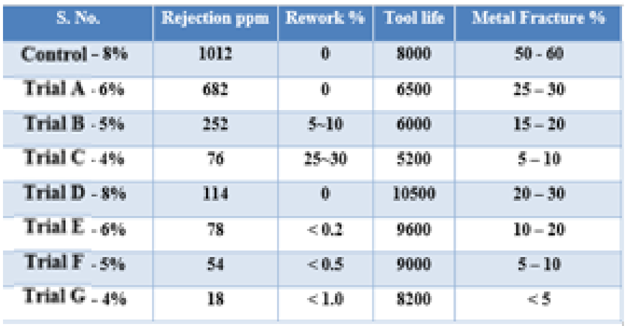


S. No.	Steel Strip condition	Punch & Die clearance
Control	Not annealed	8% Clearance
Trial A	Not annealed	6% Clearance
Trial B	Not annealed	5% Clearance
Trial C	Not annealed	4% Clearance
Trial D	Annealed	8% Clearance
Trial E	Annealed	6% Clearance
Trial F	Annealed	5% Clearance
Trial G	Annealed	4% Clearance

IV. Results

- Outcome of the trail is shown in Table 4.1. When annealed steel strip is processed with 4% tool clearance, metal fracture is reduced to less than 5% of sheet metal thickness without affecting the tool life.

Table 4.1 Result Matrix of Redesigned Process



S. No.	Rejection ppm	Rework %	Tool life	Metal Fracture %
Control - 8%	1012	0	8000	50 - 60
Trial A - 6%	682	0	6500	25 – 30
Trial B - 5%	252	5~10	6000	15 – 20
Trial C - 4%	76	25~30	5200	5 – 10
Trial D - 8%	114	0	10500	20 – 30
Trial E - 6%	78	< 0.2	9600	10 – 20
Trial F - 5%	54	< 0.5	9000	5 – 10
Trial G - 4%	18	< 1.0	8200	< 5

- Process rejection is considerably reduced and rework % is also within limits.

V. Conclusions

- When Fe 410 steel strip was annealed at different temperatures above recrystallization temperature and found that there is significant grain regrowth.
- Micro hardness values shows that grain refinement reduces variation of hardness in the material. Hence annealing at 950ºC is found to be optimum with linear grain flow.
- Reduction in clearance between tool and die resulted in significant improvement of shaving when regular steel strip was used in manufacturing.
- By using annealed steel strip with reduced clearance between tool & die, smooth surface finish is achieved in conventional manufacturing process.
- This redesigned process flow yields 95-100% shaving in blanked part.

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