ISSN 2347 - 3983
Volume 8. No. 7, July 2020
International Journal of Emerging Trends in Engineering Research
Available Online at http://www.warse.org/IJETER/static/pdf/file/ijeter153872020.pdf
https://doi.org/10.30534/ijeter/2020/153872020

Analysis of the effect of cold plastic deformation and subsequent heating on the properties of metal

Olga I. Vaganova[1], Alevtina Ya Melnikova[2], Zhanna V. Smirnova[3], Anna V. Lapshova[4], Elena A. Chelnokova[5]

[1]Minin Nizhny Novgorod State Pedagogical University, Nizhny Novgorod, Russia, e-mail: vaganova_o@rambler.ru
[2]Bashkir State University, Russia, e-mail: meln-alena@yandex.ru
[3]Minin Nizhny Novgorod State Pedagogical University, Nizhny Novgorod, Russia, e-mail: z.v.smirnova@mininuniver.ru
[4]Minin Nizhny Novgorod State Pedagogical University, Nizhny Novgorod, Russia, e-mail: any19.10@mail.ru
[5]Minin Nizhny Novgorod State Pedagogical University, Nizhny Novgorod, Russia, e-mail: chelnelena@gmail.com

ABSTRACT

Metal is used in many branches of domestic industry, so increasing its strength becomes an urgent topic for the development of various industries where metal is an integral element. An effective way to increase the strength of the metal is cold plastic deformation and heating. This article presents the experience of studying the influence of cold plastic deformation and heating on the properties of metal. With the help of a rivet, the hardness and ultimate strength can be increased by 1.5-3 times, and the yield strength by 3-7 times. The greater the degree of deformation, the stronger the coercive force increases and the lower the magnetic permeability and density of the metal. The use of plastic deformation is an effective way to strengthen the finished metal product.

Key words : cold plastic deformation, heating, metal, sliding, recrystallization.

1. INTRODUCTION

Metal products are widely distributed all over the world. Today, the issue of its strengthening is becoming more urgent.

The characteristics of metal strength are:

- tensile strength;
- yield strength;
- hardness.

In the process of cold plastic deformation, the properties of the metal change and the metal becomes stronger. Riveted metal stores 5-10% of the energy that was spent on deformation. The higher the degree of deformation, the higher the strength characteristics of the metal. The degree of plasticity and viscosity are reduced. In this article, we consider the influence of cold plastic deformation and heating on the properties of metal, its strength. Plastic deformation is presented as one of the most effective ways to strengthen metal today.

2. THEORETICAL FRAMEWORK

Deformation refers to changes in the size and shape of bodies under the influence of external forces.

Elastic deformation is a deformation that affects the shape and size of «bodies and is completely eliminated after the termination of external forces. Plastic deformation is the result of irreversible displacements of atoms» [1] under the influence of external forces. In crystals, such displacements occur by sliding and doubling.

The metal structure is formed under the influence of pressure. Each of the crystallites is deformed. Before deformation, the original grain of the annealed metal almost always has a rounded shape. Figure 1 shows the change in grain shape as a result of plastic deformation (G. V. Klevtsov).

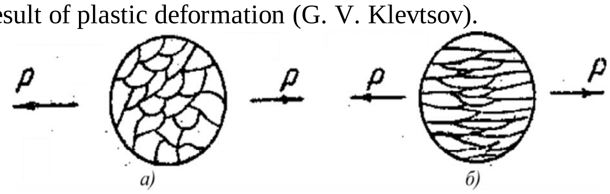

Figure 1: Changing the shape of the grain as a result of plastic deformation (a-before deformation, b - after deformation)

During plastic deformation, grains (crystallites) are stretched in the direction of the main stretching strain (for example, in the direction of rolling or drawing as in figure 1b) [1]. «Deformation resistance indicators increase with increasing degree of cold deformation» [1]. «And elasticity indicators are decreasing. This is clearly shown in figure 2» [1].

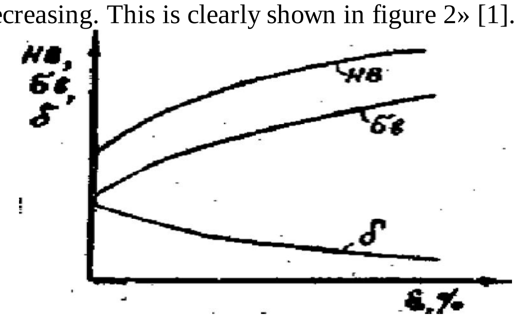

Figure 2: Dependence of mechanical properties of metal on the degree of cold plastic deformation

The basis of plastic deformation is the movement of atoms at considerable distances from the initial equilibrium position [2]. A number of properties change during plastic deformation [3]. The role of plasticity is to ensure the structural strength of parts under load [4]. During the deformation process, the metal is strengthened. The density of defects ensures the strength of the metal. Intensive riveting of metals occurs at the beginning of deformation [5]. The greater the degree of deformation, the faster the yield strength of the time resistance increases [6].
The metal is quickly riveted at the beginning of deformation. Then, with increasing strain, the mechanical properties change little [7].
With the help of a rivet, the hardness and ultimate strength can be increased by 1.5-3 times, and the yield strength by 3-7 times [8].
The greater the degree of deformation, the stronger the coercive force increases and the lower the magnetic permeability and density of the metal [9]. Despite the fact that the plasticity is reduced, the use of a rivet in increasing the strength of the metal is still widely used [10].
For example, to increase the fatigue resistance, the surface layer of the parts is glued. Cold deformation is performed at temperatures lower than recrystallization temperatures [11].
During hot deformation, the hardening is removed during recrystallization [12].
Recrystallization happens:
- primary;
- collective [13];
- secondary [14].

Primary recrystallization consists in the formation of embryos and the growth of new grains with an undistorted crystal lattice [15].
Collective recrystallization is characterized by the growth of the formed grains. At the same time, it is worth noting that some grains grow at the expense of others, due to the transition of atoms beyond the interface.
The result may be a sharp heterogeneity of the grain size structure.
The speed of recrystallization depends on the following factors:
- degree of pre-deformation;
- the degree of heating;
- heating rate;
- strain rate;
- presence of impurities in the alloy.

The main factors listed are the heating temperature and the degree of pre-deformation.
The recrystallization start temperature for pure metals is defined as Tp=0.4, where Tp is the absolute recrystallization temperature. Critical (highest) degree of deformation (up to 10%).
In this case, the size of the resulting crystallized grain exceeds the initial one by several tens of times. This phenomenon occurs in engineering, where the deformation varies from 0 to large degrees. It must be taken into account, because in some cases, grain enlargement is undesirable (the impact strength decreases sharply), and sometimes it is favorable, since there is an increase in heat resistance, we get the required electromagnetic properties. Recrystallization in the area of critical degree of deformation is caused by the combination of groups of grains into one.
Figure 3 shows changes in the structure and properties of the deformed metal according to Yu. P. Egorov [16].

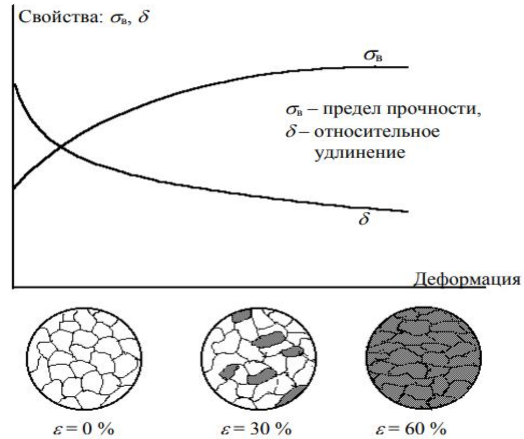

Figure 3: Structure and properties of the deformed metal depending on the degree of deformation

Under the influence of the applied load, the grains of the deformable body begin to change. They begin to stretch. The volume and their number remain unchanged. A large number of dislocations are concentrated inside each grain.
Their density increases from 10^6 – 10^7 cm^{-2} (before deformation) to 10^{10}-10^{12} cm^{-2} (after deformation). The temperature at which recrystallization begins is determined by two methods: metallographic and x-ray diffraction. There is a relationship between the recrystallization temperature (T_p) and the melting temperature (T_{pl}), which was deduced by A. A. Bochvar:
$Tp = \alpha \cdot T_{pl}$, K
If T_p can be determined by the change in hardness, then Tp is taken as the temperature at which the increase in hardness decreases by half. Figure 4 is a graph determine the temperature according to Yu. P. Egorov [16].

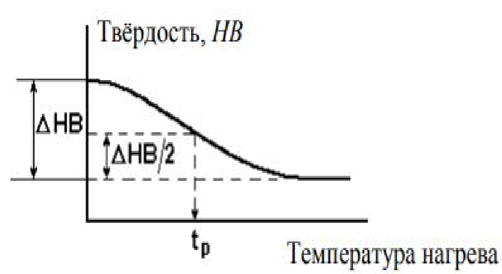

Figure 4: Determination of recrystallization temperature by changing the hardness during heating

Figure 5 shows the influence of the degree of deformation on the size of the deformable grain (according to Yu. P. Egorov) [16].

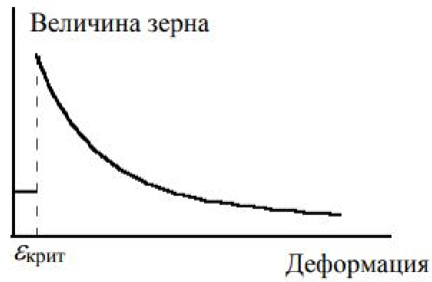

Figure 5: Influence of the degree of deformation on the size of the deformable grain

Due to cold processing, the metal comes to a state with increased free energy. Therefore, the state of the metal is thermodynamically unstable. During the heating process, it returns and recrystallizes, which change its properties back to how they changed during cold plastic deformation [17]. Resistance to deformation: the limits of strength; fluidity; hardness.

These indicators decrease, and the plasticity indicators become higher.

Indicators of plasticity include:

- relative elongation;
- narrowing.

Return processes occur when heated to relatively low temperatures.

The first stage of return is characterized by a decrease in the concentration of point defects:

- vacancies;
- hub atoms.

It is also characterized by the redistribution of dislocations without the formation of new sub-grains. Dislocations are a special kind of linear imperfections (defects) of the crystal lattice. A simple way to form dislocations in a crystal is by shifting.

Figure 6 shows a diagram of the movement of atoms when sliding edge dislocation.

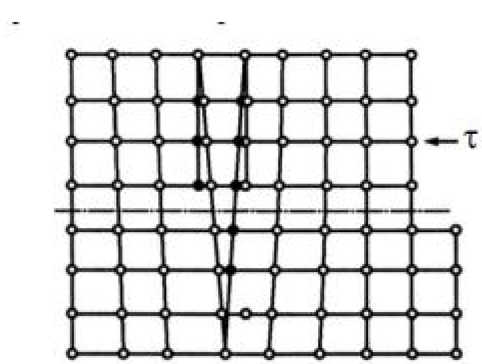

Figure 6: Diagram of the movement of atoms when sliding edge dislocation

The shift to one interatomic state is a coordinated rearrangement of atoms near the dislocation and is not accompanied by diffusive mass transfer.

So the dislocation will eventually come to the surface of the crystal and there will be a step.

The second stage of return is called polygonization.

During the return process, no significant transformations of the metal structure using a light microscope have yet been observed. The mechanical properties remain unchanged. When a cold-deformed metal is heated, changes begin to occur in its structure starting from a certain temperature, and new equiaxed grains appear instead of the fibrous structure. At the same time, the temperature of the beginning of recrystallization of metals that have been subjected to significant deformation is equal to 0.4 T_{pl} (for metals of technical frequency), for alloys (0.6 – 0.7).

3. RESULTS AND DISCUSSION

The aim of the study is to determine the effect of cold plastic deformation and temperature on the hardness of steel, aluminum and copper samples.

The following tools were used to conduct the study:

- manual mechanical press;
- set of test samples (samples made of aluminum, copper and low-carbon steel);
- hydraulic press;
- electric muffle furnace;
- pliers;
- Brinell hardness testers;
- monocular magnifier;
- set of sanding papers;
- calliper;
- the passport of the product;
- operating instructions.

We took three samples of low-carbon steel and were subjected to cold deformation:

- by 5%;
- by 10%;
- by 25%.

Then the samples were heated to 600°C.

Cylindrical steel samples were deposited at different heights on a hydraulic press. The hardness of the samples was measured using a Brinell hardness tester. As an indenter, a ball of steel with a diameter of 5 mm was used at a load of 2500 h. For the rest of the samples, a Rockwell hardness tester was used (a ball of 1.59 mm, under a load of 100 kgf).

The obtained values of HRB hardness of steel samples were translated by Brinell. Four samples of steel, copper and aluminum were deposited on a hydraulic press with a degree of deformation of more than 50%.

After deforming a metal with a degree of deformation up to 70%, the ultimate strength and hardness increase by 3 times, and the yield strength becomes 8 times greater, and the elongation decreases by up to 40 times.

With increasing temperature there is an increase in the mobility of the atoms. And when a certain temperature is reached, new equiaxed grains are formed. The old link is not restored when the riveted metal is heated.

Also, hot deformation of samples of technically pure copper to various degrees of deformation was performed and the change in the hardness of hot-formed samples depending on the degree of deformation was determined. Cold-formed copper samples were subjected to recrystallized annealing (heat treatment to remove the hardening) for 10 minutes, and changes in the hardness of annealed samples were determined depending on the degree of deformation.

4. CONCLUSION

We studied the effect of cold plastic deformation and temperature on the hardness of steel, aluminum and copper samples. The use of plastic deformation is an effective way to strengthen the finished metal product. Hardening of the metal through the use of plastic deformation is explained by an increase in the number of defects in the crystal structure: dislocations, vacancies, interstitial atoms. The use of plastic deformation changes the physical properties of the metal: the lattice distortion increases, the internal energy increases, the hardness and strength increase, the electrical resistance increases, and the degree of plasticity becomes lower. As the degree of cold deformation increases, the strength characteristics (hardness, ultimate strength, and yield strength) increase.

REFERENCES

1. J.T. Bakirov, A.A. Ainabekova, U. M. Dyikanbaeva Heat treatment and mechanical tests. Methodical instructions for laboratory work on materials science for students of mechanical engineering specialties, B.: IC "Teknik", 2011. - 36 p.
2. G.V. Klevtsov. **Fractodiagnostics of the destruction of metallic materials and structures: textbook. allowance** / G.V. Klevtsov [et al.]. - M.: MI-CC, 2007, pp. 264.
3. S. G. Grigoriev, V. A., Shabunina, Ju. M. Tsarapkina, N. V. Dunaeva. **Electronic library system as a means of self-development of students of digital generation Z (on the example of studying the course "Basics of the counselor activity")**. *Scientific and technical librarie,* No. 7. Pp. 78-99. 29. 2019. https://doi.org/10.33186/1027-3689-2019-7-78-99
4. O. A. Andrienko. **Network educational technologies and their use when working with students**. *Humanitarian Balkan Research 2019,* 1(3), 5-7. 2019.
5. N.S. Abramova, O.I. Vaganova, L.I. Kutepova, **Development of educational and methodological support in the context of the implementation of content and communication technologies.** Baltiyskiy gumanitarnyy zhurnal. Baltic Humanitarian Journal, 7, no. 2 (23), 181-184. 2018.
6. M.N. Bulaeva, O.I. Vaganova, M.N. Gladkova. **Activity technologies in a professional educational institution.** Baltiyskiy gumanitarnyy zhurnal. Baltic Humanitarian Journal), 7, no. 3 (24), 167-170. 2018.
7. Z. V. Smirnova, O.I. Vaganova, O.T. Cherney, E.V. Romanovskaya, N.S. Andryashina, D.S. Toshin, **The organization of emergency and dispatching servicing of an apartment house.** *International Journal of Innovative Technology and Exploring Engineering* 8(9), 2019. c. 1477- 1480 https://doi.org/10.35940/ijitee.I8194.078919
8. Z. V. Smirnova, M.V. Mukhina, O.V. Katkova, M.L. Gruzdeva, O.T. Chernei, **Network Interaction as a Factor of Professional Qualities' Development of Service Workers**. *Lecture Notes in Networks and Systems,* 87, pp. 698-704. International Journal of Innovative Technology and Exploring Engineering. https://doi.org/10.1007/978-3-030-29586-8_81
9. G. T. Klinkov The specificity of manifestation of pedagogical communication as a special construct. *Scientific Vector of the Balkans,* 1, 51-52, 2018.
10. A. A. Sukhikh, T. M., Makhneva, V. B. Dement'ev **Austenite in nanostructured maraging steel,** *Inorganic Materials: Applied Research,* vol. 10, no. 4, pp. 966-973. , 2019. https://doi.org/10.1134/S2075113319040415
11. K. Yu. Boyko, A.V. Skripkina and K.Yu. Smartly. **The use of syllabus funds in the technology of time management of self-educational activities of bachelors.** *Multilevel system of continuous professional education in the socio-cultural sphere: problems of continuity and integration*, 73-78. 2019.
12. I. F. Filchenkova**, Educational management of innovative activity of teachers as an object of pedagogical research.** *Vestnik Mininskogo universiteta* (*Vestnik of Minin University),* 2019. 7 (4), 3. (in Russ.). 2019. https://doi.org/10.26795/2307-1281-2019-7-4-3
13. Z. V. Smirnova, A.A. Rudenko, O.I. Vaganova, O.T. Cherney, D.S. Mokerov, E.A. Semakhin, The research of carbon construction steel at laser alloying. International Journal of Innovative Technology and Exploring Engineering. 2019
14. C. Santhosh, K. Hari Kishore, G. Pavani Lakshmi, G. Kushwanth, P. Rama Krishna Dharma, Teja, R. S. Ernest Ravindran, S. V. Cheerala, M. R. Kumar. Detection of Heavy Metal Ions using Star-Shaped Microfluidic Channel. **International Journal of Emerging Trends in Engineering Research**, 7, No. 12. 2019. https://doi.org/10.30534/ijeter/2019/067122019
15. A. Zakaria, M. S. N. Ibrahi, **Experimental Evaluation of Multiple Savonius Turbines in Oblique and Cluster Configuration**, International Journal of Emerging Trends in Engineering Research, 7, No. 12. 2019. https://doi.org/10.30534/ijeter/2019/10712201

16. Yu. P. Egorov, Yu.M. Lozinsky, E.I. **Marr Laboratory practice materials science for students, students in the field of "Mechanical Engineering"**, 2015, pp. 34.
17. A.V. Kirjukhin, O. O. Milman, A. V. Ptakhin, V. D. Kuprjashov, **Efficiency of Schemes of Active Broadband Damping of Vibration Forces Transmitted by Vibration Insulation to the Foundation**, International Journal of Emerging Trends in Engineering Research, 7, No. 12. 2019. https://doi.org/10.30534/ijeter/2019/017122019