

# The methods of sever plastic's deformation in order to fine-graining matter's structure for improvement of mechanical properties in metals

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**Abstract:** Increasing material's strength has been a significant matter since the beginning of engineering to up to now. It has always been paid attention by engineers. A variety of methods has been presented for increasing strength, stability, working range and material working life by development of engineering sciences and more identification on material properties and the material behavior, which are surrounded by some rules. Majority of these methods accompany disadvantages and restrictions, therefore, the studies in this field for modification of methods continue. One of the newest methods for this reason is the Sever Plastics Deformation Method (SPD). This method is based on creation of NANO materials increases some desirable properties such as strength, stability, resistance against corrosion and abrasion properties. Also, it prevents the reduction of other material properties like ductility, which is known an inevitable and undesirable process in majority of older strength's methods and even is caused to increase it. Increasing of desired properties of metals, which were under this process, is very significant, so that the products of this process are named Super Metals. In this research, mean while checking relations among the automatic lattice structure of matter with its mechanical properties somehow it has been mentioned to common method of SPD

**Keywords:** Severe Plastic Deformation, NANO-structured Material, Super Metals

## 1. Introduction

The Physical properties and mechanical behaviors of material strongly depend on their crystal structure [1]. The dimensions of this structure are included among the effective factors of material properties on

poly-crystalline including size of grains. Ploy crystal's material can divide into 3 categories based on size of grains, coarse-grained, ultra-fine-grained (UFG) and NANO crystal materials. The materials which their average size of grain's diameter is more than a micron

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are included the coarse-grained, the substances or materials which their size of grains is between 100 to 1000 nanometers are included the UFG and materials which their average size of grains diameter is less than 100nanometers are included the NANO crystal [2].

Sometimes material have some different and amazing properties compared with same material with the structure which non-NANO, for example NANO-structure metals because of their particular mechanical behavior and reinforced properties are called super metals. Super Metals have many usages in aviation military and medical industries [3]. material often are with crystal non-nanostructure and for using particular properties of material ,it is needed that materials structure convert from coarse-grained to ultra-fine grained by doing some process .Among methods of nanostructure's creation can be noted to thermo-mechanical methods and SPD in crystal lattice of metals[4]. Primary metal that is coarse-grained is converted to a metal that is fine structure-grained by re-crystallization, retrieval and sedimentation twin thermal conditions plastic strain in thermodynamics methods [5]. one of the advantages of SPD's method is prevention of crack's growth or creation, grading the crystal lattice of metals will be overflowed by applying frequent plastic strain which strain's size is very more compared with other methods of applying plastic strain[2],[6-11].The weight of structures and pieces can be decreased by increasing the strength in process of SPD's method. There are varieties of methods for this reason, these methods are completing and developing, certainly new methods will be

represented for solving the difficulties and restrictions of available methods. In this research, the common methods of SPD will be introduced after checking the mechanism of overflowing the grains, also the effect of this phenomenon on mechanical properties.

## **1. material's structure and mechanical properties**

Improvement of used material's properties has been considered by engineers in industry long before. As mentioned, material's mechanical behaviors and properties depend on material's structure. Increase of material's strength and maintaining appropriate ductility are the most important issues in industrial applications. Different and amazing behaviors and properties are observed in nanostructure materials compared with the same matter with non-nanostructure which this phenomenon is related to changing the size of grains in the following effect of grains size on strength on materials ductility will be checked.

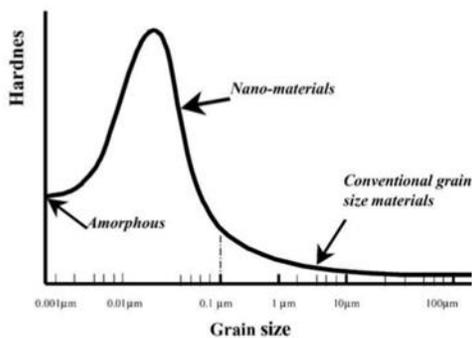
### **a. Grain's size and strength**

The total length of grains boundaries is increased by overflowing grain's diameter of the crystal lattice in metal network since grain boundaries are energetic regions and they are known as an obstacle against growth of cracks the energy level of the whole matter and also strength of matter's resistance will be increased against growth of crack and break by increasing this region in crystal lattice of metals. Overflowing grains size is one of the appropriate methods for increase of materials strength which is twin double maintaining ductility properties [12].This phenomenon is one of the most important

priorities of this method compared with the other older methods of increase of strength .Increase of strength will face decreasing ductility by hard work based on mechanical materials behavior .However, matter has very good ductility in fine grain's phenomenon [13]. Effect of grain is expressed with hall pitch's Equation in strength of metal polycrystals as Eq. (1). [14]

$$\sigma_0 = \sigma_i + KD^{-1/2}(1)$$

Here  $\sigma_0$  is lattice's resistance,  $\sigma_i$  is yield stress, D is average diameter of grains and K is a constant related to material's properties. It can be seen in Eq. (1), material's strength increases by decreasing D and if grain's size can come to the demission under 100 NANO meter, increase of strength will be remarkable strength's changes have been presented based on grain's size in Fig.1 hardness of material as a function of grain size [15].



*Fig.1 Hardness of a material as a function of grain size [15]*

## 2.2. Grain's size and ductility

Plastic deformation is made of aberrant movements, creation of twinning, metal transformation, penetration and slip of boundaries, these mechanisms can cause material's plastic deformation simultaneously plastic deformation depends on crystal

structures tacking fault energy temperature grain's size and strain slip of boundaries ,atom's influences in boundaries are known as basic mechanism of the deformation in nanostructure materials .based on existence of remarkable boundaries with high angle in nanostructure materials which these kinds if boundaries will have slips when applying force and will provide more ability of tolerance for deformation rather the form of coarse grain's structure[5,16] . also the slip of boundaries is happened twin aberrant movements which cause to continuity between grains and also provide more large plastic strain in nanostructure materials.[17]

## 3. Severe Plastic Deformation

SPD is one of the new methods for producing nanostructure material partly .this method is based on applying compressive forces with specific speeds in particular conditions which cause applying these severe strains frequently cause to kneading the matter under pressure in different ways .the crystal lattice of metals is converted to fine grain structure by absorbing energy and under pressure in this process .the pressure which is available in this process prevent from cracks and failure of materials during this process. In addition to decreasing grain's size, atom's solution is stayed on boundaries in SPD method thus the difficult situation of aberrant movements is made by them since the deformation of material is created based on aberrant movements and this event causes the increase of material's strength too high density of aberrations will be created by kneading metal in material's structures the creation of this aberrations makes the material in fine grain's structure form in

following process; The existent aberrations rearrange and the core of aberrations will be created by joining together and also the level of energy will be decreased by them. There will be new movements by applying more strain to the matter in it and the created angle between aberrant cores increase and this cause the creation of boundaries in grains. More subsidiary boundaries are created in grains by continuing the process of applying strain to the matter and also this process will repeat, finally produced grains rotate. Primary increase of aberrations will cause to decrease material's strength but by their increase of more than certain limit cause gather them by the form of finer grains which have low angle grains boundaries based on continuing grain's deformations and rotations. The demission of input and output pieces is equal in this method and the difference between these 2 pieces is for their crystal lattice structure [18-20].

#### 4. The methods of SPD

Various methods have been invented in for applying SPD in order to create nanostructure in materials with industrial applications these methods can divided into 3 categories according to the type and demission of products and pieces.

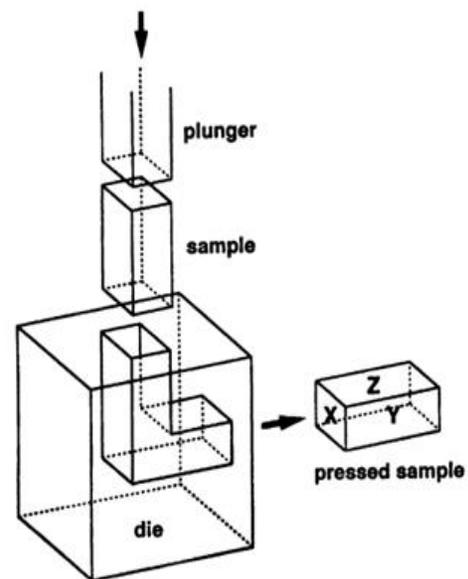
##### 4.1. SPD methods for bask materials

The first scientific results of studies which is related to creation of bask materials with fine-grained structure of coaxial with large angles boundaries represented in 1990 [6] different methods have been invented for bask materials in the following.

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##### 4.1.1. Equal channel angular pressing (ECAP) [21-23]

As it can be seen in Fig. 2, the cited piece enter to channel with steep angle and also appropriate section to primary piece and template exits with controlled speed also under pressure .the demission of exited piece is like primary piece .but there are some changes in grain's size and boundaries in template by tolerating intense shear strain of plastic pressure for achieving to the homogeneous fine grained structure in throughout of the matter, it is needed to repeat this process several times.



*Fig2. The principles of ECAP showing the three orthogonal planes X, Y and Z [24]*

For activating sidling system in through out of the matter, the piece can rotate in different demission, after doing every process .as it is represented in Fig. 3; the rotation of piece is divided into 4 ways.

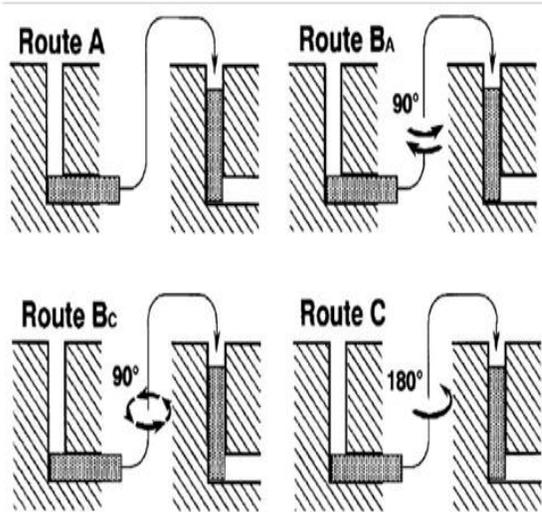


Fig3. Four ways to do channel angular pressing method (ECAP) [6]

**4.1.2. Cyclic High pressure torsion(HPT) [25, 26]**

This method is used for fine grained structure in this disc. As it can be seen in Fig. 4 the cited piece which is stained on the template that is upon created lower jaw and is effected by high pressure which upper jaw makes it .template of severs shear force and shear plastic strain is entered to piece by simultaneous of upper jaw due to the friction between pieces. There is no possibility for the usage of this method for pieces by large demission and great thickness because of applying pressure in this method and products derived from this method have more usage in electronics industry, according to this point which amount of compressive force and applied share forces and also used strain to piece are adjustable separate thus this method is considered or used as an appropriate method for studies on effects of compressive, strain and shear forces to the piece on material's structures.

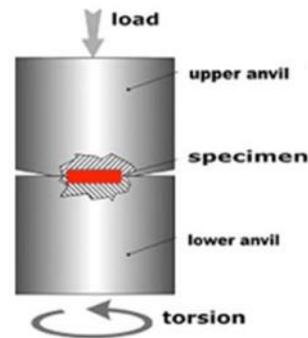


Fig4. Schematic of High Pressure Torsion (HPT) [27]

**4.1.3. Multi-directional forging (MDF) [28]**

This method accompanies with changes axis force because of repetition of the compressive force the process of this method is represented in Fig. 5 since the usage of this method is for pieces with large demission, thus it is known as one of the most useful methods of applying SPD in industrial products since the entered force in this method is lower than other methods and also the temperature of doing work is higher, it is possible to use this method to create fine-grains in metals.

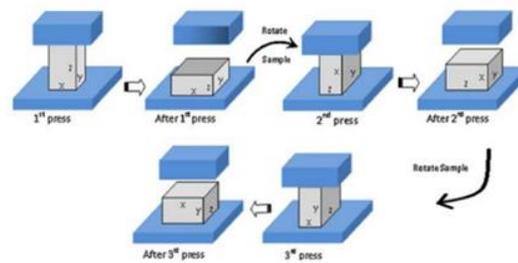
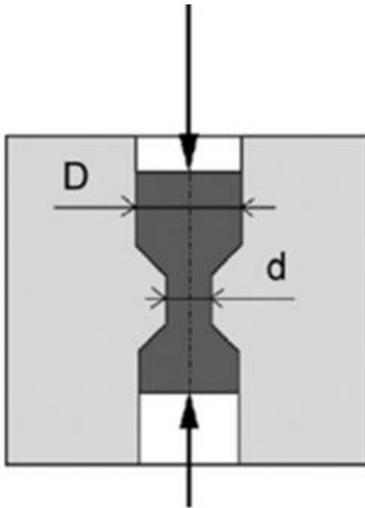


Fig5. Schematic of Multi-directional forging (MDF) [28]

**4.1.4. Cyclic extrusion-compression (CEC) [10]**

As it is visible in this method in Fig. 6, the piece with D diameter by upper punch pressure after passing a gorge extruded with

the less diameter in size of  $D$  through the opposite side of the template which has equal size with first side and this process continues and repeats similarly thus severe plastic strain imported to the material will cause to fine grains without creation of crack and break under the pressure in piece this method is useful for the pieces by the limited size.



*Fig.6 schematic of cyclic extrusion compression (CFC) [29]*

#### 4.2. SPD methods for sheets

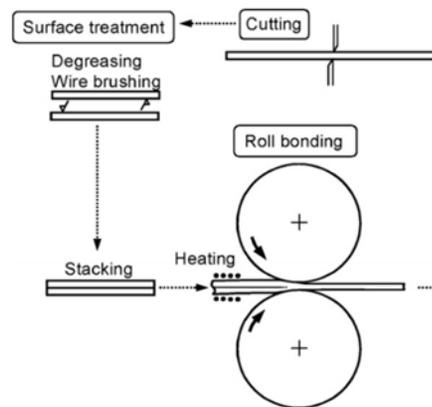
Sheets have very usages in automobile manufacturing's industry and aerospace especially they (sheets) have great importance according to importance of decreasing weight and increase of strength against creation of the structure's heat in aerospace industries. In methods of applying plastic strain the products of the process is like the demission of primary piece. Applying great forces which causes applying severe plastic strain seems slightly complex, because sheets usually have large demission, new methods have been invented for this work which can use them in order to create fine grains in sheets. We will explain the complete introduction of 2 process.

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#### 4.2.1 Accumulative roll bonding (ARB) [30-32]

ARB is only method which production of sheet with large demission with fine grain structure is achieved by it this process is possible by the use of conventional rolling devices too.

In this method 2 sheets are put over each other, after decreasing surfaces and cutting and each them by the thickness of sheets are equalled  $2t$ . Sheets are mingled by applying forces in passing 2 sheets under forming rolls and again output sheet's thickness comes to  $T$ . Output sheet is halved and again are put over each other and this process is repeated frequently in addition by repeating this process in several times, the final product is made of a homogeneous matter and 2 fine structures alloys. The process of ARB is displayed in Fig. 7



*Fig7. Diagrammatic representation of the accumulative roll-bonding (ARB) process [33]*

#### 4.2.2. Repetitive corrugation and straightening (RCS) [34]

The corrugating is created on bent sheets in primary template in this method, after it the sheet without any changes is smoothed in template two and this process is repeated frequently. In this case, fine grains structure

is created in sheets by applying severe plastic strain .one of the difficulties of this method is increase of sheet's length because of repetitive straightening and corrugation which causes to apply heterogeneous.

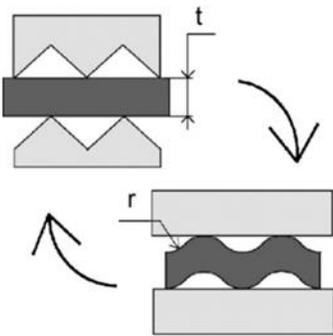


Fig8.Principle of repetitive corrugating and straightening[34]

### 4.3. Severe plastic deformation methods for pipes

Pipes are widely used in industry and in many new applications the capability of high pressure is one of the requirements of the project. So methods of increase strength in pipes are considerable of hard plastic deformation. For aiming this goal different methods have been developed that we will introduce them in the following.

#### 4.3.1. Parallel tubular channel angular pressing (PTCAP) [35]

As you see in Fig. 9, in this method by pressing the upper cylindrical punch into the angular channel, pipe in passing the angular part of the tubular channel faced with increasing diameter. Then by pressing the bottom cylindrical punch with another passing of the angular part to the other side will be extruded with primary diameter. The physical structure of the pipe with this process will change and the diameter of the

grains will be increased. By repeating this process, we can create acceptable size of Fine grains in metals.

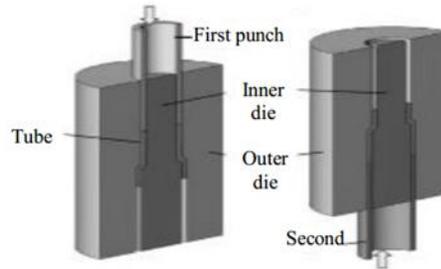


Fig9. Schematic of Parallel tubular channel angular pressing (PTCAP)[36]

#### 4.3.2. Tube Channel Pressing (TCP) [37]

In this method a mandrel will be inserted in the pipe to maintain internal diameter and the pipe will be crossed from a channel with the same diameter of the external diameter pipes. There is a bottleneck with fewer diameters in the middle of the channel; so by crossing throw this bottleneck the pipe will have plastic strain and the diameter topically will decrease. By crossing the bottleneck, diameter of the pipe will expand to primary size. The mandrel in the pipe, have the same diameter decrease to the bottleneck so that Thickness of the pipe will not change. Fig-10 will show this process schematically.

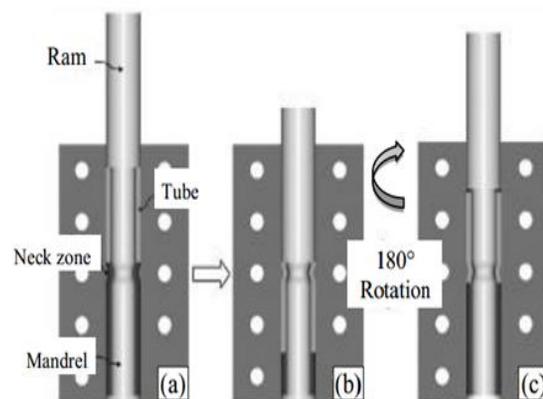
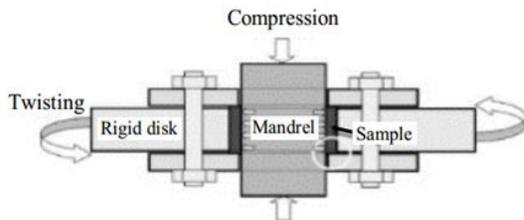


Fig10. Tube Channel Pressing (TCP) [37]

#### 4.3.3. High-pressure tube twisting [38]

In this method the tube is placed inside a disk and a Mandrel is passed through it and axial force is applied to the Mandrel during the process in order to build up pressure inside the tube by lateral expansion of the Mandrel. Then by applying force to the rigid disk and torsion to the tube, shear strain is applied to the tube wall. Fig-11 will show this process schematically. One of the imperfections of this method is the difference torque into the tube wall and consequently Shear strain is different between the inner and outer surfaces of pipes, that it would cause differences in grain size in the interior and exterior surfaces. This difference can cause differences in the mechanical properties in this surface.



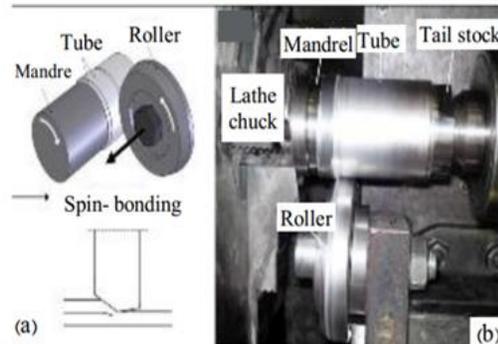
*Fig11.Schematic of Tube Channel Pressing (TCP) [38]*

#### 4.3.4. Accumulative Spin-Bonding (ASB) [39]

This method is similar to Accumulative roll bonding (ARB) that is used to connect two sheets together. For this purpose, two tubes that one diameter is larger than the other one stuck inside each other, And a Mandrel pass through them. They will put mandrel and tubes in the three systems lathes and the bearing will placed into the tool place. At the same time of rotating the Mandrel and pipes; roller along the axis of the tube moves in contact with the pipe. By applying plastic strain, it causes a link between the pipes and fine structure in the pipe. Fig-12 shows the

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performance of this process. The outer tube that is in direct contact with the roller will have more thickness decrease. One of the most important issues in this way is Inability to use pipes with the same size; because the pipes should be inserted together.



*Fig12 (a) Schematic illustration of the spin-bonding and (b) tube spinning set up used for spin-bonding on lathe [39]*

#### Conclusion

As in this study was examined, grain size in the polycrystalline structure is effective on the material properties and their mechanical behavior. According to the improved properties and increasing component such as strength and resistance of corrosion and wear, and good ductility properties of materials are highly regarded in the industry; engineers always looking for ways to improve the properties of the material. Among these methods, severe plastic deformation processes of the metals are very important. To achieve these goals, various methods of severe plastic deformation have been developed for different sizes of the materials. Methods of applying severe plastic strain to the material are not limited to the methods referred in this research. A variety of methods are invented and developed for this process and each of them has its own limitations and disadvantages. They have taken steps to fix these bugs and limitations that lead

to new approaches or modifications of previous methods. For example most methods examined in this study are interrupted, and the need to repeat multiple steps can prolong the process. Most of these methods have changed in order to make the process continuous and reach the desired fine structure in less time. Research and developments are keeping on improving the existing methods and new approaches.

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