SEVERE PLASTIC DEFORMATION AND ITS METHODS

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Abstract: This paper provides the information regarding the field of severe plastic deformation (SPD), which is an evolving technology in metallurgical sciences in these days. It discusses the severe plastic deformation and the mechanism involved in it. Further, it describes the methods of SPD, its advantages and limitations as well as applications.

Index Terms - Severe Plastic Deformation, ECAP, CGP, HPT, ARB, RCS, multi directional forging, cyclic extrusion and compression, twist extrusion, ultra-fined grains

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I. INTRODUCTION:

The Hall-Petch relation [1] states that the yield stress of the grains is inversely proportional to the grain size. It is known that the strength of a material depends on its ability to restrict the dislocations. The grain boundaries act as constraints to the grains. The grain boundaries are piled up against each other in the lattice. In case of a deformation, if the size of the grain boundaries is large, there would be a larger void in between them, so it is easier to pass the dislocations from one grain boundary to another grain boundary i.e. the force required to pass the dislocation is less. Thus, the strength of the material is considerably less. But, in case of smaller grain size, the force required to pass the dislocations is high because the grains are piled up tightly against each other and the strength of the material increases. There are several methods developed to reduce the grain size in order to obtain the desired properties of a material e.g. vapor deposition, high-energy ball milling, fast solidification and severe plastic deformation (SPD). In this paper, the achievements in the field of Severe Plastic Deformation Technology and the role of SPD in development of nanotechnology are explored.

II. SEVERE PLASTIC DEFORMATION:

Severe Plastic deformation is one of the methods for obtaining ultra-fine crystalline structure in different bulk materials and alloys, which possess different crystallographic structure. Though the mechanism of formation of ultrafine crystalline structure is under investigation, it is known that the application of higher range of shears on a single plane causes the formation of sub micro level crystalline structure. And the deflection in the material is insignificant.

Mechanism: SPD mechanism involves 4 stages. At first, when a plastic strain is applied, the dislocations are formed and they are rearranged into an elongated cell. Then it is followed by formation of sub grain due to the disorientation in the cells. This process repeats until there is a sufficient space available to sub grains to rotate. Further, the additional deformation causes the sub grains to rotate with high angle boundaries with equiaxed grain orientation. An SPD processed material can obtain ultra-fine grains ranging from 100nm to 200nm. There are several advantages of an SPD processed material than Nano structured material (NSM). SPD methods can overcome the problem of residual porosity and the formation of impurities in the material which is not possible by the regular nanotechnology methods. Unlike NSM, these methods can be applicable for large sized billets also. The experimental results [2] obtained during the X-Ray analysis of an SPD processed material says that the crystalline size of the material is reduced to 50nm. It is the reason, the SPD materials called as bulk nanostructured materials. Any SPD process is affected by two factors 1) Strain rate and 2) No. of passes. Strain rate is the rate of strain applied with respect to the dimension of the billet and the no. of passes is the no. of times the operation made on billet. By varying these two factors we can obtain desirable grain size.Valeiv [2] stated three requirements to obtain submicron level structure: 1) The material should have predominantly high angle boundaries 2) The structure must be uniform over the sample volume and 3) The large plastic strains should not generate internal damage or cracks. To meet these requirements, there are several methods developed under Severe Plastic Deformation. Some of them are ECAP (Equal Channel Angular Pressing), Reciprocating extrusion compression, HPT (High Pressure Torsion), CGP (Constrain Groove Pressing), ARB (Accumulative Roller Bonding) and Corrugation and Straightening.

III. METHODS OF SEVERE PLASTIC DEFORMATION:

ECAP (Equal Channel Angular Pressing):

The method of ECAP was developed by Segal [3] in the beginning of 80s. It is applicable for billets of square or circular cross section. Generally, the diameter or the diagonal length of the billet should not exceed 20mm [2]. In this method, the billet is pressed through a die using an equal channel angular facility in which the angle of intersection is 90^0. The billet is subjected to multiple pressing through the die. Sometimes ECAP is operated at different temperatures and different angles of intersection to obtain various desired properties. The die consists of two angles. Outer angle is designated by Φ and inner angle is designated by Ψ. The frequently used angles are 90^0 and 20^0respectively. At first, the billet is pressed through the dies (Route A) and subjected to defined plastic strain. Then the billet is taken out from the die, rotated trough 90^0 and pressed trough the dies again (Route BA). Then the billet is taken out from the dies and again rotated through 180^0 and pressed trough the dies (Route C).

For the first pass, the billet is acted by a pure stress. It causes the grains to develop a spherical cell form and when then the billet is rotated through 90^0, the cell is lengthened and takes an ellipsoidal form. This is due to the change in the shear plane. And when the billet is rotated trough 180^0, the strain is acted on the same plane as of pure strain but in the opposite direction. This operation causes the recrystallization of grains to a defined form and reduced grain size. For each pass of the billet trough the dies, the strain value increases and this increase in strain value results in the increase in resistance of the grains to the deformation i.e. By increasing the no. of passes, we can obtain more fine grain structure.

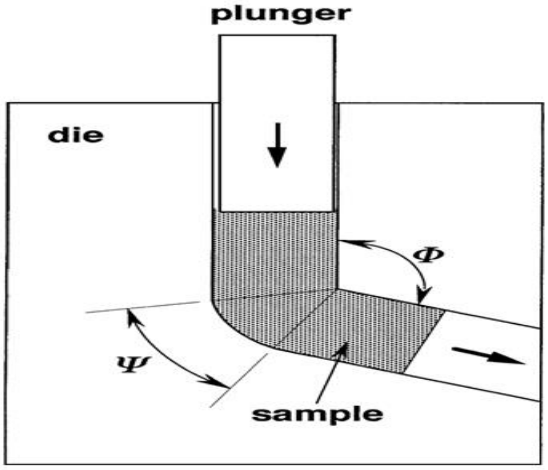

Fig.1.Schematic diagram of ECAP

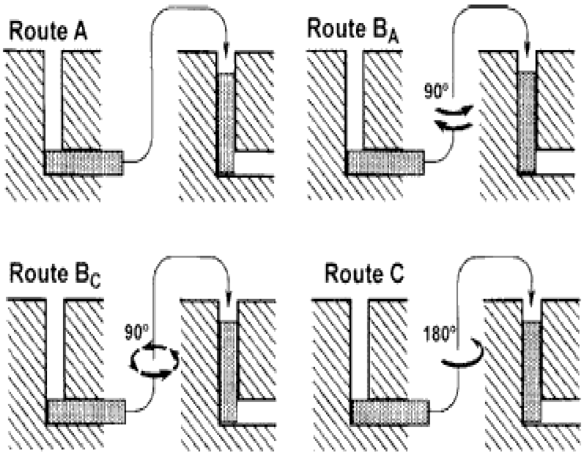

Fig.2.Different routes available for ECAP

CGP (Constrained Groove Pressing):

This method was developed by Zhu [4] in 2001.It is based on repetitive corrugation and straightening. This method includes two types of dies in which one is used as a corrugated tool and the other as straightening tool. The dies are designed on the basis of the loading conditions of the operation. It is applicable for rectangular plates and thin slabs. At first, the flat slab is placed between the corrugated dies and a pure plastic strain is applied on the slab. Then the slab is placed between the straightening dies and pressed between them. By the end of this process, the billet is partially acted by the strain. So, for the uniform distribution of shear, the slab is rotated through 180^0 and once again passed through corrugated and straightening dies. The arrangement of side plates is made to absorb the excess loadings and there are eight allen screws are arranged for proper alignment of the specimen and the dies. It is advantageous when it comes to large plastic strains unlike ECAP. But the strain distribution is not uniform. It may result in heterogeneous grain formation.

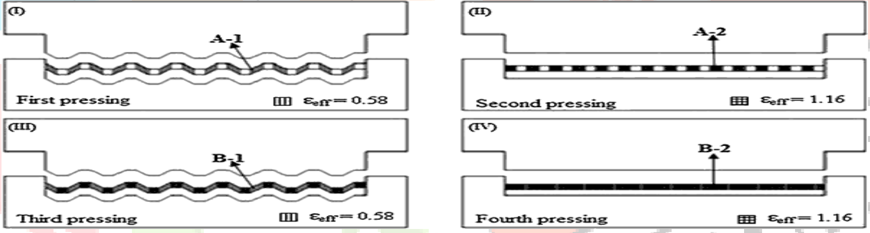

Fig.3.Schematic diagram for CGP and stages involved in it

HPT (High Pressure Torsion):

This method was investigated by Bridgeman [5] and developed by Erbel using copper.It is applicable for disk shaped billetsIn this method, there are two anvils are used in which one is fixed and the other is rotatable. The anvils are provided with cylindrical grooves and the disk-shaped billet is to be placed between the cylindrical grooves. At first, the billet is placed on the fixed anvil in the cylindrical groove and movable anvil is placed on the billet as shown in the figure. The movable anvil is rotated at higher speeds and stopped after certain number of revolutions. During the placing of anvils on the billet, a small amount of compression stress is applied on the billet and when the anvil rotates, the billet is subjected to a large range of long duration torsions. This makes the changes in the crystal structure and predominantly reduces the size of the grains. Here, the disks of smaller thickness can only be used since the shear distribution is not uniform for thick billets. A small region is created between the billet and anvil so as to prevent the anvils from damages.

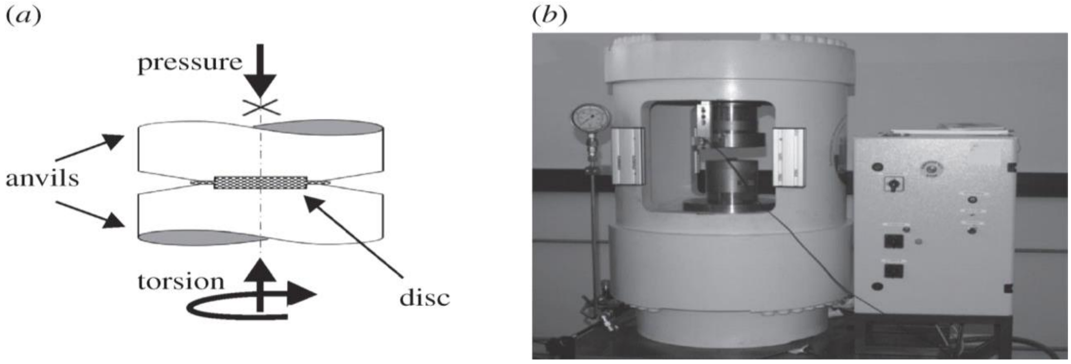

Fig.4. (a) Schematic diagram for HPT, (b) HPT equipment

ARB (Accumulative Roll Bonding):

ARB method [6] is applicable for sheet metals. It consists of two different sized rollers revolving at different speeds and different orientations and the sheet metal is to be passed through the gap between the rollers. At first, the sheet metal is treated with heat to the required temperature. Then it is passed though the rollers. Since the rollers are rotating with different speeds, the deviation in speeds causes the shear development in the sheet. Smaller the gap between the rollers, greater will be the shear development. After the sheet comes out from the rollers, it is cut by half and passed through the rollers again. According to the structural requirement, the sheet is folded and passed through the rollers several times.

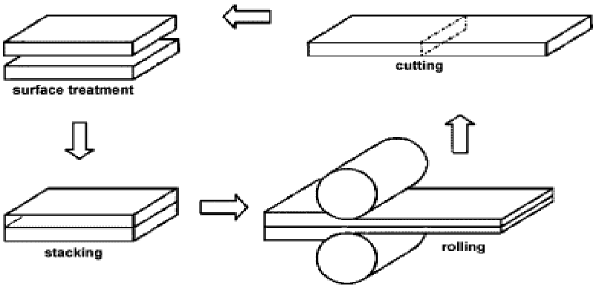

Fig.5. Schematic diagram for ARB

RCS (Repetitive corrugation and straightening):

This method is applicable for sheet metals. It is similar to CGP in operation. This method includes two types of dies, one is corrugated and the other is flat. At first, the sheet metal is pressed between the corrugated dies. The deformed sheet metal is the placed between the flat dies and pressed using a hydraulic press. This procedure is repeated until we can obtain the desired material properties. It can be easily adapted to current industrial rolling facilities. It has a potential to produce ultra-fine materials in a continuous and economic way.

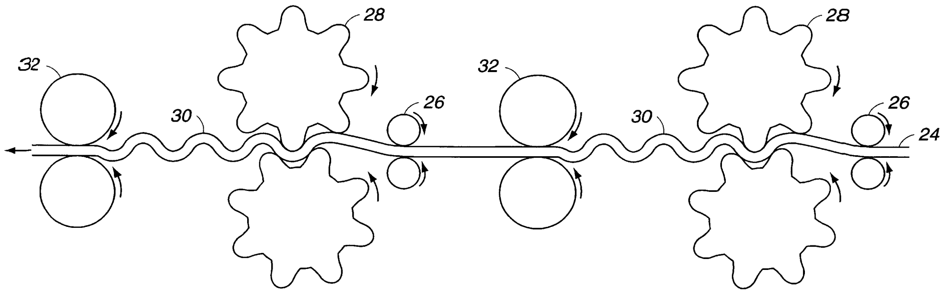

Fig.6. Schematic diagram of RCS

Multi directional forging:

This method was developed in 90s. It mainly deals with the dynamic crystallization of metals in single metal phase or alloys. Though the strain homogeneity obtained is less than that of ECAP and HPT, it can handle brittle materials in a better way. The process starts at elevated temperatures and the specific loads are relatively low. The principle of this process is to perform multiple repetitions of forging including setting and pulling with changes of axes of applied load.

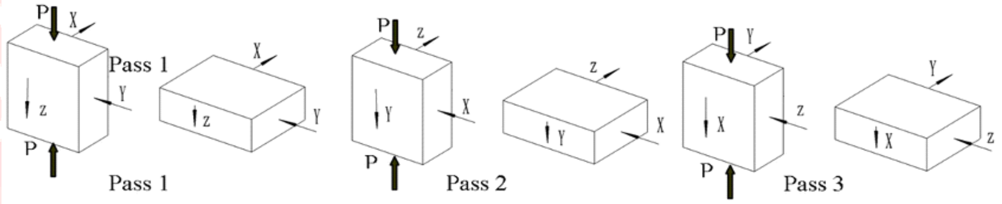

Fig.7. Multi direction forging operation

Cyclic extrusion and compression:

This method involves pushing of sample from one cylindrical chamber to another cylindrical chamber of diameter less than that of the first chamber. The first chamber provides the compression action on the sample and it is extruded into the second chamber. The sample is again acted by the compression force by the piston of the cylinder. Then the extrusion is reversed in the second cycle to give accumulated true strain. By increasing the no. of passes, we can obtain required properties of the extruded material. The strains developed during the extrusion process is higher when compared to ECAP and HPT, but the structure obtained by the similar to them due to extra annihilation of dislocations due to the cyclic character of straining.

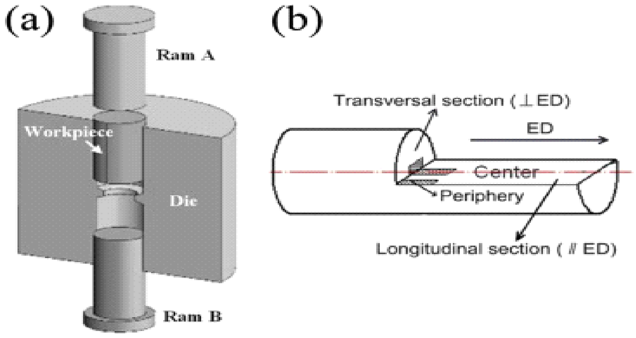

Fig.8. (a) Cyclic extrusion and compression set up *(b) work piece*

Twist extrusion:

This method was introduced in 2004. During the process, the billet is pushed through n extrusion die. The cross section of the work piece is maintained by the die. The work piece is twisted through a designated angle around its longitudinal axis and later it is twisted backwards and the work piece regains its shape. For every pass of the specimen, it is twisted through a specified angle and by the end of the cycle, the specimen regains its shape. The disadvantage of this method is that the strain distribution is not uniform throughout the specimen. This leads to inhomogeneous mechanical properties. By increasing the no. of possess we can reduce the non-homogeneity of stain distribution.

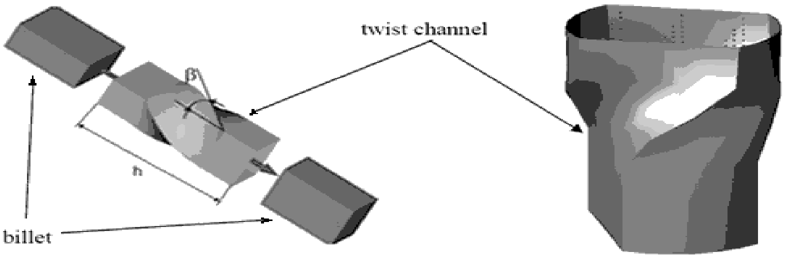

Fig.9. Twist extrusion

IV. ADVANTAGES OF SEVERE PLASTIC DEFORMATION

Strength and ductility are the most primary parameters of a material, which will assign all other mechanical characteristics. We can observe the change in the strength and the ductility in dependence to the grain size. So, it is easier to obtain the required amount of properties to the material. After the property of strength and ductility, fatigue and creep behavior also an important property to analyze. From the experimental results, it is known that the fatigue behavior does not strongly depend on the grain size. But, when ECAP is combined with some heat treatment processes, fatigue is observed in the materials. Thermal stability of low carbon steels can be improved by ECAP. We can improve the thermal stability by increasing the no. of passes. It improves the recrystallization of the material. Corrosion resistance also depends on the grain size. For improved fineness of the crystal, we can observe improved corrosion resistance. We can also observe improved fatigue resistance with smaller grain sizes.

V. DISADVANTAGES AND LIMITATIONS OF SEVERE PLASTIC DEFORMATION

It is known that the grain size of a material can be reduced to a certain level. But, when it reaches its saturation point, it cannot further reduce the grain size. Since, the fatigue resistance is less dependent on the grain size, it is not possible for all the SPD methods to improve the life span of the material. The thermal stability of certain SPD processed materials is unstable, In HPT, we cannot use billets of large thickness otherwise it may lead to non-uniform strain distribution. For more fineness, we have to increase the no. of passes. And sometimes it may lead to the failure of the specimen due to the increased pressure for each pass. The cost of the equipment is high and the maintenance cost is also high.

VI. APPLICATIONS

SPD processed materials has many applications in engineering discipline. We can obtain monolithic materials with sub-micron and Nano crystalline grain sized materials having improved mechanical properties. Also we can obtain Nano composites of light weight alloys with unpredictable strength. An SPD processed titanium has many applications in biomedical sciences. It is a fatigue resistant, corrosion resistant, high tensile strength and it is nontoxic in nature. We can obtain metal hydrides by impinging hydrogen into metal during SPD process. The cold rolled alloy AZ91D has faster dehydrogenation kinetics and the incubation time is less than that of magnesium. It is useful in many industrial applications. SPD steel has many industrial applications. SPD processed low carbon steel has high thermal stability. So, it can be used in high temperature conditions. It is also useful in automobile and aeronautical industries in making of the frames and body components.

VII. CONCLUSION

Severe Plastic Deformation is emerging technology in these days for developing fine grained materials effectively in a simple way. Though they are not sufficient to the requirements, they capable of serving good results. The important properties like strength can be increased but yield strength and fatigue are not completely studied under SPD. The study of corrosion resistance is less adequate and yet to be concluded.

VIII. REFERENCES

[1] E.O. Hall, Proc. Phys. Soc. London, (1951), N.J. Petch, J. Iron Steel Inst. London, (1953)
[2] R.Z. Valiev, R.K. Islamgaliev and I.V. Alexandrov, Progr. Mat. Sci., 45 (2000)
[3] V.M. Segal, V.I. Reznikov, A.E. Drobyshevkij and V.I. Kopylov, Metally 1 (1981), 115
[4] Zhu YT, Jiang H, Huang JY, Lowe TC (2001). Mater Trans 32: 1559-1562.
[5] J. Bridgmen, , M. Techizdat, ed., Moscow, p.230, (1936).
[6] N. Tsuji, Y. Saito, H. Utsunomiya, Scripta materialia 39 (9), 1221-1227