Texture and Anisotropy Symposium
DGM – SF2M

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Oral Presentations

Microstructure, texture and strength development during high pressure torsion of CrMnFeCoNi high-entropy alloy

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The equiatomic fcc high-entropy alloy CrMnFeCoNi was severely deformed at room and liquid nitrogen temperature (RT and LNT) by high-pressure torsion (HPT) at pressures up to 10 GPa and max. shear strains of about 290. The microstructure was analyzed by X-ray line profile analysis and transmission electron microscopy. The texture and phase transformation from fcc to hcp was measured by X-ray microdiffraction and diffraction of high-energy synchrotron radiation. The fraction of hcp phase after pressure release and heating-up from LNT to RT was determined by Rietveld analysis. Microhardness measurements after severe plastic deformation were done at RT. It is shown that at a shear strain of about 20 a steady state grain size of 24 nm and a dislocation density of the order of $10^{16} m^{-2}$ is reached. Mechanical twinning at RT depends on the shear strain. The amount of martensitic phase transformation depends on pressure, temperature and storage at RT. The texture developed is typical for sheared fcc and hcp metals. The strength of the nanocrystalline material produced by HPT at LNT is lower than that produced at RT. The results are discussed in terms of different mechanisms of deformation, including dislocation generation and propagation, twinning, grain boundary sliding and phase transformation.

Elastic strain induced abnormal grain growth in a graphene nanosheets (GNSs) reinforced copper (Cu) matrix composite

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The recrystallization texture that develops during annealing process of deformed polycrystalline metal is important as being largely responsible for the anisotropic mechanical properties of the materials. However, although lots of mechanisms have already been proposed, contradictions always appear in the results of different researchers, especially for the formation of cube texture in fcc metals. In our work, graphene nanosheets (GNS) reinforced copper (Cu) matrix composites were fabricated through electrophoretic deposition (EPD) and vacuum hot-pressing sintering process. The results from EBSD, neutron diffraction as well as synchrotron radiation diffraction all show that a strong cube component formed in the GNS/Cu, while the pure Cu sintered with the same method exhibits coarse grains with random orientations. Further elastic strain states and elastic strain energy analyses indicated that the abnormal growth of Cube oriented grains result in the lowest elastic strain energy. The obtained results provide us a new technique to obtain highly textured material from polycrystalline materials and reveal the mechanism of the recrystallization and strong preferential orientation mechanism of the laminated materials.

Formation of peripheral coarse grain in Al-Mg-Si profiles

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Safety components such as crash beams in cars, busses and trains are often manufactured from Al-Mg-Si profiles. In this application, they have to show high ductility in bending deformation and low susceptibility to corrosion. In both cases, the largest loading occurs initially at the surface and the sub-surface region. The performance is governed by the microstructure and texture developing during the extrusion process.

In the past, through-thickness variation of texture in different Aluminum alloys has been investigated extensively in sheet rolling. However, regarding Aluminum profiles this is mainly the case for the texture formation in the bulk. Therefore, our study investigates the microstructure and texture formation at a plane profile section in different Al-Mg-Si alloys of classes EN AW6005, AW6005A and AW6082, extruded at varying extrusion rates into the same profile geometry. The through-thickness variation of texture and microstructure (figure 1) distinguishes two zones, the bulk and the peripheral coarse grain layer (PCG). In the bulk, our investigation confirms the expected microstructure related to plane strain deformation. Depending on net driving force for recrystallization the microstructure shows either a fine-grained $\beta-$ fiber at low net driving forces or a coarse-grained cube orientation at high net driving forces, respectively. The formation and extent of the PCG is linked to the transition between the two types of microstructures in the bulk. The grains of the PCG layer grow under distinct orientations with a common <101>‖TD axis orientation into the $\beta-$ fiber microstructure until further growth is impeded with decreasing net driving forces for recrystallization by the formation of the coarse-grained cube-oriented microstructure. A mechanism of preferential growth of grains in the PCG is proposed by means of 40° {111} misorientation between the Copper Twin orientation in the PCG layer and the S component in the fine-grained bulk.

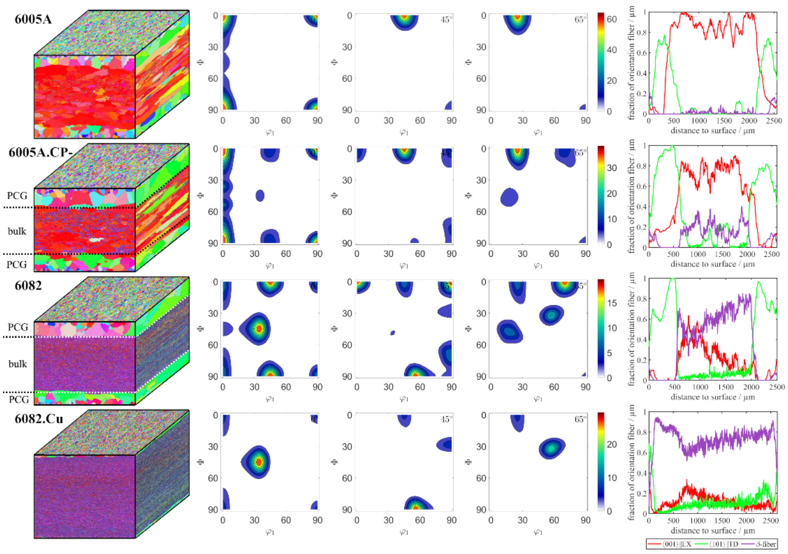

Figure 1: Microstructure cubes, orientation density function (ODF) maps and plot of orientation fiber distribution over wall thickness for alloys 6005A, 6005A.CP- and 6082 at 10 m/min extrusion speed. The microstructure cubes show grain and texture distribution within the profile in the PCG layer and the bulk. ODF maps of EX direction in ϕ_2- sections of 0 °/ 45 °/ 65 ° represent the macro texture. The fiber distribution shows the development of <001>‖ EX-, <101>‖ TD- and $\beta-$fiber content over the wall thickness.

The role of nano-segregation in the evolution of {411} <148> recrystallization texture in ferritic alloys

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Polycrystalline metals undergo crystal rotations during thermomechanical processing. Rolling of bcc metals into sheets, gives rise to the so-called rolling textures, consisting of alpha and gamma fibers. Subsequent annealing and recrystallization generally have a softening effect on the texture intensity, however, texture memory from earlier material processing stages is evident. In low-carbon steels, the final texture typically consists of the {111} <uvw> and {11h} <1/h 12> fibers. Within the latter, a rather interesting feature of the recrystallization texture is the {411} <148> texture component. This texture component is frequently observed in interstitial free (deep drawing applications) and electrical steels (magnetic flux carriers), yet the specifics of its origin and growth are not clear. Texture evolution can also be dramatically affected by alloying elements which tend to segregate on interfaces. In this study, we investigate the effect of Sn alloying in Fe-Si alloys and their static recrystallization behavior. To link crystallographic orientation preferences with chemical information, we use texture analysis with sequential electron back-scatter diffraction complemented with site-specific chemical analysis by atom probe tomography. High-stored energy nucleation of recrystallization is found to be greatly affected by Sn. An intriguing aspect of texture evolution with nano-segregation is that the recrystallization of the {411} <148> texture component is considerably strengthened. The effect of Sn on the nucleation and growth aspects of this texture component is then discussed.

The ~ {311} <136> Recrystallization Texture Component of Non-Oriented Electrical Steels

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Keywords: Electrical Steel, Recrystallization Texture, Oriented Nucleation, Selective Growth.

The ~ {311} <136> texture component frequently appears in the recrystallization texture of non-oriented electrical steels, either in the texture of the finished product or in an intermediate processing state. This paper presents a brief review of a number of features of this component. First, a precise description of the ~ {311} <136> component is presented, as this component is identified under different denominations in the technical literature. Second, it is reviewed what conditions may contribute to the development of the ~ {311} <136> component. Surprisingly, it is noticed that ~ {311} <136> orientations are omnipresent in the recrystallization texture of extra and ultra-low carbon steels, but only in rare occasions this component emerges as a dominant component of the macroscopic recrystallization texture. A necessary condition for the appearance of the ~ {311} <136> component in the macro-texture is the suppression of nucleation and/or growth of the conventional {111} orientations. Third, the mechanisms of nucleation and growth of ~ {311} <136> orientations are discussed in terms of the classical theories of oriented nucleation and selective growth. Various elements are listed that may enhance our insight in the origin in the deformed structure and its formation during recrystallization of this remarkable texture component

With what precision one can simulate an experimental texture obtained by plastic deformation?

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Modelling and simulation are powerful tools to shed light on the mechanisms that produce the evolution of anisotropy in polycrystalline materials. Efficient texture simulations are especially challenging, because of the 3D nature of the texture. When simulation results are compared to experiments, they are often done just by visual inspections, although direct numerical comparison is readily possible. The ATEX software creators included a texture comparison tool in their software package, which is able to characterize the degree of agreement between two textures by simple scalar quantities. This tool is used in several examples in this study for comparing simulated and experimental textures in various deformation conditions, with discussions about the mechanisms that are operating during plastic deformation of polycrystals.

Friction, wear, and texture

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Information on how to optimise the crystallographic texture of metallic materials to enhance their tribological properties is still very scarce. Nonetheless, texture analysis is slowly being introduced in the field because the evolution of microstructure and crystal orientation provides important information on the subsurface modifications induced during wear. The presentation will consist of two parts.

First, it will be shown how orientation mapping helps in the understanding of the specific wear rates of cold-rolled copper (CR) annealed at 600° for 15, 30 and 45min. Contrary to common belief, the softest metal in this set shows the lowest wear rate. The friction coefficient also decreases as annealing time increases. Inverse pole figure maps show that the subsurface microstructure is more strongly refined in the hardest materials. These also show textures which are similar to the ones observed in severe plastic deformation introduced by shear, while the texture of the material annealed for 45min is more reminiscent of a torsion texture induced by lower strain levels. It was therefore concluded that all samples are modified by the same process, but this process evolves more slowly at lower friction coefficients, because work transfer to the substrate is slower. Second, a brief analysis will be presented on what can be learned from wear experiments in terms of the fundamental metallurgical processes in severe plastic deformation. Inverse pole figure maps were produced along the microstructural gradient induced by sliding friction in cold rolled copper and the same material after annealing for 45min (RX45). Static annealing occurs in CR at approximately 130μm from the surface, under the driving force of the additional plastic strain induced by the wear process. Above this level, both in CR and RX45, the misorientation distribution and kernel average misorientation (KAM) provide evidence of a process where the accumulation of misorientation by dislocation absorption in grain boundaries competes with the formation of a new substructure in the grain interior. The top layer of CR shows clear evidence of dynamic recrystallisation, with a smaller grain size, low KAM and a reduced nanohardness as compared to the underlying microstructures.

Nucleation texture prediction of rolled IF Steel based on the Advanced-Lamel Crystal Plasticity Model.

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Plastic deformation induces heterogeneities in dislocation density and preferred crystallographic orientations in the microstructure of polycrystalline materials. During the early of the recrystallization process, rearrangement of dislocations may generate migration of high angle grain boundaries, which gives rise to strain-free crystallite volumes, the so-called recrystallization nuclei. In this regard, the nucleation process of recrystallization strongly depends on the pre-existing deformation state. Therefore, an accurate description of the deformed state of the polycrystalline aggregate might provide sufficient information to predict the possible nucleation texture. This presentation addresses the prediction of nucleation textures in cold rolled IF-steel samples based on the crystal plasticity (CP) simulations performed with the Advanced-Lamel (ALAMEL) model. The current approach shows that the nucleation texture of recrystallization can be simulated with reasonable accuracy through the simultaneous implementation of two nucleation laws. The first law is based on the absolute value of the plastically stored energy, whereas the second emulates the Strain Induced Boundary Mechanism (SIBM) by considering the gradient of the Taylor factor between crystal orientations forming a pair in the ALAMEL crystal plasticity simulations. The obtained results capture some features of the nucleation texture that cannot be obtained by applying the two nucleation laws separately.

Facet-3D: a crystal plasticity-based yield function for sheet metal forming simulations

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Plastic anisotropy of the material is a key factor which should be appropriately captured by the yield function and reflected during the finite element (FE) simulation. Whereas phenomenological yield functions fitted to experimental data can do this for several deep drawing alloys, they may fail in modelling the behaviour of alloys with pronounced anisotropic properties. We present a generic while efficient crystal plasticity based yield function, Facet 3D, which can be used for the simulation of sheet forming processes assuming generalized plane stress conditions. In this study, the performance of Facet-3D for a cup drawing simulation of A6016-T4 aluminium alloy from ESAFORM 2021 benchmark is demonstrated. Predicted cup height and punch force values are compared with the experimental data as well as those obtained by FE simulations with other phenomenological yield functions. The simulations were carried out by implementing Facet 3D into AutoForm R10 as an R&D Plugin material.

Crystal plasticity simulation of in-grain microstructural evolution during large deformation of IF-steel

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High-resolution three-dimensional crystal plasticity simulation and electron backscatter diffraction (EBSD) analysis are used to investigate deformation heterogeneity and microstructure evolution during cold rolling of interstitial free (IF) steel. The in-grain texture evolution and misorientation spread are consistent for simulation and experimental results. Crystal plasticity simulation shows that two types of strain localization develop during the large deformation of IF-steel. The first type forms areas with large strain accumulation that appear as river patterns extending across the specimen. This type of shear localization is non-crystallographic and can be seen as a cluster of shear bands. In addition to these river-like patterns, a second type of strain localization with rather sharp and highly localized in-grain deformation bands is identified. These localized features are dependent on the crystallographic orientation of the grain and extend inside a single grain. In addition to the strain localization, the evolution of in-grain orientation gradients, dislocation density, kernel average misorientation, and stress in major texture components are discussed.

Poster Presentations

Anisotropic behaviour of magnetic ageing of electrical steels

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Magnetic ageing is characterized by the increase in iron losses of soft magnetic steels in the core of electrical devices during the operation of the machine at moderate temperatures, typically 200° C. The degradation of in-service efficiency is attributed to the formation of precipitates, carbides or nitrides, in the microstructure that alter the movement of magnetic domain walls. Based on the link between the evolution of macroscopic magnetic properties (effect) and microscopic precipitation (cause), the Johnson –Mehl – Avrami – Kolmogorov (JMAK) law describing the kinetics of precipitation was used to model the time evolution of iron losses with the magnetic ageing. In this study, measurements of the evolution of magnetic properties as a function of the magnetic excitation direction (RD or TD) evidenced the anisotropic behaviour of such materials with respect to magnetic ageing. Such behaviour has to be linked to the morphology and orientation relationship of the precipitates with regard to the domain walls mobility under magnetic excitation and texture of the base material.

A Novel Approach to Control Strength-Ductility Balance of Medium-Mn Q&P Steel via Purposely Retaining Ferrite

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In this work, two low-density medium-Mn Q&P steel are compared, and a new control strategy for mechanical properties is proposed. Compared with the common composition system of C-Si-Mn, Al added significantly expands the temperature range where Ferrite (F) exists. During the heating process, the recovery and recrystallization of F compete with austenitization, which effectively inhibits the coarsening of austenite. Secondly, F significantly affects the recrystallized texture of medium-Mn steel, which affects the subsequent austenite nucleation and growth. Thirdly, deliberately retained F effectively segments and refines fresh martensite-austenite (M/RA) islands, which can significantly improve the strength and ductility simultaneously. The results show that the strength-ductility combination of medium-Mn Q&P steel can be extremely improved by introduce F. After being subjected to an annealing temperature of 860° C, the M/RA constituents show a finely, uniformly granular morphology, thereby obtaining excellent elongation of 24%, extremely high ultimate tensile strength (UTS) and yield strength (YS) of 1345MPa and 1163MPa, respectively, and the product of strength and elongation (PSE) is greater than 32GPa%.

Microstructure and texture development during printing of Fi-Ni alloy on a ductile cast iron substrate by Wire and Arc Additive Manufacturing

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Keywords: Wire and Arc Additive Manufacturing, Ductile cast iron, Ni-Fe alloy, Microstructure and texture.

In the present work, we explore the deposition of a Fe-55%Ni alloy on a ductile cast iron substrate using the Wire and Arc Additive Manufacturing process. The macrostructural observations revealed that the interfacial region between the substrate and deposited alloy can be divided in two different subregions including the heat-affected zone (HAZ) and the partially melted zone (PMZ); the microstructure of each region was analyzed. It also was found that the microstructure of the deposited alloy consists of large elongated ɣ(Ni, Fe) phase grains along the building direction. The formation of some cracks was observed within the deposited layers as well as the PMZ. The texture measurements also showed that <100> II building direction is the main texture component of the deposited alloy.

Crystallographic characterization of representative volume element in DP steels

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Keywords: Automotive body, 3D EBSD characterization, Microstructure, Representative volume element.

Representative volume elements are required for full-field finite element simulations to predict the forming behavior of an automotive body part directly from the microstructure. Therefore, the 3D reconstructed volumes and the corresponding microstructural properties are presented for two grades of steels using wide-field 3D-EBSD measurements. Although 3D-EBSD characterization provides more realistic data of the grain morphology in the microstructure, it is a time-consuming and tedious in terms of data acquisition. Therefore, it raises the question if 3-D EBSD measurements cannot be substituted by extracting statistical data from conventional 2D measurements. Therefore, it is necessary to evaluate the reliability of 2D characterization statistics compared to 3D. In this regard, a 2D characterization was found to be sufficient to obtain representative texture and grain size information. Statistics of certain microstructural state variables derived from 2D data are as reliable as those obtained from 3D data, with the exception of geometrical features of the microstructure.