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Design of product properties by suitable planning of a cold forging process

Oblikovanje lastnosti izdelka z ustreznim načrtovanjem procesa hladnega kovanja

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Abstract

One of the main advantages of the cold forming technology is improvement of mechanical properties such as tensile strength and hardness. At cold metal forging the hardness increases by plastic deformation, also known as work hardening. The degree of plastic deformation is represented by equivalent plastic strain. It is generally accepted that the mechanical property such as hardness are directly related to equivalent plastic strain. If the operating sequence to manufacture a certain product by cold forging is suitably planned, the required value of equivalent strain or appropriate hardness in the product's cross-section is achieved. The paper deals with planning of mechanical properties in manufacture of antivibration elements for the needs of the automotive industry and hubs of magnetic ignition systems for the motorcycle industry. At the production of antivibration elements the resistance to permanent plastic deformation in the case of axial dynamic loading of a product have to be assured, while in the case of hubs of magnetic ignition systems the appropriate hardness in the product's cross-section has to be achieved. A reliable design of the desired mechanical properties of products is assured by suitable planning of the forming processes in the virtual environment with the support of numerical simulations.

Key words: cold forging, product property design, hardness, FE simulation

Izvleček

Ena izmed glavnih prednosti hladnega preoblikovanja je izboljšanje mehanskih lastnosti izdelka, kot sta natezna trdnost in trdota. Pri hladnem preoblikovanju trdota narašča s plastično deformacijo, kar je poznano kot hladno utrjevanje. Stopnja plastične deformacije je izražena z ekvivalentno plastično deformacijo. Splošno je znano, da je mehanska lastnost, kot je trdota, direktno povezana z ekvivalentno plastično deformacijo. Če je preoblikovalno zaporedje za izdelavo izdelka ustrezno načrtovano, lahko dosežemo zahtevano ekvivalentno deformacijo oziroma ustrezno trdoto po prerezu izdelka. Članek podaja načrtovanje mehanskih lastnosti pri izdelavi antivibracijskih izdelkov za potrebe avtomobilske industrije ter pest magnetnih vžigalnikov za potrebe industrije motornih koles. Pri antivibracijskih elementih moramo zagotoviti odpornost proti trajni plastični deformaciji v primeru aksialne dinamične obremenitve izdelka, medtem ko pri pestih magnetnih vžigalnikov z ustrezno trdoto po prerezu izdelka zagotavljamo obratovanje pri visokih vrtljajih. Zanesljivo oblikovanje želenih mehanskih lastnosti izdelkov lahko zagotovimo z načrtovanjem preoblikovalnih procesov v virtualnem okolju ob podpori numeričnih simulacij.

Ključne besede: hladno preoblikovanje, oblikovanje lastnosti izdelka, trdota, simulacija z MKE

Introduction

From the perspective of production processes, cold forming (CF) is one of the most important technologies which enable production of geometrically demanding and accurate products. The CF technology aims at plastic deformation of a blank from simple initial forms by the forming process to a product of a complex form and dimensions. The main reasons for using the CF technology mostly in the automotive industry are as follows[1–3].

— Great accuracy of dimensions and good surface qualities in mass manufacture of products,
— Efficient material use; generally smaller refinishing operations, including machining, are required,
— Improved mechanical properties as a result of hardening in cold, the fibres flow is uninterrupted and adjusted to the product loading, which enables the products to withstand greater dynamic loads and to be lighter accordingly,
— Technology is economical and environment friendly.

In cold plastic deformation, the material is hardened. This causes structural changes of material. Grains are elongated in the direction of the main deformation. Owing to the material hardening, there are changes of mechanical, physical and chemical properties of metal (Figure 1). By greater deformation, true stress, tensile strength, material hardness, and electrical resistance increase. At the same time reduction of elongation, contraction, impact toughness, resistance to corrosion, heat conductivity and elasticity module occur.

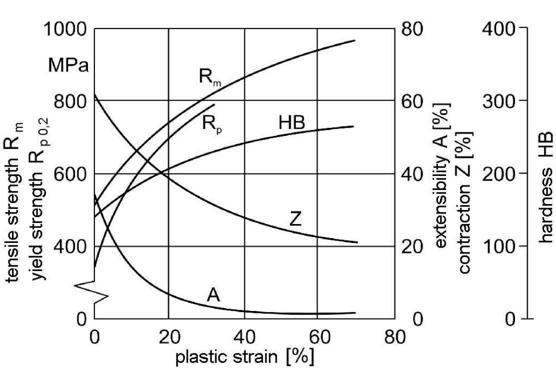


Figure 1: *Changes of mechanical properties as a consequence of cold forming process.*

Up to now many researches have been made towards predictions of mechanical properties of a product. If we are familiar with the ratio between the hardness and effective strain of the formed part material and the strain flow of the formed part, we can predict the course of hardness of a cold-formed part. Kim et al. performed a pressure test by the help of an experiment and FE simulation for the steel AISI 1010[4]. Hardness values regarding pressure test and effective deformations from the FE simulations have been analysed in the same point of a formed-piece. The curve and/or ratio between the hardness and the effective strain were acquired by a regression analysis. In the next study, a similar analytical model for hardness prediction of a formed piece was presented, which is based upon the known effective strain that was achieved by the FE analysis of a formed-piece[5]. The model was confirmed by an experiment, so that hardness prediction of a formed-piece is quite accurate. Tekkaya[6] carried out an analysis of final imprinting in a cold-formed part in order to find equivalent Vickers hardness and to gain the ratio between the Vickers hardness and the flow stress. Mechanical properties of a product like hardness, yield stress, elongation, residual ductility and tensile test depend directly on the equivalent deformation caused in cold forming. The article by K. Osakada and J. Yanagimoto[7] emphasizes that distribution of an equivalent deformation of the formed-piece is gained through the FE simulation and in this way we can – by a suitable ratio – define the course of mechanical properties of a product. D. Biermann et al. recommended a new way of product manufacture, which already at the planning stage considers the real material properties defined by a production process (Figure 2), while the classical way of a product planning considers only ideal material properties[8]. In this way, knowledge on local material properties are gained in tensile tests, damages, other stress, textures and micro structures used already in the process of planning, what enables product manufacture true to size. Safety factor and product weight are in this way substantially reduced, which results in reduced consumption of energy in primary production of materials as well as in the later use of a product.

Hardening in cold forming can be used to one's advantage in product manufacture, where specific product properties like a defined hardness in the product cross-section or specified tensile stress are required. By suitable planning of the forming operation sequence required for a product manufacture, we can achieve the specified mechanical properties of a product. Schematic course of the process steps for a suitable planning of mechanical properties of a product with the forming process is shown in Figure 3. In this kind of planning of the specified mechanical properties, one has to pay attention to obtain a healthy product in the cross section cut, which means there are no damages of the product.

The purpose of this paper is to show planning of the specified mechanical properties in the products by the cold forming technology for the needs of the automotive and motorcycle industries. First example shows planning of manufacture of the automotive antivibration bush, where in case of axial dynamic loading of a product resistance to permanent plastic deformation is required. The second example shows manufacture of a hub of magnetic ignition system for the needs of motorcycles with the requirement for a suitable tensile stress in the product cross-section. We can assure a reliable planning of the desired mechanical properties of products by creating the forming processes in the virtual environment with the support of numerical simulations.

Requirements for the manufacture of an antivibration busch

During driving, the car is subject to various vibrations both for external impacts, caused by the roadway, and internal impacts resulting from various drive elements. The external impacts caused by the roadway can be insulated by tyres with mufflers and dumpers, while the internal vibrations are insulated by antivibration elements. Figure 4 shows over 20 different antivibration elements, which are built into a car in order to insulate vibrations. These are elements that are used as vibration insulation as for example in vibrations from an engine, exhaust system, suspension etc. Usually these are steel, tube-like parts, whose external surface if potted by rubber. In MAHLE Letrika we make various tube-like elements for the needs of antivibration elements (Figure 5(a))[9]. These metal tube-like elements are made by the cold forming technology. The product requirements include a specific form and resistance to permanent plastic deformation. Such form and resistance can be achieved only by the cold forming technology. Figure 5 (b) shows the allowed plastic deformation in case of axial dynamic loading of a bush.

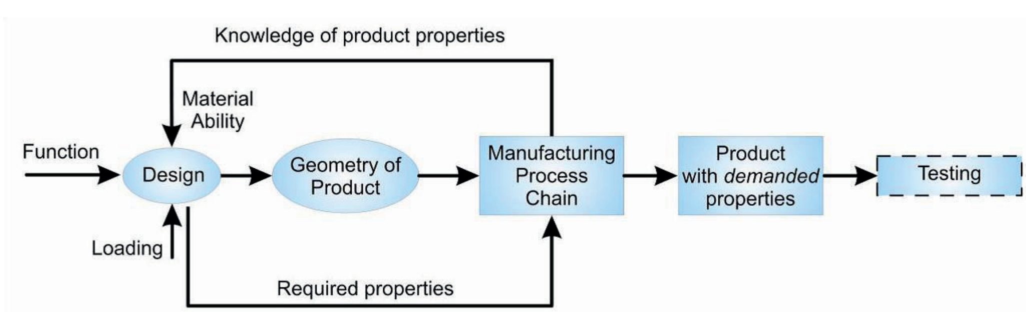


Figure 2: *New approach in designing and manufacturing products[8].*

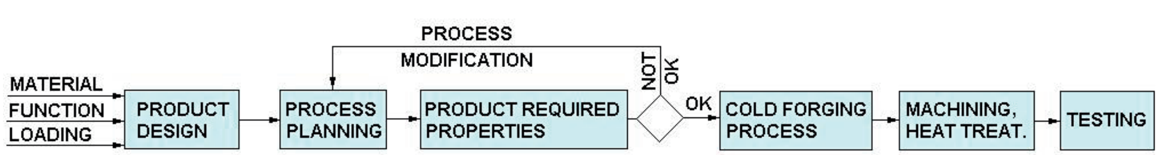


Figure 3: *A flow chart for design product properties by suitable planning of the cold forging process.*

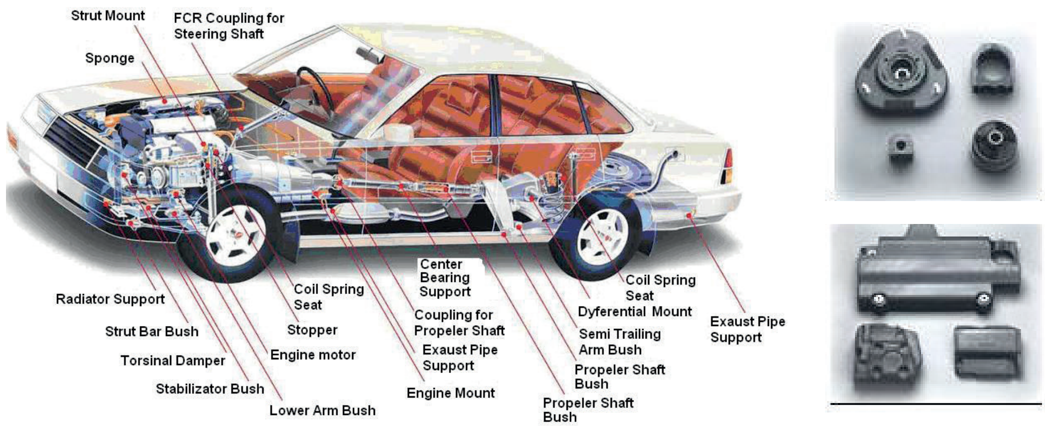


Figure 4: *Various antivibration elements built in a car.*

(a)

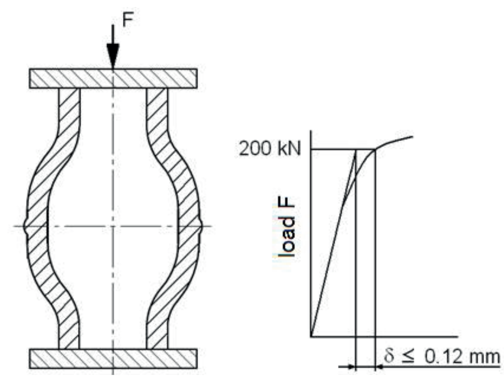

(b)


Figure 5: *(a) metal tube-like parts of antivibration elements, (b) allowed plastic deformation in loading of an antivibration bush.*

Planning of antivibration busch by CF technology

To make a steel Ck 25 (DIN) bush, double passing through the press is required. In the first passing, operations follow in the sequence from (a) to (d) as shown in Figure 6. First, we plan the initial blank, which has previously been annealed and surface-treated by a phosphate and molybdenum disulphide, to a suitable external diameter. Then, the subsequent operations follow: centring, backward extrusion and bottom punching. After the first passing, the formed-piece is annealed properly and again surface-treated. In the last operation (e), reduction/narrowing of the upper part of the pre-form to the appropriate final form is made. We planned the operation sequence and metal flow during the pre-forming operation by the help of the programme DEFORM 2D[10].

The final bush form and material hardening during the forming process have to ensure the requirements regarding the plastic deformation in case of an axial loading (Figure 5(b)). Figure 7 (a) shows the flow of effective deformations in the product cross-section simulated by the FE method. The upper curve in the diagram (Figure 8) shows the impact of loading on the permanent plastic deformation analysed in the virtual environment. A cold formed bush achieves permanent plastic deformation of a few hundredths of a millimetre in case of loading by 200 kN, which is within the limits of the allowed deformation 0.12 mm. The results have been confirmed also by physical tests in production. We were interested also in what would the resistance be if a bush was made by the machining procedure and/or in the non-hardened condition (Figure 7 (b)). In this case, we exceed the permanent plastic deformation already at loading of 120 kN as shown in the lower curves in the diagram (Figure 8). Even at full non-hardened bush (Figure 7 (c)) the situation is essentially the same as at non-hardened bush. A critical section is the same in both bushes.

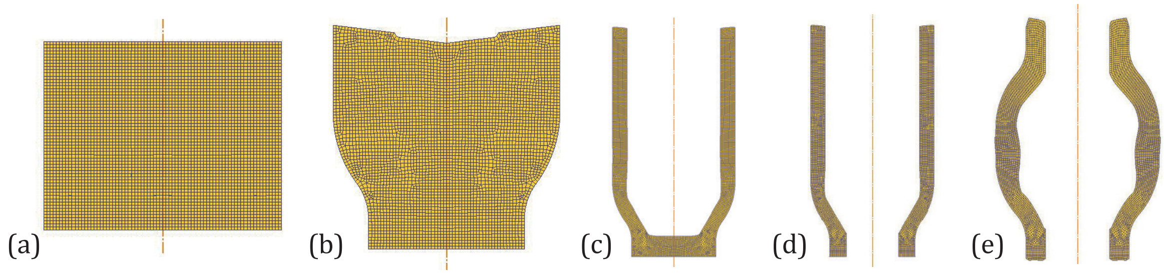


Figure 6: *Operational plan of the forming operation sequence for manufacture of a bush.*

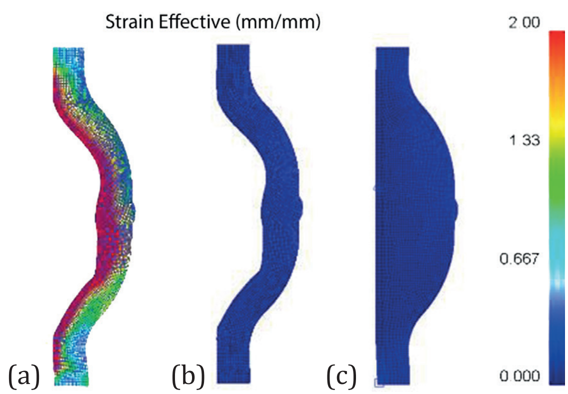


Figure 7: *(a) CF bush - hardening in the cross-section, (b, c) non-hardened bush.*

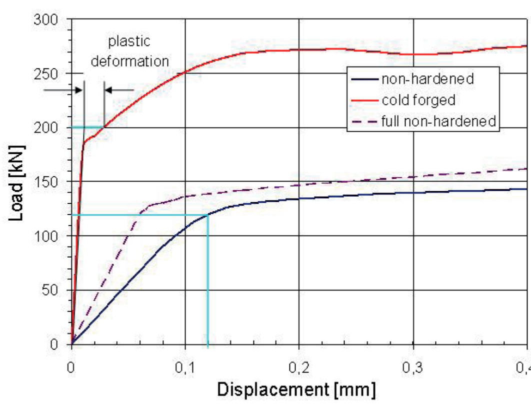


Figure 8: *Plastic deformation of a bush in dependence on loading.*

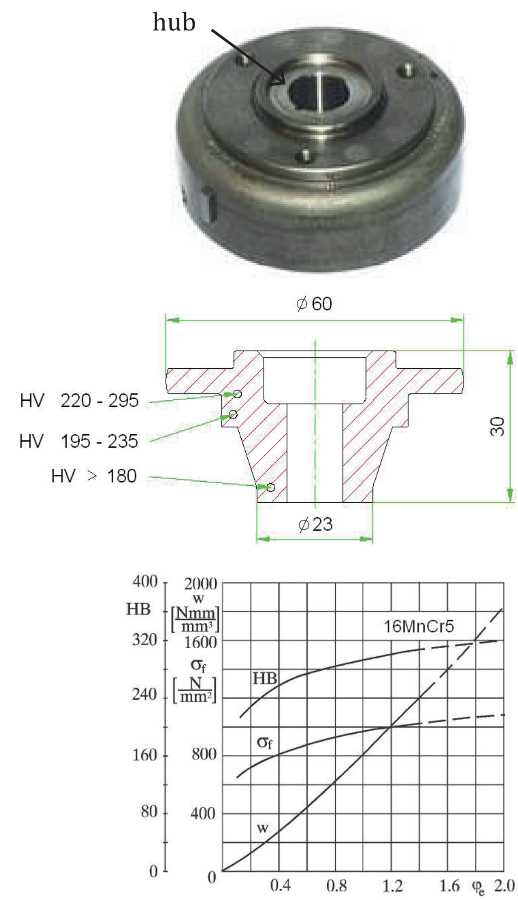


Figure 9: *The flywheel, hub of magnetic ignition system and hardness in dependence on the true strain for steel 16MnCr5.*

Requirements for a hub of magnetic ignition system

The next example of improved mechanical properties is shown in manufacture of a hub of magnetic ignition system. A hub is a component element of the magnetic ignition system, which is used in motorcycles (Figure 9). The hub's job is to transfer the torque from the shaft to the flywheel at a high rotational speed. A basic requirement of a hub made of steel 16MnCr5 is that it has a suitable hardness in the cross-section, which in this way ensures product hardness.

An appropriate hardness in the product cross-section is achieved when a hub is made by the cold forming technology. The forming processes have to be planned so that they ensure a suitable deformation in the desired product points. Bigger deformation at the same time denotes greater hardness as shown in the diagram in Figure 9. Attention has to be paid so that deformation does not exceed the critical limit, which could cause material damage.

Planning of an appropriate hardness in the hub cross-section

As already described in the introduction, the cold forming technology enables improvement of mechanical properties due to material hardening during a forming process. Planning of an appropriate hardness in the product cross-section by the cold forming technology depends on the following factors:

- It is necessary to have data on the forming properties of a material at disposal. Figure 9 shows the curve of the flow stress σf, the curve of the hardness HB and the specific forming work w from the size of the true strain ϕe for steel 16MnCr5[11],
- Available hardware such as presses, number of forming operations that can be carried out in one passing through the press,
- Software to make simulations of material flow and hardening during the forming process. Experimental appraisal of hardness is connected to great costs in respect of tool making, test implementation on a press, measurement of hardness in the formed-piece cross-section etc.
- Knowledge and experience in the field of CF metals. Definition of optimum sequence of forming operations is required, which on one hand enables achieving of the suitable hardness in the product cross-section and on the other hand as long tool life as possible, automatic operating of the formed pieces during passing through the press etc.

The forming process is planned at the end, i.e. from the final form to the initial blank. First, we design a suitable pre-form for the final operation. In Figure 10 (a), (b) two pre-forms are made and flow of an appropriate effective strain of a product gained by the FE simulation. Based on the comparison we can make an analysis about the pre-form (a) causing bigger effective deformations on the final product, while the pre-form (b) ensures a more homogeneous deformation, which pretty well meets the requirements regarding the distribution of the required hardness in the product cross-section. However, to optimize a suitable pre-form more FE simulations have been made, Figure 10 show only two of them.

Figure 11 shows the sequence of the forming operations gained by the FE simulation method. The machined-piece with a suitable product weight is first surface treated. The forming operations follow from operations (a)–(c) for the first passing through a vertical mechanical stress 630 t. Heat treatment follows, then the pre-form (c) process annealing and surface treatment, and the second passing through the press for operations (d)–(g). The simulated hardness flow in the product cross-section is shown in Figure 12. The highest hardness is achieved in the lower and upper side of the flange and in the inside of the hub hole.

The hardness flow meets the hardness of the product requirements. Approval of suitable planning of the forming operation sequences and hardness in the hub cross-section is acquired only in the product mass production. Inspection of cold-formed hubs showed that hardness meets the planned/required hardness in the product cross-section well. An accurate analysis of the product micro-structure is required in order to determine possible material damages due to local hardening and/or forced flow of material.

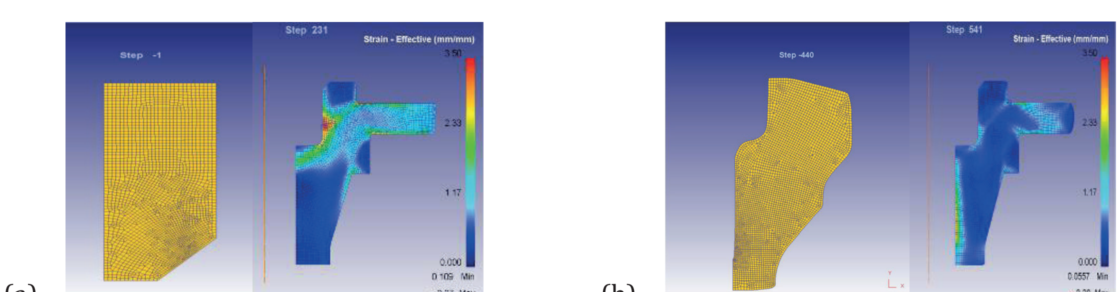


Figure 10: *(a), (b) various pre-forms and flow of the effective strain in the product final form.*

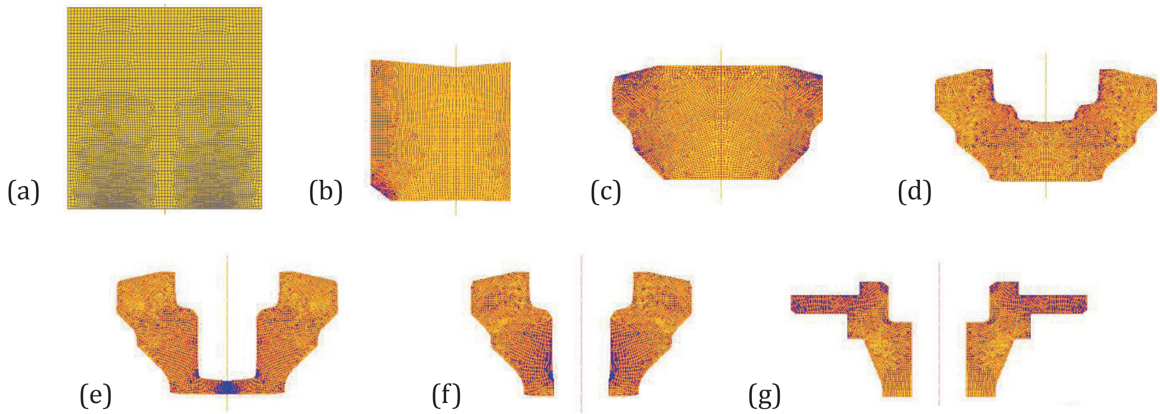


Figure 11: *Sequence of the forming operations for the manufacture of the hub of magnetic ignition system.*

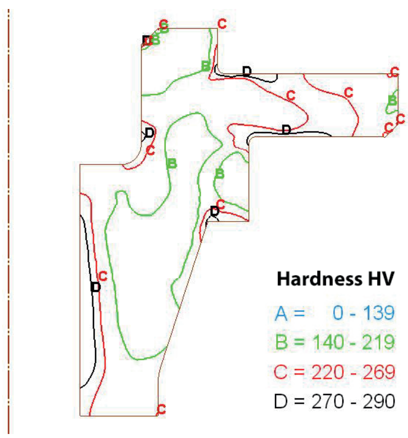


Figure 12: *The hardness flow in the hub cross-section simulated by the help of FE simulation.*

Conclusions

The paper deals with planning of suitable mechanical properties in a product by the CF technology. Two examples of product manufacture for the needs of the automotive industry and industry of motorcycles are shown, in which the functional requirement is a product resistance against the permanent plastic deformation in case of an axial loading and distribution of suitable hardness in the product cross-section. By the support of a FE simulation and suitable planning of the forming operations sequence we can ensure the specified functional requirements in the products and thus make a good use of the advantages offered by the CF technology.

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