

Prednosti in omejitve pri uporabi materialov z oblikovnim spominom za praktične uporabe

The Advantages and Problems of Using Shape-Memory Materials in Practical Applications

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Novi materiali omogočajo v strojništvu doseganje ciljev, ki do odkritja teh materialov niso bili uresničljivi. Razvoj materialov se usmerja predvsem k izboljševanju najpogosteje zahtevanih lastnosti, nekateri materiali pa izkazujejo določene posebnosti, zaradi katerih je področje njihove uporabe še posebej široko. Med slednje spadajo tudi materiali z oblikovnim spominom, ki so pod vplivom temperaturnih sprememb zmožni spreminjati obliko in pri tem tudi opravljati delo. V prispevku so opisane posebnosti teh materialov ter njihove prednosti in pomanjkljivosti pri uporabi za praktične primere.

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(Ključne besede: materiali pomnilni, spomin oblikovni, superelastičnost, varovala termična)

New materials lead to advances in mechanical engineering, advances which could not be realized before these materials were discovered. In most cases, materials are developed to improve their most frequently used properties, but some of these materials also exhibit specific properties which make them useful in a wide variety of applications. An example are the shape-memory materials, which, under the influence of temperature changes, are capable of changing their shape and producing work. In this paper the specific properties of shape-memory materials and the advantages and disadvantages of using these materials in practical applications are discussed.

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Materiali z oblikovnim spominom so pri segrevanju oziroma ohlajanju prek določenega temperaturnega območja zmožni spreminjati obliko iz deformirane v prvotno in nasprotno. Čeprav so jih odkrili že pred več desetletji in bi lahko njihove lastnosti uporabljali v mnogih, zelo različnih primerih, so ti materiali oziroma njihove lastnosti mnogim še vedno neznani. V raziskovalne namene je bilo preučeni že mnogo možnosti uporabe, vendar pa je le redko uporaba teh materialov res nujno potrebna. V večini primerov je zaradi njihove visoke cene, ki se zaradi povečevanja uporabe teh materialov sicer znižuje, vsaj za zdaj še vedno ceneje uporabiti običajne materiale, želena gibanje, ki bi ga drugače opravljali elementi z oblikovnim spominom, pa omogočiti z uporabo elektromotorjev, pnevmatskih in

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If heated or cooled through a certain temperature range, shape-memory materials can change their shape from deformed to original or vice versa. Even though they were discovered decades ago and their properties have been used in various applications, these materials are still unknown to many people. Scientists have already found many ways to use shape-memory materials, but in only a few cases is the use of these materials really necessary. Shape-memory materials are expensive, however, their increasing use is leading to a reduction in these costs. In most cases it is still less expensive to use standard materials, with the movement - which would otherwise come from the shape-memory elements - provided by electromotors, hydraulic or

hidravličnih ventilov ali kako drugače. Pri tem pomeni največjo težavo dejstvo, da so cenovno najbolj neugodne prav TiNi zlitine, ki imajo najboljše mehanske in oblikovne spominske lastnosti in se zato uporabljajo v skoraj 90% uporab. Raziskovalci so sicer odkrili že mnogo cenejših materialov z oblikovnim spominom, vendar pa so le redki od teh primerni za uporabo v praksi. Razlogi za to so premalo izrazita lastnost oblikovnega spomina, izgubljanje te lastnosti med uporabo ter zahtevna izdelava in termomehanska obdelava. Poleg TiNi in Cu zlitin, ki so že precej raziskane in se tudi največ uporabljajo, raziskujejo učinek oblikovnega spomina predvsem še v Fe zlitinah, ki obetajo nižjo ceno. Cenovno gledano je torej uporaba materialov z oblikovnim spominom ustrezna le v primeru, če so elementi iz teh materialov dovolj majhni.

Naslednja težava je izdelava takšnega elementa. Materiali z oblikovnim spominom so sicer na voljo v različnih oblikah, v različnih termomehanskih stanjih in z različnimi temperaturami, pri katerih pride do spremembe oblike, vendar ima načrtovani element v mnogih primerih povsem specifično obliko in tudi želene termomehanske lastnosti so pogosto drugačne od lastnosti materialov, ki so na voljo. V tem primeru lahko element želene oblike in z ustreznimi termomehanskimi lastnostmi izdelata kar proizvajalec materialov z oblikovnim spominom, vendar pa ima to za posledico še večje stroške in daljšo čakalno dobo.

1 TEMELJI OBLIKOVNEGA SPOMINA

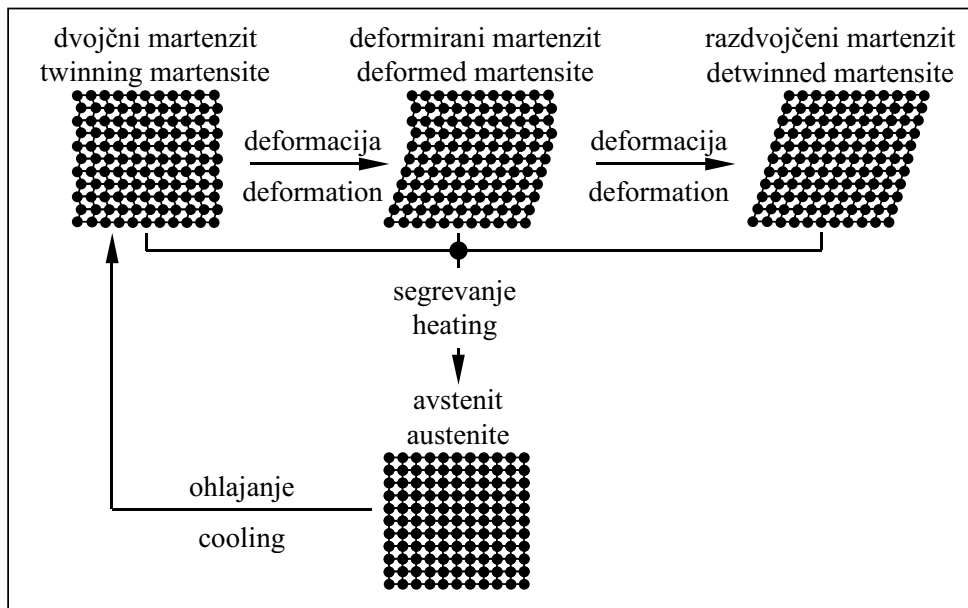
Osnovo oblikovnega spomina pomeni nasprotna martenzitna transformacija, ki se pojavi pri segrevanju dovolj malo plastično deformirane nizkotemperaturne faze. O martenzitni transformaciji običajno govorimo pri kaljenju jekel, vendar pa jo lahko najdemo tudi v materialih z oblikovnim spominom. Z martenzitno transformacijo namreč v splošnem označujemo brezdifuzijski način nastajanja nove faze, pri katerem pride do strižnega premika atomov, med katerim se atomi v posameznih kristalnih ravninah premikajo odvisno eden od drugega, ter prestanejo strižni premik kot celota. Slednje je tudi razlog, da martenzit ohrani sestavo in razporeditev atomov avstenita, kar je eden od pogojev za pojav oblikovnega spomina. [1] Deformirana in prvotna oblika izdelka namreč ustrezata martenzitu oziroma avstenitu, povezava med obema oblikama pa je na neki način zapisana v materialu, zato pri preoblikovanju iz ene strukture v drugo ne sme priti do nikakršnih nepovratnih sprememb. To je tudi razlog, da se mora popačenje kristalnih rešetk, do katerega pride med martenzitno transformacijo, nadomestiti z dvojčenjem in ne z zdrsi. Pri zdrsi namreč pride do trganja medatomskih vezi, zato je takšna transformacija nepovratna. V dvojčenem martenzitu so atomske vezi nepretrgane in ostanejo takšne tudi pri dovolj majhnih deformacijah, zato se pri segrevanju tako nedeformirana kakor tudi deformirana dvojčena martenzitna struktura preoblikujeta v enako avstenitno strukturo, kakor prikazuje slika 1.

pneumatic valves. It is unfortunate that TiNi alloys, which have the best mechanical and shape-memory properties and are therefore used in almost 90% of the applications, are also the most expensive. Many cheaper shape-memory materials have been discovered, but only a few of them are suitable for practical applications. The reasons for this are a too weak shape-memory effect, a fading of the effect during use and complicated manufacturing or thermomechanical treatments. Besides TiNi and Cu alloys, which have been thoroughly investigated and are also the most frequently used materials, the shape-memory effect in Fe alloys is being looked into because of the potentially low price of these alloys. The use of shape-memory materials tends to be economic only if the elements made from this material are small.

The manufacturing of such elements represents another problem. Even though shape-memory materials are available in different shapes, with different thermomechanical treatments and with different characteristic temperatures, the desired shape and thermomechanical properties often differ from the properties of available materials. In such a case the shape-memory element can be produced by a specialized manufacturer, but this means higher costs and longer delivery times.

1 THE BASICS OF SHAPE MEMORY

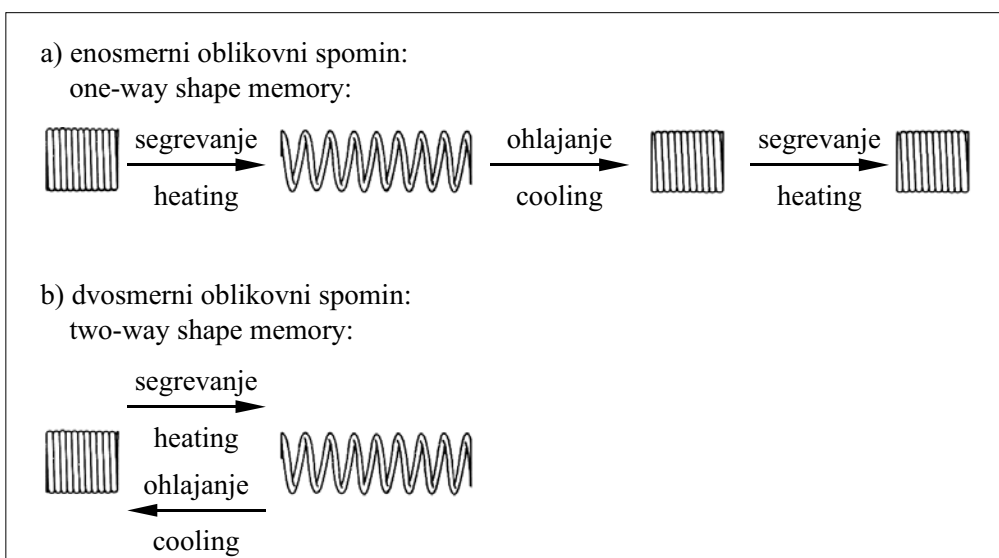
A reverse martensitic transformation which occurs during the heating of a moderately plastically deformed low-temperature phase represents the basics of the shape-memory effect. Martensitic transformations are usually mentioned in connection with steel quenching, but can also be found in shape-memory materials. A martensitic transformation generally means the diffusionless formation of a new phase, with the atoms in particular crystallographic planes moving as a unit rather than individually. In this way martensite retains the chemical composition and atomic arrangement of the austenite, which is necessary for the shape-memory effect to occur [1]. The deformed and initial shape of the product correspond to martensite or austenite, while the connection between these two shapes is somehow written in the material. As a result, no irreversible changes should occur during the transformation from one structure to the other. This is also the reason why lattice distortion, which occurs during the martensitic transformation, should be compensated by twinning and not by slip. During slip the atomic bonds are broken, which makes such a transformation irreversible. Twinning does not break the atomic bonds, which can remain unbroken even for small deformations. Therefore, the undeformed and the deformed martensite structures are transformed into the same austenite structure during heating, as shown in Figure 1.



Sl. 1. Sprememba martenzita v avstenit in nasprotno
 Fig. 1. Transformation from martensite to austenite and in the opposite way

Oblika v martenzitem stanju deformiranega izdelka se torej pri segrevanju do avstenitnega področja spremeni nazaj v tisto obliko, ki jo je imel izdelek pred deformacijo. Tega procesa ne moremo ponoviti brez ponovne deformacije, zato imenujemo ta pojav enosmerni oblikovni spomin. S posebnimi termomehanskimi postopki pa je mogoče v materialu povzročiti mikronapetosti, ki omogočajo dvosmerni oblikovni spomin. Tako obdelanemu materialu se oblika spremeni pri vsakem ohlajanju ali segrevanju prek temperature preoblikovanja. Eno- in dvosmerni oblikovni spomin sta prikazana na sliki 2.

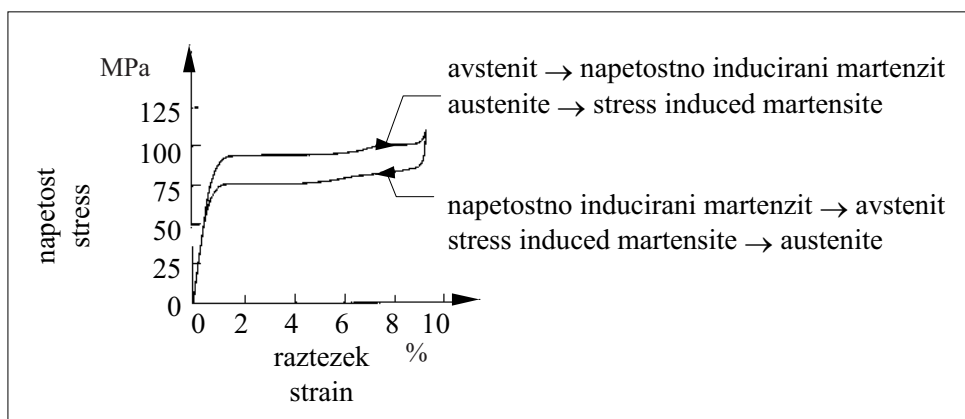
The shape-memory material which was deformed in the martensitic state returns to its original shape when heated to the austenite temperature range. This process is called the one-way shape-memory effect because it cannot be repeated without a new deformation. Microstresses which cause the appearance of two-way shape memory can be induced in the material with a special thermomechanical treatment. The shape of such material changes during every cooling or heating through the transformation temperature. One- and two-way shape memory are shown in Figure 2.



Sl. 2. Eno- in dvosmerni oblikovni spomin [2]
 Fig. 2. One- and two-way shape memory [2]

Nastanek martenzita lahko z zunanjimi napetostmi povzročimo tudi v tistem temperaturnem območju, v katerem je običajno že avstenit, tako nastalemu martenzitu pa pravimo napetostno inducirani martenzit. Zunanje napetosti namreč širijo stabilnost martenzita pri višjih temperaturah in torej širijo temperaturno območje, v katerem je martenzit. Pri višjih temperaturah je za nastanek martenzita potrebna večja napetost, vendar je temperaturno območje, v katerem lahko dobimo napetostno inducirani martenzit, navzgor omejeno, saj bi prevelike napetosti povzročile v materialu pojavljanje zdrsov. Glavna prednost napetostno inducirane martenzita je ta, da zunanje napetosti povzročijo enako usmerjenost kristalnih rešetk, zato pride pri premeni avstenita v napetostno inducirani martenzit do velikih povračljivih raztezkov. Če rahla razbremenitev povzroči destabilizacijo martenzita oziroma nastanek avstenita. Ta lastnost je zelo uporabna, imenujemo pa jo superelastičnost. Na sliki 3 je prikazana napetostna krivulja materiala z oblikovnim spominom v temperaturnem območju superelastičnosti [2].

Loading the material in the austenite temperature range can result in the appearance of the so-called stress-induced martensite, because the stresses increase the stability of the martensite at high temperatures and therefore broaden the temperature range where martensite can be found. Martensite can appear at higher temperatures if larger stresses are applied, but the temperature range of stress-induced martensite has an upper limit, because stresses which are too big would cause the material to slip. The most useful characteristic of the stress-induced martensite is that during the transformation from austenite to stress-induced martensite the stress causes an equal orientation of all the crystal lattices which results in the maximum reversible strain. Even slight unloading can cause martensite destabilisation and the appearance of austenite. This property is called superelasticity and is used very often. Figure 3 shows a stress-strain curve of a shape-memory material in the temperature range of superelasticity [2].



Sl. 3. Superelastična zanka [2]

Fig. 3. Superelastic loop [2]

Materiali z oblikovnim spominom imajo torej kar tri posebne lastnosti, po katerih se razlikujejo od drugih materialov. Katero od teh lastnosti se odločimo izkoristiti, pa je odvisno od namena izdelka.

2 PRIMERI PRAKTIČNE UPORABE MATERIALOV Z OBLIKOVNIM SPOMINOM

Materiale z oblikovnim spominom lahko uporabljamo na mnogo različnih načinov, ki jih lahko v grobem razdelimo v štiri glavne kategorije.

Prosta povračljivost: Edina naloga izdelkov, ki spadajo v to kategorijo, je sprememba oblike oziroma opravljanje določenega giba ob minimalni sili. Sem spadajo na primer igrače, katerih namen je predvsem razvedrilo in prikaz učinka oblikovnega spomina.

Ovirana povračljivost: Če je med preoblikovanjem materiala sprememba oblike izdelka

Shape-memory materials therefore have three specific properties by which they differ from other materials. Which of these properties we decide to use, depends on the purpose of the product.

2 SOME EXAMPLES OF THE USE OF SHAPE-MEMORY MATERIALS

Shape-memory materials can be used in many different ways, these uses can be roughly divided into four main categories:

Free recovery: The only function of products in this category is to move with minimum force during the shape change. Examples of such products are toys, whose purpose is entertainment and the presentation of the shape-memory effect.

Constrained recovery: If, during the transformation of the material, the change of product's

onemogočena, nastaja med njim in oviro sila. Premik in zato tudi delo sta minimalna. Nastala sila se pogosto uporablja za spajanje elementov.

Aktuatorji: Aktuatorji med gibanjem, do katerega pride med spremembo oblike, s silo delujejo na okolišne elemente in opravljajo delo. Ker se oblika izdelkov z oblikovnim spominom ne spremeni pri določeni temperaturi, temveč v nekem temperaturnem območju, lahko aktuatorje ob natančnem uravnavanju temperature uporabimo tudi za pozicioniranje različnih mehanizmov v nekem območju, katerega meji sta definirani s prvotno in deformirano obliko elementa z oblikovnim spominom.

Superelastične uporabe: Superelastičnost največkrat uporabljamo v tistih primerih, v katerih je pri majhnih spremembah sile potreben velik raztezek. Uporabna pa je tudi pri izdelkih, ki se med uporabo večkrat zvijajo ali kako drugače deformirajo, po uporabi pa mora njihova oblika ostati nespremenjena. [2]

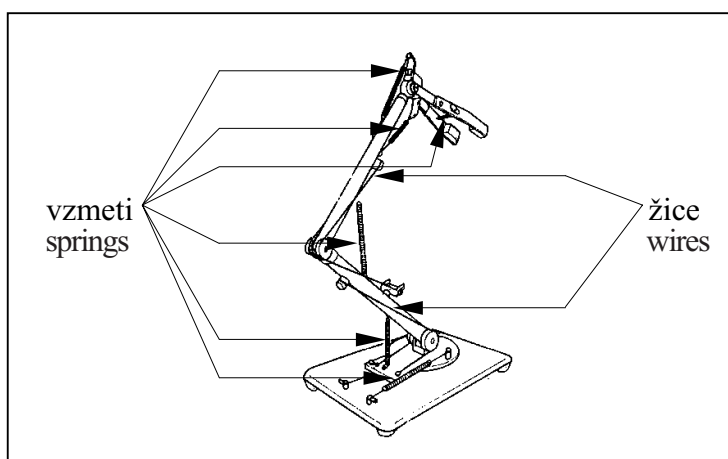
Raziskave možnosti uporabe materialov z oblikovnim spominom so potekale predvsem v smeri nadomeščanja elektromotorjev in podobnih naprav z elementi z oblikovnim spominom. Tak primer je uporaba tankih žic in vzmeti z oblikovnim spominom za krmiljenje manjšega robota, kakor prikazuje slika 4. Te elemente je mogoče hitro segreti z uporabo majhnih električnih tokov, zaradi majhne mase pa je tudi ohlajanje na zraku dovolj hitro. S tem je omogočeno hitro delovanje robota, poleg tega pa je njegova teža bistveno manjša kakor pri uporabi elektromotorjev. Izdelava žic in vzmeti iz materialov z oblikovnim spominom je že dovolj razširjena, da je uporaba takšnih elementov tudi cenovno upravičljiva.

shape is constrained, force is generated between this product and the obstacle. The movement and work are therefore minimal. This generated force is often used to assemble elements.

Actuators: During the movement caused by the change of shape, actuators act with force on nearby elements and produce work. Because the shape of the products with shape memory does not change at a certain temperature but over a temperature range, actuators can also be used to position different mechanisms in a range, the limits of which are defined by the initial and deformed shape of the shape-memory element. In this case, the temperature must be very precisely controlled.

Superelastic applications: Superelasticity is often used in situations where large strains are needed with small forces. It is also useful in those products which are frequently bent or otherwise deformed during their use but must keep the same shape after the use [2].

The research work on the use of shape-memory materials has focused on replacing electromotors or similar devices with shape-memory elements. An example is the use of thin shape-memory wires and springs to control a small robot, as shown in figure 4. These elements can be rapidly heated with low electric currents, while their light weight allows quick cooling in air. The robot is able to move quickly and its weight is much less than for on electromotor-based robot. Also, the manufacturing of shape-memory wire and springs is widespread enough to make the use of these elements economic.



Sl. 4. Robot z žicami in vzmetmi z oblikovnim spominom [1]

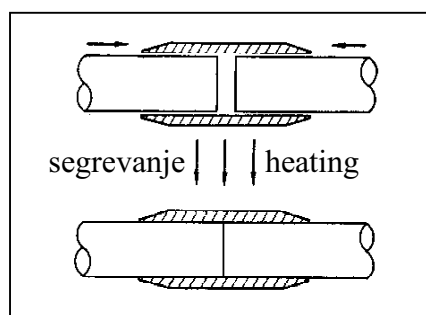
Fig. 4. Robot with shape-memory wires and springs [1]

Kakor je bilo že omenjeno, je zaradi manjših stroškov v večini primerov še vedno primerneje uporabiti elektromotorje oziroma podobne pogonske naprave, zato so bolj zanimive tiste možnosti uporabe materialov s spominom, pri katerih elementov iz teh materialov ni mogoče nadomestiti z drugimi

As mentioned earlier, the costs are, in most cases, still lower if electromotors or similar devices are used. However, this is what makes those uses where shape-memory elements cannot be replaced with other devices even more interesting. One such example is connecting pipes or other round elements

napravami. Eden takšnih primerov je spajanje cevi oziroma drugih valjastih predmetov z objemkami z oblikovnim spominom, kar kaže slika 5. Po vstavitvi obeh koncev cevi v objemko povzroči povišanje temperature zmanjšanje njenega notranjega premera, s čimer dobimo močan in tesen spoj. Temperatura, pri kateri se oblika objemke spremeni, je lahko nižja od temperature okolice, kar omogoča, da izvedemo spoj brez dodatnega segrevanja. Takšen način spajanja cevi je zato zelo primeren tam, kjer bi varjenje oziroma kakšna druga visokotemperaturna tehnika spajanja povzročila poškodbe sosednjih elementov [1].

with pipe couplings, as shown in Figure 5. After both ends are inserted into the pipe coupling, the temperature increase causes the inner diameter of the pipe coupling to contract, which results in a strong and tight connection. The temperature at which the shape of the pipe coupling changes can be below the outside temperature, allowing to make a connection without heating. This pipe-connecting method is therefore very useful in situations where welding or some other high-temperature method could damage nearby elements [1].



Sl. 5. Spajanje cevi z objemko z oblikovnim spominom [1]
Fig. 5. Pipe connecting with a shape-memory coupling [1]

Področje, na katerem so materiali z oblikovnim spominom že sedaj dokaj dobro uveljavljeni, je medicina. Na tem področju se uporabljajo le TiNi zlitine, ki imajo poleg ustreznih mehanskih lastnosti tudi dobro biološko združljivost, namenjene pa so izdelavi medicinskih instrumentov ter ortopedskih in zobozdravstvenih pripomočkov. Medicinski instrumenti in ortopedski pripomočki so običajno izdelani iz materiala, v katerem pride do spremembe oblike pri telesni temperaturi, v zobozdravstvu pa se uporablja predvsem superelastična žica. V nasprotju z medicinskimi instrumenti, katerih naloge so običajno kratkotrajne, lahko ortopedski pripomočki zaradi dobre združljivosti TiNi zlitine s telesnimi tkivi svojo nalogo v telesu opravljajo tudi po več mesecev [2].

Materiali z oblikovnim spominom se pogosto uporabljajo tudi v različnih varovalnih ventilih v vodovodnih, plinskih ali drugih napeljavah, njihova naloga pa je ustaviti pretok tekočine pri čezmernem povišanju temperature. Trenutno je predvsem zanimiva uporaba materialov s spominom v termičnih varovalih za plin, saj je uporaba teh naprav v mnogih državah že zakonsko predpisana. Uporaba materialov z oblikovnim spominom v teh napravah ima glede na druge izvedbe določene prednosti in pa tudi določene pomanjkljivosti, kar je opisano v nadaljevanju.

3 TERMIČNO VAROVALO Z OBLIKOVNIM SPOMINOM

Termična varovala za plin so naprave, ki jih vgrajujejo pred končne porabnike plina. Njihova naloga je

Medicine is a field where shape-memory materials are already well established. Only TiNi alloys, which have appropriate mechanical properties and good biocompatibility are used in medicine. These alloys are used for medical instruments as well as orthopedic and dental devices. Medical instruments and orthopedic devices are very often made of material in which the shape change occurs at body temperature, while in dentistry, superelastic wire is the most common material. Medical instruments are usually in contact with body tissues for only a short time, however, orthopedic devices can stay inside the body for a few months [2], which requires good biocompatibility.

Shape-memory alloys are also frequently used in safety valves for water, gas or other installations, where they are designed to stop the fluid flow if the temperature gets too high. The use of shape-memory materials in gas thermic safety valves is very interesting, because in many countries the use of these devices is already prescribed by law. The use of shape-memory materials in other devices has advantages and disadvantages, these are described in the following section.

3 THERMIC SAFETY VALVE WITH SHAPE MEMORY

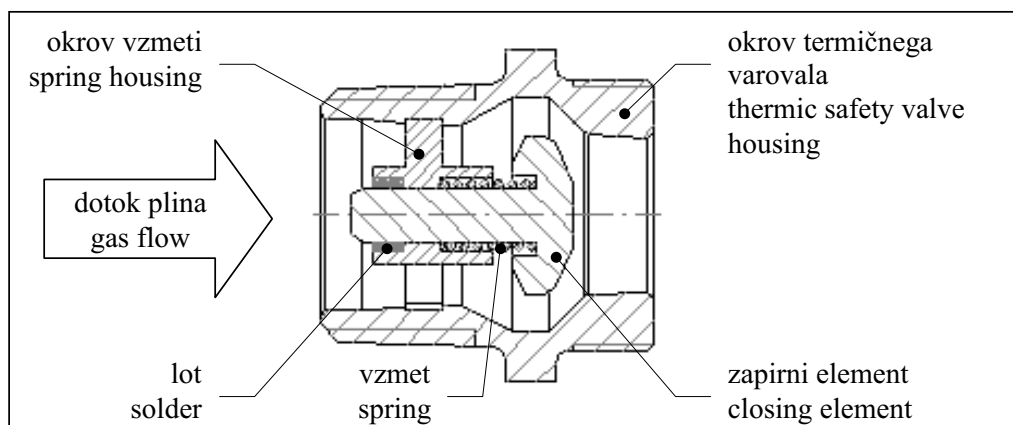
Thermic safety gas valves are devices which are inserted into gas pipelines. Their task is

zaustavitev dotoka plina v prostor v primeru čezmernega povišanja temperature, s čimer se v primeru požara bistveno zmanjša možnost eksplozije plina. Varnostni predpisi, ki zahtevajo uporabo termičnih varoval v plinskih napeljavah, so močno pospešili razvoj teh naprav, ta je potekal predvsem v smeri iskanja čim bolj preprostega in poceni, a kljub temu zanesljivega mehanizma za zapiranje ventila.

Za uspešno opravljanje svoje naloge mora torej mehanizem za zapiranje termičnega varovala vsebovati element za zaznavanje kritične temperature in aktiven element, ki omogoča ali povzroča premik zapirnega elementa. Izvedba takšnega mehanizma z uporabo toplotnega zaznavala in pnevmatskega valja ali druge pogonske naprave bi bila seveda povsem neprimerna, saj bi bili tako cena kakor velikost takšnih termičnih varoval neustrezni. Zaradi zahtev po enostavnosti, majhnih izmerah in nizki ceni so se kot najprimernejši za izdelavo mehanizmov za zapiranje termičnega varovala izkazali materiali, pri katerih je mogoče spremembo njihovih lastnosti, do katere mora priti pri ustrezni temperaturi, izkoristiti za sproženje zapirnega mehanizma. Takšni materiali, ki torej delujejo kot temperaturno zaznavalo in hkrati tudi kot aktivni element, so predvsem loti z ustrezno temperaturo tališča in pa materiali z oblikovnim spominom. Uveljavile so se predvsem izvedbe z loti, saj so loti v splošnem mnogo bolj poznani in raziskani kakor materiali s spominom. Zgradba ene od izvedb termičnega varovala z lotom je prikazana na sliki 6. Pri dovoljenih temperaturah je zapirni element z lotom utrjen v legi, ki dopušča pretok plina. Pri kritični temperaturi se lot stali, kar omogoča vzmeti, da se raztegne, potisne zapirni element ob izstopno odprtino termičnega varovala in s tem zapre pretok plina.

to stop the flow of a gas into the room if the temperature rises too much, this significantly decreases the possibility of a gas explosion. Safety regulations which demand the use of thermic safety valves in gas installations have stimulated the development of these devices, especially the search for a simple, cheap, but still reliable valve-closing mechanism.

The thermic safety valve mechanism should consist of a critical-temperature sensor and an active element to close the valve. To use a temperature sensor and a pneumatic valve or a similar device in this mechanism would, of course, be unsuitable, while the price and the size of the valve would lead to problems. Because of the demands for simplicity, small dimensions and low price, materials which change at a certain temperature to activate the closing mechanism seem to be the best choice. Materials which work as the temperature sensor and at the same time as the active element can be solders with an appropriate melting point or shape-memory alloys. Solders are more often used because they are much better known and researched than shape-memory alloys. A possible variant of the soldered thermic safety valve is shown in figure 6. At ordinary temperatures the closing element is fixed in position with a solder, this allows the gas to flow. At a critical temperature the solder melts and allows the spring to stretch, pushing the closing element against the outlet and stopping the gas flow.



Sl. 6. Primer termičnega varovala z lotom
Fig. 6. An example of a thermic safety valve with a solder

Takšno termično varovalo za plin v skoraj vseh pogledih ustreza zahtevam, manjše težave se pojavijo le pri sestavljanju notranjih elementov. Lotanje je namreč v tem primeru zaradi oblik spajanih elementov dokaj zahtevno, poleg tega pa je za strditev lota potreben določen čas, ki podaljša skupni čas montaže.

V termičnih varovalih z elementi z oblikovnim spominom je načelo delovanja običajno zelo podobno,

This type of thermic safety valve meets most of the requirements, only the assembly of the inner elements can cause problems. The shapes of the connected elements make soldering quite difficult and the time required for the solder to harden lengthens the total assembly time.

In thermic safety valves with shape-memory elements the working mechanism is very similar, ex-

le da zapirni element v osnovni legi ni utrjen z lotom, temveč s primerno oblikovanim elementom iz materiala z oblikovnim spominom. Ta element je vez med zapirnim elementom in okrovom termičnega varovala ali pa med zapirnim elementom in okrovom vzmeti. Sprememba oblike elementa z oblikovnim spominom, do katere pride pri ustrezni temperaturi, sprosti zapirni element, ki ga vzmet potisne v drugo lego in s tem onemogoči pretok plina.

Da bi element z oblikovnim spominom ustrezal zahtevam, mora biti zaradi razmeroma visoke cene materialov s spominom čim lažji oziroma čim manjši. Majhne izmere elementa so zahtevane tudi zaradi omejenega prostora v notranjosti termičnega varovala. Za doseganje konkurenčne cene izdelka je najbolj primerno, če je element izdelan iz žice, saj so materiali z oblikovnim spominom v tej obliki najcenejši in tudi ponudba je največja. Žica je ustrezna tudi zaradi preprostega oblikovanja, pri čemer pa je treba paziti, da polmeri ukrivljenosti žice niso premajhni, ker prevelike deformacije oziroma raztezki privedejo do poslabšanja ali celo izgube lastnosti oblikovnega spomina. Če elementa ni mogoče izdelati iz žice, lahko izbiramo med preostalimi oblikami, v skrajnem primeru pa je pri nekaterih ponudnikih materialov z oblikovnim spominom mogoče naročiti izdelavo elementov posebnih oblik.

Termična varovala z elementom z oblikovnim spominom je mogoče preprosteje in hitreje sestaviti kakor izvedbe z lotom, katerih edina težava je montaža. Uporaba materialov z oblikovnim spominom v termičnih varovalih za plin je torej teoretično idealna, vendar se zaradi težav pri konstrukciji elementa z oblikovnim spominom in pri nabavi materiala izdelovalci teh naprav raje odločajo za izvedbe z loti. Ponudniki materialov z oblikovnim spominom namreč tudi kupcem ne ponujajo dovolj informacij o tistih mehanskih lastnostih, ki so potrebne pri konstruiranju določenega izdelka. Preskušanje vzorcev in iskanje ustreznega materiala zahteva veliko časa in tudi denarja, zato se mnogi potencialni kupci raje odločijo za alternativne izvedbe svojih izdelkov.

4 SKLEP

Čeprav bi lahko posebne lastnosti materialov z oblikovnim spominom s pridom izkoristili v marsikaterem primeru, se uporaba teh materialov zelo počasi zvečuje. Razloga za to sta predvsem razmeroma visoka cena in slabo poznavanje teh materialov. Večina proizvajalcev, ki bi želela razviti uporabo z elementi z oblikovnim spominom, bi se morala najprej podrobno seznaniti z lastnostmi teh materialov, preučiti njihovo ponudbo na trgu in s preskusi priti še do preostalih podatkov, potrebnih za razvoj izdelka. Celoten razvojni proces bi bil zato dolgotrajen in drag, zato se poskuša večina proizvajalcev temu izogniti z uporabo bolj znanih materialov in naprav.

cept that in the initial position the closing element is not fixed with solder but with a shape-memory element. This element represents a bond between the closing element and the thermic safety-valve housing or between the closing element and the spring housing. The change in the shape of the shape-memory element at a particular temperature releases the closing element, which is pushed by the spring into opposite position, where it stops the gas flow.

For the shape-memory element to meet the requirements, it must be as light and as small as possible due to the high price of shape-memory materials. This element also has to be small because of the limited space inside the thermic safety valve. For the product to have a competitive price the element should be made from wire, because materials in this form are the least expensive. Wire is also a good choice because it is easily shaped, providing that the bending radii are not too small: large deformations can lead to fading or even to a complete loss of the shape-memory effect. If the element cannot be made from wire, another shape must be selected. In extreme situations it may be necessary to manufacture specially shaped elements.

Thermic safety valves with shape-memory elements are easier and faster to assemble than solder-based valves. The use of shape-memory materials seems to be ideal, but due to problematic shape-memory-element design and the ordering of the material, the manufacturers of these devices prefer to choose the soldered options. Even to their customers shape-memory material suppliers do not give enough information about the mechanical properties which are necessary to design a particular product. Because testing samples and searching for the right material take a lot of time and money, many potential customers prefer to choose products that are not loaded on shape-memory materials.

4 CONCLUSION

Even though the properties of shape-memory materials could be used in many applications, the use of these materials is increasing very slowly. The reasons are the relatively high price and the lack of knowledge associated with these materials. Most of the manufacturers wanting to develop a certain application with shape-memory elements would first have to learn about the specific properties of these materials, study the market and do tests to obtain the data necessary for the development of this application. Because this whole process would be time consuming and expensive, many manufacturers simply use standard materials and devices.

Dokler ti materiali ne bodo bolj razširjeni in poceni, bo njihova uporaba omejena predvsem na primere, pri katerih zaradi prostorskih omejitev uporaba elektromotorjev ali drugih pogonskih naprav ni mogoča, in tam, kjer imajo elementi z oblikovnim spominom funkcijo temperaturnega zaznavala ter pogonske naprave hkrati.

Kakor je bilo že omenjeno, pomeni izdelava elementov iz materialov z oblikovnim spominom eno večjih težav pri uporabi teh materialov, saj o možnostih njihove obdelave ni na voljo dovolj podatkov. Zato so v nadaljevanju raziskav uporabnosti materialov z oblikovnim spominom načrtovani testi, s katerimi bi dobili osnovne podatke o možnostih njihove obdelave. Ti podatki bi olajšali razvoj izdelkov z elementi iz materialov z oblikovnim spominom in tudi pripomogli k lažjemu odločanju proizvajalcev za uporabo teh materialov v njihovih izdelkih.

As long as these materials are in niche markets and their price remains high, their use will be limited either to those applications where space limitations do not allow the use of electromotors and similar devices or applications where shape-memory elements function as both the temperature sensor and the drive.

As already mentioned, the manufacturing of shape-memory elements represents a major problem in the use of these materials because there is not enough available information on the machining of these materials. Therefore, research which would give some basic information on machining is required. This would make the development of new products with shape-memory elements easier and would also help manufacturers of devices to use these materials in their applications.

5 LITERATURA

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