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ECOLOGY - VEHICLE AND ROAD SAFETY - EFFICIENCY

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PREDGOVOR

8. međunarodni kongres „Motorna vozila i motori 2020“ organizovan je u neobičnim okolnostima. Dok je svetom vladala pandemija CORONA virusa, vredni autori iz zemlje i inostranstva pripremali su svoje radove u okviru motoa Kongresa „Ekologija–Vozilo i bezbednost saobraćaja-Efikasnost“. Imajući u vidu trenutnu situaciju, odziv autora je bio vise nego zadovoljavajući. Za prezentaciju na Kongresu su prihvaćena ukupno 44 rada, koji su recenzirani i vezani sa jednom od postojećih glavnih tema Kongresa:

- Tehnologija sistema prenosa snage,
- Konstrukcija i proizvodnja vozila,
- Dinamika vozila i sistemi inteligentne kontrole,
- Interfejs vozač/vozilo, informacioni sistemi i sistemi za pomoć vozaču i
- Bezbednost drumskog saobraćaja.

Naši uvodničari, eminentni stručnjaci u oblasti motornih vozila i bezbednosti saobraćaja, pripremili su četiri uvodna predavanja koja predstavljaju savršen okvir za ostala istraživanja prezentirana na Kongresu. Akcenat uvodnih predavanja je bio na trendovima i perspektivama u bezbednosnom dizajnu vozila, dilemama u vezi postizanja nulte emisije vozila, kao i stanju bezbednosti drumskog saobraćaja i zakonske regulative vezane za vozila u Srbiji.

Tematske sekcije Kongresa potvrdile su multidisciplinarnost tehnologija vozila i važnost bezbednog okvira njegovog funkcionisanja. Prezentirani su radovi iz oblasti hibridnih vozila, alternativnih pogona, novih materijala i tehnologija u proizvodnji vozila, primene industrije 4.0, naprednih metoda smanjenja potrošnje energije i uticaja vibracija na putnike i raznih aspekata bezbednosti saobraćaja.

Uz tradicionalnu podršku Ministarstva nauke, prosvete i tehnološkog razvoja, Univerziteta u Kragujevcu, Fakulteta inženjerskih nauka i Međunarodnog časopisa “*Mobility and Vehicle Mechanics*“, organizatori Kongresa su odlučili da se, zbog preventivne zaštite zdravlja učesnika, Kongres po prvi put organizuje na Internet mreži (*online*). Organizovana je plenarna sekcija, kao i više radnih tematskih sekcija, na kojima su razmenjena dragocena iskustva stručnjaka iz oblasti automobilske industrije, istraživačkih instituta i akademskih institucija.

Nadamo se da će idući Kongres, čije je održavanje planirano za dve godine, da privuče još veći broj učesnika sa novim, aktuelnim temama primerenim brzom razvoju tehnologija motornih vozila.

Kragujevac,
8. oktobar 2020. godine

Naučni i Organizacioni odbor
Međunarodnog kongresa „Motorna vozila i motori 2020“

FOREWORD

The 8th International Congress "Motor Vehicles and Engines 2020" was organized in unusual circumstances. While the CORONA virus pandemic ruled the world, hardworking authors have been preparing their papers within the motto of the Congress "Ecology - Vehicle and Traffic Safety - Efficiency". Given the current situation, the response of the authors was more than satisfactory. A sum of 44 papers was accepted for presentation at the Congress. All papers were reviewed and linked to one of the existing main topics of the Congress:

- Power Train Technology,
- Vehicle Design and Manufacturing,
- Vehicle Dynamics and Intelligent Control Systems,
- Driver/Vehicle Interface, Information and Assistance Systems and
- Road Traffic Safety.

Our keynote speakers, eminent experts in the field of motor vehicles and traffic safety, have prepared four introductory lectures that provide the perfect framework for other research presented at the Congress. The emphasis of the introductory lectures was on trends and perspectives in vehicle safety design, dilemmas regarding achieving zero vehicle emissions, as well as the state of road traffic safety and legal regulations related to vehicles in Serbia.

The thematic sections of the Congress confirmed the multidisciplinarity of vehicle technologies and the importance of a safe framework for its functioning. Papers in the field of hybrid vehicles, alternative drives, new materials and technologies in vehicle production, application of Industry 4.0, advanced methods for reducing energy consumption and the impact of vibration on passengers and various aspects of traffic safety were presented.

With the traditional support of the Ministry of Science, Education and Technological Development, University of Kragujevac, Faculty of Engineering and the International Journal “Mobility and Vehicle Mechanics”, the organizers of the Congress decided to organize the Congress on the Internet network (online) for the first time. A plenary section was organized, as well as several working thematic sections, where valuable experiences of experts from the automotive industry, research institutes and academic institutions were exchanged.

We hope that the next Congress, which is planned to be held in two years, will attract an even larger number of participants with new, current topics appropriate to the rapid development of motor vehicle technologies.

Kragujevac,
October 8th, 2020

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Vladimir Dunić[1]

SHAPE MEMORY ALLOYS IN AUTOMOTIVE INDUSTRY – OVERVIEW, APPLICATION, MODELING

ABSTRACT: Shape Memory Alloys (SMA) are widely known as smart materials used as actuators in many engineering systems. SMA are known as very thermo-sensitive materials, which have different responses in various environments. Also, the loading or deformation rate of SMA structures has a significant influence on the material temperature change. The reason is the complex phase-transformation process between the austenite and martensite what results in complex thermo-mechanical behavior. These properties are essential for efficiently applying such materials to actuate specific processes by the phenomena of superelasticity or shape memory effects, which exhibit under proper conditions. With the overview of SMA's current application in the automotive industry, in this paper, the recent research results in SMA modeling and simulation are analyzed to propose the possibilities, limitations, and directions of future research in this field of application.

KEYWORDS: shape memory alloys, automotive industry, application, modeling, actuators

OVERVIEW OF SMA BEHAVIOR

Shape Memory Alloys (SMA) are a multifunctional type of materials that can manifest two phenomena: superelasticity effect and shape memory effect. The same material can exhibit both effects depending on the exploitation temperature of the material. To define the effects, firstly, it is essential to identify SMA characteristic phase transformation temperatures: austenitic start A_s and finish A_f, and martensitic start M_s and finish M_f temperature, presented in Figure 1. The superelasticity effect occurs when the material operates above the austenitic finish temperature. In that case, the phase transformation from austenite to detwinned martensite is stress-driven by mechanical loading. The shape memory effect occurs when the material is deformed at the temperature below the martensitic finish temperature. After heating above the austenitic finish temperature, the material will recover its shape. The shape memory effect can be one-way or two-way. Both superelasticity and shape memory effects are described in Figure 1. These effects and large inelastic deformation (up to 10%) of SMAs offer the possibility of exploitation in various applications, but the most often are actuators and sensors. The material behavior depends on the composition of SMA, thermomechanical processing, and the working environment. Material properties (Young's modulus, electrical resistivity, thermal conductivity, and thermal expansion coefficient) of SMA are different in the martensitic and austenitic phases. The actuator's design challenges investigated in [1] are transferring the heat into and out of the active element, low energy efficiency, durability, and reliability what leads to the conclusion that SMA elements should be prevented from overheating, overstressing, and overstraining.

APPLICATION OF SMA IN AUTOMOTIVE INDUSTRY

The application of SMA is wide in industry and engineering: automotive, aerospace, biomedical. In the automotive industry, there is an increasing need for actuators for luxury features. According to [1], there are about 200 actuation tasks controlled by SMA actuators. Actuators in automobiles are usually DC motors or solenoids. SMA simplifies and reduces the cost of many automotive actuators [2]. One of the first articles related to the application in the automotive

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industry was related to the actuators. Stoeckel [3] presented the SMA actuators' entering the automotive industry in the early 90s. The SMA actuators were used as thermal and electrical. At that time, only Cu-Zn-Al alloys and the Ni-Ti alloys were available. In the automotive industry, Ni-Ti was preferred due to the high strength and electrical resistivity, large recovery strains, good workability, and corrosion resistance. He proposed thermal actuators by patent literature surveys such as a temperature-sensitive governor valve, pressure control in an automatic transmission, and smoother shifting at low temperatures, temperature-sensitive boost compensators, and a temperature-compensated valve lifter, shape-memory washers to reduce gearbox noise. Also, SMA electrical actuators were applied as remote fog-lamp louver opening devices and windshield wipers. The problems were noticed when the ambient temperature approaches the transformation temperature of the shape memory alloy. The same author extended his research in [4] when he investigated fastener rings, which can be used to terminate shielding braid to a connector or an oxygen sensor, fix the location of a bearing or gear, assemble radially disposed of elements. At the beginning of 21 century, Wu et al. [5] investigated SMA's industrial application. However, they noticed the automotive industry as very interesting due to SMA actuators' wide application in transmission fluid control, plug for sealing high-pressure diesel engine injectors. A decade later, Williams and Elahinia in [2] investigated the SMA actuator's design, modeling, and experimental behavior for the position of a rear-view mirror. They designed and fabricated a prototype of an SMA actuated mirror. In 2011, Strittmatter and Gümpel in [6] considered SMA actuators' application for the bonnet lifting system. Gheorghita et al. investigated SMA's application in safety systems in the car industry [7]. They found out that the amount of dissipated energy increases with the loading rate and gives higher forces necessary for SMA actuators. Jani et al. in 2013 [1], considered the share of SMA related publications and patents and found out that there are more than 20,000 worldwide patents have been issued on SMAs. However, that real application was at a low level, although SMA sensors or actuators can find their application in various parts of the automobiles such as the engine, transmission, brake, battery, engine control unit, climate control, wiper, airbags, mirrors, seats, dashboard, roof, safety belts, spoilers, boot, fuel cup, suspensions, doors, exhaust, bumpers, fog lamp, headlight, engine hood. They also noticed that SMA has very high work density (25 times greater than electric motors) what qualify them for actuators that offer significant forces.

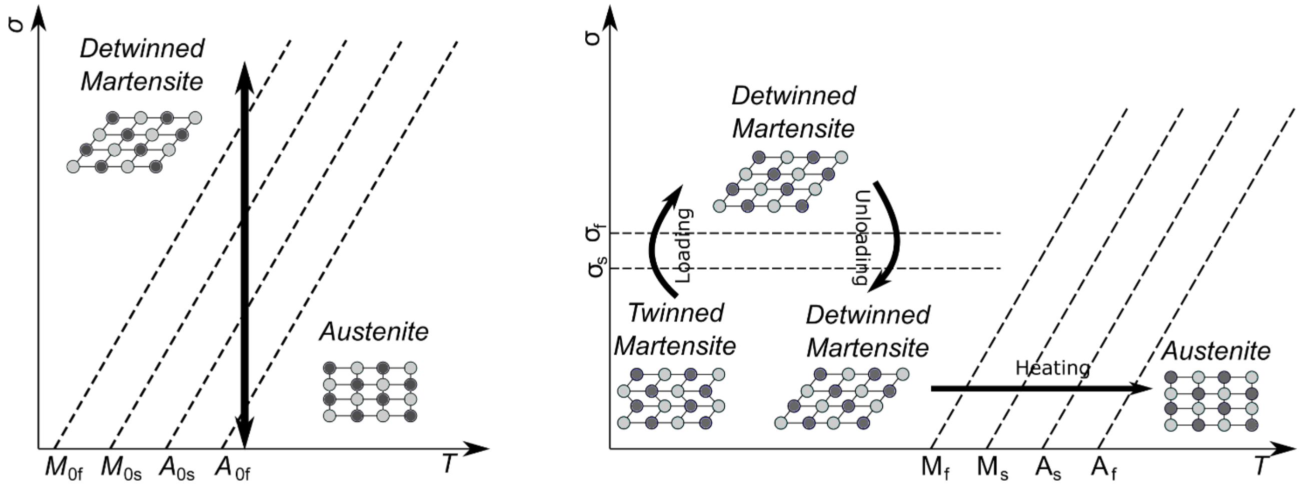


Figure 1 Superelasticity and shape memory effect in SMA

MODELING OF SMA

The researchers and engineers tend to develop the SMA constitutive model, which is simple but, at the same time, gives more simulation details. Also, demand is a few material constants. There are several approaches in the scientific literature, but the two major groups are micromechanics-based models and phenomenological models. More details are given in Dunić et al. [8]. In the last several years, at the Faculty of Engineering, the phenomenological SMA model has been implemented into the finite element method (FEM) software PAK for structural analysis. The model is improved [9], and thermo-mechanical coupling [10] is realized in a staggered iterative scheme. Those features allowed more accurate simulation of SMA structures that are essential for the automotive industry application where the SMA is used as sensors and actuators. The simulation of the loading rate influence [11] and the martensitic phase transformation-induced creep behavior in SMA is investigated and successfully demonstrated [12].

A brief review of SMA constitutive model

One of the most developed SMA constitutive models is based on the Lagoudas theory [13]. It is based on Gibbs's free energy $g(\boldsymbol{\sigma}, T, \xi, \mathbf{e}_{tr})$, where variables are the stress $\boldsymbol{\sigma}$, the temperature T, and the internal state variables ξ, $\mathbf{e}_{tr}$. “Any change in the current microstructural state of the material is strictly a result of a change in the martensitic volume fraction” is an assumption which is mathematically described by equation [13]:

$$\dot{\mathbf{e}}_{tr} = H\mathbf{n}_{tr}\dot{\xi}, \quad (1)$$

where H is the maximum of achievable transformation strain and ξ is the fraction of martensite in the volume. The transformation strain vector $\mathbf{n}_{tr}$ is given concerning the direction of the martensitic phase transformation:

$$\mathbf{n}_{tr} = \begin{cases} \dfrac{3\mathbf{S}}{2\bar{S}}; & \dot{\xi} > 0 \\ \dfrac{\mathbf{e}_{tr}}{\bar{e}_{tr}} & \dot{\xi} < 0 \end{cases}. \quad (2)$$

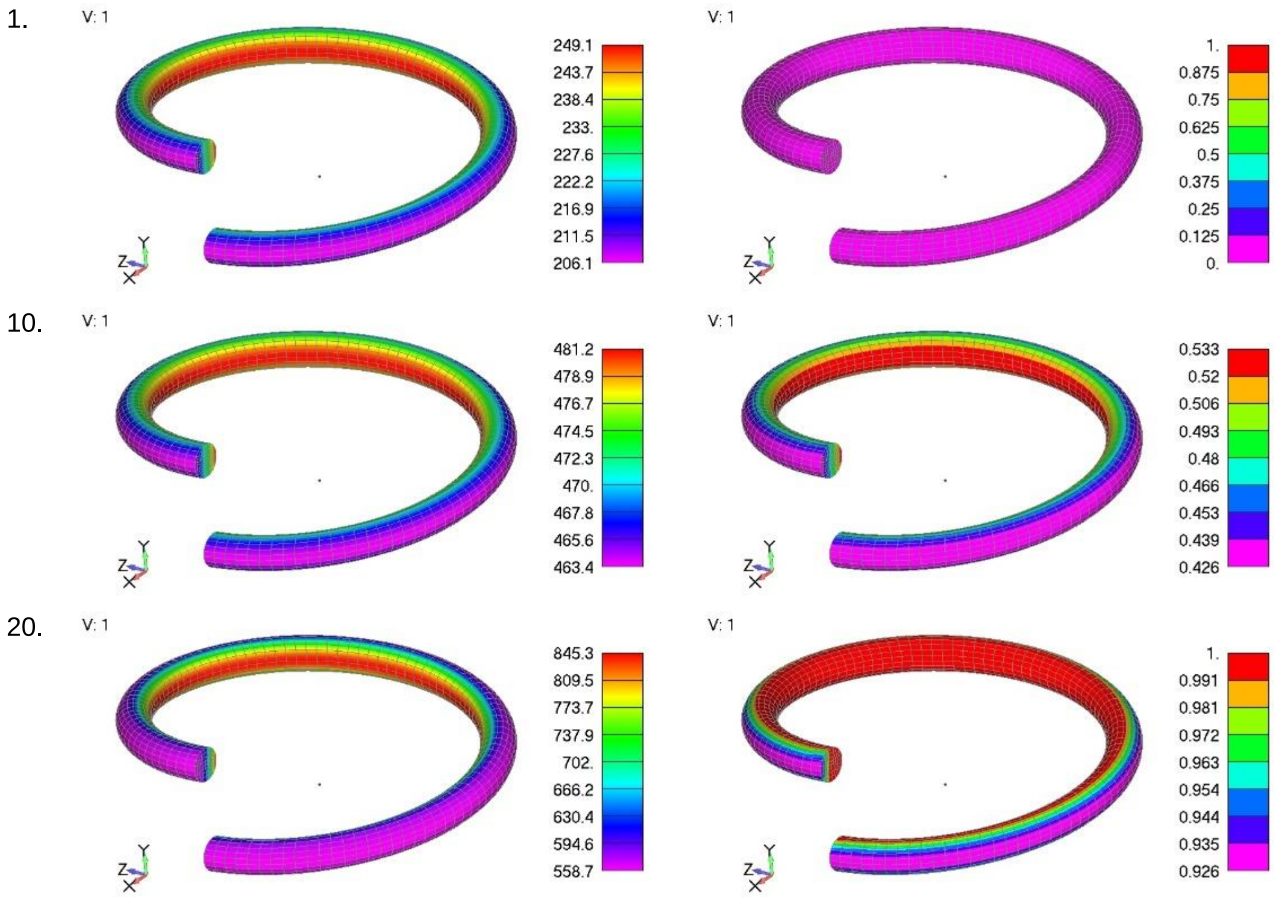
The transformation function is defined by Lagoudas [13] as follows:

$$\Phi = \begin{cases} \Pi - Y; & \dot{\xi} > 0 \\ -\Pi - Y; & \dot{\xi} < 0 \end{cases} \quad (3)$$

where $\Pi(\boldsymbol{\sigma}, T, \xi)$ is the thermodynamic force and Y is the threshold value. The assumption of constant integration direction (deviatoric stress or transformation strain) of the stress integration procedure is used in [9]. The separation of the total stress on the deviatoric and mean part provided the possibility to reformulate the transformation function in an effective manner and solve only one equation on the integration point level. More details are given in [9] and [14].

Table 1 Material parameters of the SMA

$E_A[MPa]$	$E_M[MPa]$	$\nu[-]$	$M_{0s}[K]$	$M_{0f}[K]$
62000	31000	0.33	251.3	213
$H[-]$	$r\Delta s_0^M[MPa/K]$	$r\Delta s_0^M[MPa/K]$	$A_{0s}[K]$	$A_{0f}[K]$
0.047	-0.364	-0.364	260.3	268.5



a) effective stress field b) martensitic volume fraction field

Figure 2 SMA spring segment

Application of modeling in the automotive industry

The FEM modeling of mechanical engineering structures is essential in product design. The SMA constitutive model provides the possibility to predict the behavior in exploitation conditions. The example of the ring segment of spring is proposed. One end of the segment is fixed, while the second end is loaded by 7 mm of prescribed displacements in the y-direction. The segment is constrained in the x, z – plane to simulate the behavior in the tube. Figure 2 shows the effective stress field, the displacement field, and the martensitic volume fraction field. The material parameters used for the simulation are given in Table 1. The model is considered to be at the constant room temperature. The nonlinear analysis is performed in 20 equal time steps. As can be noticed, the effective stress field has the same distribution overall loading range. Simultaneously, the martensitic volume fraction is different at the beginning, in the middle and at the end of the loading.

CONCLUSIONS

SMA are smart, multifunctional materials that can be used in the automotive industry as sensors or actuators. Superelasticity and shape memory effects are phenomena that depend on the exploitation temperature of the SMA structure. In this scope, some automotive industry parts can be made of SMA. One of the main disadvantages is high production costs and complicated material processing due to SMA's high thermosensitivity. To decrease costs, FEM modeling of the SMA structures would be essential. Various authors in the last few decades successfully simulated the behavior of SMA specimens, and the most significant achievements are the thermo-mechanical coupling of the SMA constitutive model and application of large strain theory in an effective manner. The SMA spring segment simulation is presented to show the specific behavior of the SMA structures, the distribution of the martensitic volume fraction for the most common type of loading.

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