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Introducing cobalt nickel aluminum ferromagnetic shape memory alloy for endodontic file manufacturing

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Abstract---Since the introduction of nickel titanium (NiTi) to the field of endodontics, it paved the way for fast and reliable root canal instrumentation. Rotary instruments are solely manufactured from NiTi alloy, due to its favorable mechanical and physical properties such as flexibility and cutting efficiency. The main problem with rotary NiTi instruments is their high fatigue susceptibility, and the unexpected incident of instrument separation inside the root canal, complicating the case even further and might even doom the tooth for extraction if the fractured fragment was unretrievable with the presence of peri-apical pathology. Many attempts were made to enhance the physical and mechanical properties of NiTi alloy through modification to the manufacturing process or with different heat treatment or even adding alloying elements to it. However, there has never been an attempt to replace the whole alloy. Cobalt Nickel Aluminum (Co-Ni-Al) alloy is a ferromagnetic shape memory (FMSM) alloy, possessing favorable mechanical and physical properties making it a good candidate to replace NiTi in the manufacturing of rotary instruments. With its main advantage being the ability to be retrieved with magnetic pulses after being separated. The following review shed some light to some of the properties of these alloys and the possibility to start using Co-Ni-Al alloy as a replacement for NiTi for endodontic instruments.

Keywords---endodontic file, manufacturing, nickel aluminum.

Introduction

There are two principally different types of alloys used for endodontic therapy; stainless steel and nickel-titanium. The first alloy is mostly used for manufacturing of manual operated endodontic instruments, which are considered resistance to fracture. Stainless steel files are comparably inexpensive and there are several burs and instruments designed for slow-speed handpiece operation such as Gates Glidden drills, Peeso burs, and pilot drills for intraradicular post cavity preparation [1]. However, the main disadvantage for this alloy is reducing flexibility and increasing stiffness of the file with increasing the file size. This can lead to different problems including canal straightening, transportation, zipping and end with perforation, in addition to its comparatively high corrosion rate and low fatigue resistance [2].

The second alloy used in the fabrication of endodontic files, especially those powered by engine, is nickel-titanium (NiTi). This alloy offers unique properties, specifically flexibility and corrosion resistance [2]. Walia and colleagues thought that the pseudoplastic properties of 55-nitinol might prove advantageous in endodontics and initially tested hand instruments [3]. They found that size #15 NiTi instruments were two to three times more flexible than stainless steel instruments; in addition to superior resistance to angular deflection. Furthermore, any plastic deformation for the cutting file flutes was hardly recorded when an instrument was bent up to 90 degrees. Also forces required to bend endodontic files to 45 degrees were reduced by 50% with NiTi in comparison to stainless steel [4].

On the other hand, NiTi instruments may have imperfections such as milling marks, metal flash, or rollover [3, 5]. Some researchers have speculated that fractures in NiTi instruments originate at such surface imperfections. Surface irregularities may provide reservoirs of corrosive substances, most notably sodium hypochlorite (NaOCl). Chloride corrosion may lead to micro pitting and possibly subsequent fracture in NiTi instruments [6]. Immersion in various disinfecting solutions for extended periods (e.g., overnight soaking) produced corrosion of NiTi instruments and subsequent decreased torsional resistance [7].

Another approach to overcome NiTi physical drawbacks is the modification of the base alloy that significantly alter material properties within the atomic ratio [8]. The first commercialized alloy was M-Wire (SportsWire, Langley, OK), which was shown to have higher fatigue resistance with similar torsional strength [9]. To this date, no attempts were done to change the alloy itself, hence, the aim of this paper was to review available published information about another alloy; Cobalt Nickel Aluminum (Co-Ni-Al) ferromagnetic shape memory alloy regarding its structure, properties, and clinical application in medicine. Also, to suggest its use as an alternative to NiTi in the fabrication of rotary endodontic files.

Components and manufacturing of Co-Ni-Al alloy

The nickel-aluminum paramagnetic $L1_0$ martensite ($Ni_{64.66}Al_{36.34}$ as the classical β -alloys) is assumed to be a functional material with a high-temperature shape memory effect [10]. As nickel is partially (up to 50%) replaced by cobalt, and the

L_{10} martensite in these alloys passes from the paramagnetic to the ferromagnetic state. The Co-Ni-Ga and Co-Ni-Al systems have a similar configuration of the boundary between the (β) one-phase and ($\beta + \gamma$) two-phase regions in the corresponding equilibrium diagrams. As the melting temperature rises, this boundary shifts perceptibly towards the two-phase region, predetermining the possibility that a supersaturated β solid solution is obtained by quenching from a high temperature. As the cobalt concentration increases, the martensitic transformation temperature drops sharply, but the Curie temperature becomes higher; the Curie temperature curves do not coincide for the L_{10} martensite and the β austenite. The most interesting compounds from the viewpoint of their use as magnetically controlled shape memory (MCSM) materials fall within a very narrow interval of concentrations [10].

The Co-Ni-Al system has long and widely been used as the basis of superalloys or heat resistant sputtered coatings. Co-Ni-Al alloys are appealing as MCSM materials since their plasticity is sufficiently high in the polycrystalline (PC) and microcrystalline (MC) states. As the interval of the compounds, the interested should be in close to the boundary between the (β) one phase and ($\beta + \gamma$) two phase regions. These alloys can rather easily be plasticized by adding a small quantity of the plastic component to the structure. The quantity of the γ -phase can be strictly controlled by the composition and the thermal treatment of the two phase alloy [11].

Co-Ni-Al alloys with the β -CoAl phase are generating intensive interest in their development as smart materials [12]. Unlike the case of conventional shape memory alloys (SMAs) such as Ti-Ni alloys, the martensitic transformation underlying the shape memory effect is induced by an applied magnetic field. The response time of the shape changes accompanying magnetically controlled martensitic transformation in the FSMAs is therefore much faster than that of the shape changes accompanying thermally controlled martensitic transformation in the SMAs. The shape change produced in FSMAs by the application of the magnetic field is considered to be magnetostriction; that is, the phenomenon of changes in dimensions of a specimen caused by a change in its state of magnetization [13].

Application of Co-Ni-Al (shape memory) alloy

Shape memory alloys (SMAs) have attracted considerable attention because of their potential applications in industry as sensors and compact actuators and in medicine as self-expanding stents, orthodontic and orthopedic devices, etc. [14]. MCSM sensors may be constructed using the inverse MSME (magnetically controlled shape memory effect): When the materials shape changes, the effective magnetization curve of the material is altered. This effect can be used to monitor the shape of the material by measuring its magnetization. In addition to sensing, power generation by the inverse MSME has been demonstrated. When an element of $\text{Ni}_{501}\text{Mn}_{28.4}\text{Ga}_{215}$ MSMA is compressed at a velocity of 1.5 m/s, a voltage of over 60 V is generated using a simple electromagnetic circuit [15].

Besides the orthodontic field, the SMA devices are broadly applied in the therapeutic vascular devices. In particular, the introduction of the shape memory

alloys boosted the development of mini-invasive techniques where the pathology is treated by the percutaneous insertion of the device rather than surgical intervention. The first vascular SMA application which appreciate its property was the venous “Simon filter” used to prevent emboli in patients unable to tolerate anticoagulants [15]. Other common devices are those used to close ventricular septal defects, which are characterized by the presence of an atrial hole in the surface between the two low-pressure chambers of the heart. This is important to overcome the surgical method which includes an invasive and hazardous approach via a thoracotomy and manual suture of the hole. The alternative of using a mini-invasive approach is appealing. The device is made of SMA wires and of an impermeable polyurethane membrane. The insertion procedure consists of three steps: (i) positioning of the catheter with the crimped device through the superior vena cava, (ii) positioning of the catheter tip in the left atrium and release of half of the device, and (iii) completion of procedure via release of the remaining part of the device in the right atrium. According to the device typology, both shape memory and pseudoplastic effects are utilized [16].

Co-Ni-Al alloy offers superior properties over NiTi alloy in terms of flexibility, fatigue resistance, hardness, and corrosion resistance. In addition to its ferromagnetic property which is a game changer. So it's safe to assume that rotary endodontic files manufactured from Co-Ni-Al alloy would perform better in shaping root canals as well as making the procedure of separated instrument retrieval much easier and more predictable.

Conclusions

Since shape memory alloys were intensively investigated for their use in medical field, ferromagnetic shape memory Co-Ni-Al system is suggested for use in the fabrication of root canal instruments. The shape memory effect of this alloy combined with its ferro-magnetic properties with its favorable physical and mechanical properties can offer many advantages to be used as endodontic file to overcome several drawbacks of NiTi instruments.

References

1. Hargreaves, K.M. and L.H. Berman, *Cohen's pathways of the pulp*. 2021.
2. Ingle, J.I., et al., *Endodontics*. 2008, Hamilton: Decker.
3. Walia, H.M., W.A. Brantley, and H. Gerstein, *An initial investigation of the bending and torsional properties of Nitinol root canal files*. *J Endod*, 1988. 14(7): p. 346-51.
4. Shen, Y., et al., *Current challenges and concepts of the thermomechanical treatment of nickel-titanium instruments*. *J Endod*, 2013. 39(2): p. 163-72.
5. Tripi, T.R., et al., *Defects in GT rotary instruments after use: an SEM study*. *J Endod*, 2001. 27(12): p. 782-5.
6. Alapati, S.B., et al., *Scanning electron microscope observations of new and used nickel-titanium rotary files*. *J Endod*, 2003. 29(10): p. 667-9.
7. O'Hoy, P.Y., H.H. Messer, and J.E. Palamara, *The effect of cleaning procedures on fracture properties and corrosion of NiTi files*. *Int Endod J*, 2003. 36(11): p. 724-32.

8. Pereira, E.S., et al., *Mechanical behavior of M-Wire and conventional NiTi wire used to manufacture rotary endodontic instruments*. Dent Mater, 2013. 29(12): p. e318-24.
9. Johnson, E., et al., *Comparison between a novel nickel-titanium alloy and 508 nitinol on the cyclic fatigue life of ProFile 25/.04 rotary instruments*. J Endod, 2008. 34(11): p. 1406-1409.
10. Kositsyn, S.V., et al., *Investigation of microcrystalline NiAl-based alloys with high-temperature thermoelastic martensitic transformation: I. Resistometry of the Ni-Al and Ni-Al-X (X = Co, Si, or Cr) alloys*. The Physics of Metals and Metallography, 2006. 102(4): p. 391-405.
11. Liu, X.J., et al., *The use of phase diagrams and thermodynamic databases for electronic materials*. JOM, 2003. 55(12): p. 53-59.
12. Ando, K., et al., *Effect of Alloying Elements on fcc/hcp Martensitic Transformation and Shape Memory Properties in Co-Al Alloys*. MATERIALS TRANSACTIONS, 2006. 47(9): p. 2381-2386.
13. Fitra, Legowo, D., Utomo, B., Suroto, N. S., Parenrengi, M. A., & Al-Fauzi, A. (2021). Intracranial foreign body granuloma caused by oxidized cellulose polymer and etherified sodium carboxymethyl cellulose: an experimental study with orictolagus cuniculus rabbits. International Journal of Health & Medical Sciences, 4(2), 267-272. <https://doi.org/10.31295/ijhms.v4n2.1741>
14. O'Handley, R.C., et al., *Phenomenology of giant magnetic-field-induced strain in ferromagnetic shape-memory materials (invited)*. Journal of Applied Physics, 2000. 87(9): p. 4712-4717.
15. Suryasa, I. W., Rodríguez-Gámez, M., & Koldoris, T. (2022). Post-pandemic health and its sustainability: Educational situation. International Journal of Health Sciences, 6(1), i-v. <https://doi.org/10.53730/ijhs.v6n1.5949>
16. Morgan, N.B., *Medical shape memory alloy applications—the market and its products*. Materials Science and Engineering: A, 2004. 378(1-2): p. 16-23.
17. Deodhar, C. and A. Thondiyath, *Combinational scissor-grasper for use in laparoscopy*. 2014.
18. Machado, L. and M. Savi, *Medical application of shape memory alloys*. Brazilian journal of medical and biological research = Revista brasileira de pesquisas médicas e biológicas / Sociedade Brasileira de Biofísica ... [et al.], 2003. 36: p. 683-91.