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Endodontic Files Metallurgy

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Abstract

Endodontic treatment success relies on the proper cleaning and shaping of the root canal. All the surface of the root canal must be prepared to remove the infected dentin. Many file are available with various advantages and limitations for every system to prepare the root canal. This article highlights about the metallurgy of the file that is used to manufacture the file.

Keywords: Austenite; Martensite; Controlled memory; R-Phase; C-Wire.

INTRODUCTION

Endodontic files are available which differ based on the metal that is used for the manufacturing of the file in addition to the file design. The treating dentist must prepare the canal with little iatrogenic damage to the anatomy and avoid instrument separation in the canal in which case retrieval is very difficult. NiTi rotary files that are manufactured by different heat treatment such as max-wire, c-wire, t-wire, controlled memory (CM), R-phase, and M-wire. NiTi alloys can have three phases in their microstructure: austenite, martensite, and R-phase.

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The application of stress causes the material to transform from austenite to martensite when a critical stress level is reached. Beyond this point any increase of deformation occurs without appreciable stress elevation, until the transformation is finished.[1,2]

AUSTENITE AND MARTENSITE PHASE[1,3]

Austenite can be transformed to martensite by stress (e.g. insertion of the instrument into a curved root canal). This effect is called stress induced martensite (SIM) transformation. Austenitic phase has a cubic crystal lattice compare to the martensitic monoclinic crystal lattice which aids in complete recovery of the deformation.

Heat-treated files (martensitic phase) are much more flexible than non heat treated instruments (austenite phase) but, more importantly, they are also exponentially more resistant to cyclic fatigue. The first peak during the heating stage is related to the phase transformation from martensite to R-phase. The second peak, at the higher temperature, is assigned to the subsequent phase transformation from R-phase to austenite. A hybrid microstructure with martensitic peaks provides resistance to crack propagation than a fully austenitic microstructure.

NiTi instruments are available along a large spectrum that spans a pure austenitic (A) phase rotary file to a pure martensitic (M) phase instrument. These 2 forms represent 2 crystalline structures of the same nickel titanium metal, each with different characteristics. Traditional NiTi files are in the A phase and are referred to as shape memory files. Recently, files have been introduced that are heat treated to change their crystalline phase to M, and these files are referred to as controlled memory files. The austenite phase is resistant and rigid, while martensite.

R-PHASE[2,3,4]

R-phase are flexible and quite ductile. Under certain conditions (e.g. ageing at temperatures around 400 °C to cause the precipitation of Ti_3Ni_4 phase, substitution of a third element (iron, aluminium) or heat treatment after cold working to create rearranged dislocation structures), a rhombohedrally distorted phase (R-phase) may appear prior to the transformation to martensite. Its an intermediate phase (R-phase) between martensite and austernite. This R-phase transformation is established as a martensitic transformation itself that competes with the subsequent martensitic transformation. R-phase alloys have more flexibility, torsional resistance (TR) and Cyclic fatigue resistance (CFR), than conventional alloys with the same geometry, in both dry and aqueous environments, and also when used in reciprocating motion. It has a rhombohedral structure that can be formed during forward transformation from martensite to austenite on heating and during reverse transformation from austenite to martensite on cooling. However, they have low TR than M-wire alloys. The R-phase had a lower elastic modulus than those of martensite and austenite, and the transformation strain for R-phase transformation is less than one tenth of that of martensitic transformation. Therefore, these characteristics of R-phase can be considered to be strong evidence for the superior flexibility of the CM-wire and R-phase groups. The R-phase shows good superelasticity and shape memory effects; its Young modulus is typically lower than that of austenite. Thus, an instrument made from the R-phase wire would be more flexible, exhibit superior resistance to functional fatigue and to mechanical fatigue.

In the R-phase, NiTi cannot be ground but it can be twisted. Once twisted, the file is heated and cooled again to maintain its new shape and convert it back into the austenite crystalline structure, which is super elastic once stressed.

M-WIRE[2,5,6]

NiTi wire subjected to a series of heat treatment and annealing cycles during the drawing of the wire. This cycling process aim to stabilize the crystalline structure of the Nitinol in its more martensitic condition at body temperature.

The benefits of this M-Wire alloy are increased flexibility and improved resistance to cyclic fatigue of the instruments. Instruments made from M-Wire with a ProFile design (multiple taper design, Radial landed U file flutes and a special safety tip design) exhibited nearly 400% more resistance to cyclic fatigue than super elastic wire instruments of the same size. Instruments with M with technology include ProTaper Next, Profile Vortex, WaveOne and Reciproc.

C-wire*[5,7]*: the alloy is given a proprietary heat treatment which will have controlled memory property that improved the cyclic fatigue resistance, increased blade flexibility and more separation resistance of the instrument. It has shape memory, Pre-bendable and the natural curvature is maintained.

When compared to traditional superelastic NiTi instruments, heat treatment significantly alters the phase transformation behavior by raising the temperature at which austenite transforms.The two crystalline forms of titanium, compact hexagonal (also known as austenite) and body centered cubic (also known as martensite), are both allotropes. The titanium alloying components are categorized as neutral elements, betagenic elements, or stabilizers of the phase and alphagenic elements, or stabilizers of the phase, depending on the stabilizing impact of the and phases. The transition temperature must either rise or fall for the phases to stabilize. The crystalline phase of the NiTi alloy that is most resistant to cyclic fatigue is martensitic.[17,18]

Controlled memory NiTi wire (CM Wire)[3,6]

CM wire is a mixture of martensite, R-phase, and a small amount of austenite. CM wires had a much higher maximum strain before fracture. is a novel NiTi alloy with flexible properties that was introduced in 2010. CM NiTi files have been manufactured using a special thermomechanical process that controls the memory of the material, making the files extremely flexible but without the shape memory of other NiTi files, as opposed to what is found with conventional superelastic (SE) forms of NiTi.

Electropolishing

Electrochemical surface treatment[4,7,8]

After the machining process, instruments receive this surface treatment, which increases cutting efficiency while reducing defects resulting from the manufacturing process, thereby increasing fatigue resistance.

Cryogenic treatment[6,8,9]

The cold treatment of metals during manufacturing is advocated so as to improve the surface hardness and thermal stability of the metal. The optimum temperature range for cold treatment is between -60˚C and -80°C depending upon the material and the quenching parameters involved.

Alloys with gold thermal treatment[9,10]

These files have martensite structures at body. Gold instruments had 2-stage specific transformation behavior, indicating that reverse transformation of the alloy occurred via the intermediate R-phase, thereby reflecting the complex phase transformation associated with the manufacturing process. Wave One Gold and Pro Taper Gold are the two files with gold treatment and exhibited superelasticity.

Blue phase treatment[5,11]

In the NiTi Blue Wire alloy, the thickness of this titanium oxide layer is 60-80 having in turn a great influence on the reliability and mechanical properties of NiTi files, especially on increasing the cutting efficiency and wear resistance. All Gold and Blue heat treated files demonstrated enhanced flexibility and fatigue resistance compared with conventional NiTi and M-Wire instruments.

Max Wire alloys (Martensite-Austenite Electropolish fleX) alloys[7,11,13]

Heat treatment of alloy results in a three dimensional alignment of crystal structure matrix leading to improved flexibility and fatigue resistance.

T-wire alloys[6,13,14]

Heat treatment after the grinding process, the traditional microstructure of the NiTi alloy is slightly changed, enabling the instrument to have higher fatigue resistance and increased flexibility. Have high cyclic fatigue resistance and lower bending stiffness. Higher austenite finish (Af) temperature of T-Wire alloy might enable files to have softer structure. Thermal processing raised the austenitic transformation temperature of NiTi alloy and enhanced the arrangement of crystal structure, which accordingly improved the performance of instrument.

Electric discharge machining technology, [15-17]

Electropolishing is a standard surface treatment process employed as a final finish during manufacturing of NiTi instruments. An electric potential and current are applied, which result in ionic dissolution of the surface. In this process, the surface chemistry and morphology are altered while surface imperfections are removed as dissolved metal ions. Simultaneously, Ti is oxidized to TiO_2, which protects the underlying material from further corrosion.

CONCLUSION

All the different phases have different advantages. The astute practitioner must use the best system for the relevant case and ensure that the canal is thoroughly instrumented and all the walls are prepared with the file to ensure enough removal of the infected dentin and at the same time maintain the natural anatomy of the root canal.

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