TEMPOROMANDIBULAR JOINT REPLACEMENT- A RATIONALE FOR USE OF DIFFERENT GRADES OF PLASTICS IN TMJ PROSTHESIS

Neha Pardeshi[1], Mehak Sharma[2], Manoj Soni[3]

[1] *Student, Mechanical and Automation Engineering Department, Indira Gandhi Delhi Technical University for Women, New Delhi, India*
[2] *Research Scholar, Mechanical and Automation Engineering Department, Indira Gandhi Delhi Technical University for Women, New Delhi, India*
[3] *Student, Mechanical and Automation Engineering Department, Indira Gandhi Delhi Technical University for Women, New Delhi, India*

ABSTRACT

Temporomandibular joint (TMJ) connects the mandible or the lower jaw to the skull and regulates the movement of the jaw. It is a bi-condylar joint in which the condyles, located at the two ends of the mandible, function at the same time. The TMJ is one of the most complex as well as most used joint in a human body. The important functions of the TMJ are mastication and speech. Temporomandibular disorder (TMD) is a generic term used for any problem concerning the jaw joint. Injury to the jaw, temporomandibular joint, or muscles of the head and neck can cause TMD. The most common TMJ disorders are pain dysfunction syndrome, internal derangement, arthritis, and traumas. In TMJ implant there are replacements of two parts:
1. Fossa replacement and 2. Condyle replacement
The TMJ implant fossa component is comprised of a fossa bearing fabricated from ultra-high molecular-weight polyethylene (ASTM F648) and a mesh backing fabricated from unalloyed titanium (ASTM F67). In this research work we are using four types of plastics such as Polypropylene (PP), High density poly ethylene (HDPE), Ultra high molecular weight polyethylene and Nylon. We will compare these four plastics that are these plastics also suitable for fossa material or not. By comparing their surface finish in graph, we can conclude that which of these plastics is best for fossa replacement. It can form the basis of a future research for designing a new age TMJ prosthesis for people suffering with TMJ diseases and in need for surgery.

Keyword: - *TMJ, Fossa, Condyle, Mandible, HDPE, Nylon, Titanium, Polypropylene, Prosthesis*

---

1. TMJ ANATOMY

The TMJ is the articulation between the condyle of the mandible and the squamous portion of the temporal bone. The condyle is elliptically shaped with its long axis oriented mediolaterally, whilst the articular surface of the temporal bone is composed of the concave articular fossa and the convex articular eminence [1]. The TMJ is a bilateral synovial joint that functions in speech, mastication, and deglutition and allows movement of the mandible in three planes of space. It is atypical in that the articular surfaces are covered by white fibrocartilage (mostly collagen with only a few cartilage cells), rather than the more usual hyaline cartilage. Beneath the articular covering of the head of the condyle is a layer of hyaline cartilage [1].
The TMJ consists of:

1. Mandibular condyle
2. Temporomandibular fossa
3. Articular disc
4. Joint capsule (lined by synovial membrane)
5. Ligaments
6. Muscles of mastication
7. Blood and nerve supply

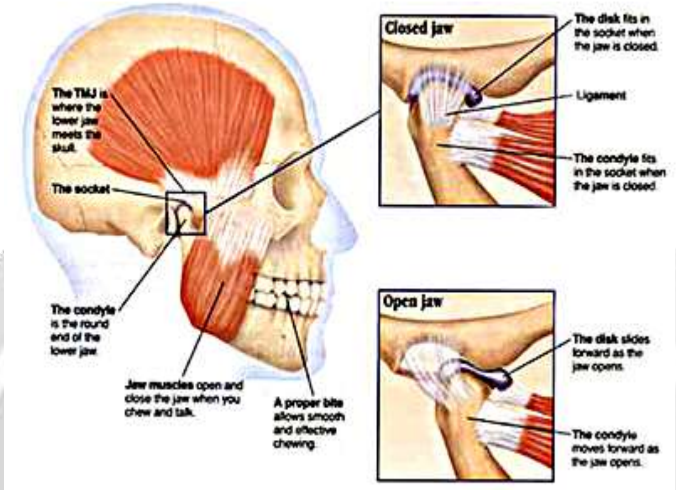


Figure 1 – Anatomy of TMJ

2. Conditions Affecting TMJ

Some of the conditions that may affect the TMJ include:
1. Pain in the TMJ or associated muscles
2. Limitation of joint movement
3. Disc displacement
4. Condylar dislocation
5. Deviation
6. Systemic autoimmune diseases, connective tissue disorders, and arthritic conditions
7. Osteoarthritis
8. Neoplasm

3. How to select a material for TMJ Implant

Choosing the appropriate materials however begins with understanding key engineering concepts and desirable implant properties.

3.1 Biocompatibility

The first tenet of implant design is to attain good fixation while causing the least amount of damage to the surrounding tissue.

3.2 Modulus

The elastic modulus of a material is the measure of resistance to deformation for a given load or stress.

3.3 Stiffness

Stiffness of a material is dependent on both the elastic modulus and geometry of the device (equivalent to the arithmetic product of two values). For two objects made of the same material, the larger the object the stiffer it is and thus more resistant to deformation. One way to use relatively rigid materials without necessarily creating an implant that is excessively stiff is to make the implant hollow or very porous. This design concept enables the fabrication of implants that better share the load.

3.4 Stress shielding

When different materials are placed adjacent to one another with a uniform load applied to both, the stiffer material will resist changes in deformation more than the more flexible material. For example- when a titanium metal plate (a higher modulus of elasticity than bone) is fixed adjacent to bone, stresses applied will be seen by the stiffer metal plate. Bone is said to be “stress shielded”.

3.5 Notch sensitivity

In addition to reducing stress shielding, promotion of bone in growth through porous metal coating will also increase implant fixation. The porous coating of hip implants has been shown to promote bone ingrowth. The ingrown bone rigidly fixes the implant and prevents pain and implant-host interface failure. The addition of a porous coating to the surface of implants however causes stress concentrators that may propagate a fracture in notch sensitive material. Notch sensitivity is the degree to which the sensitivity of a material to fracture is enhanced by the presence of a surface homogeneity such as a notch created by surface porous coating. Notch sensitive materials are also prone to fracture at sudden changes in section, cracks or scratches. In general, ductile materials are less notch sensitive than ductile materials.

3.6 Modularity

Modularity is another important concept in implant design, enabling the use of advantageous use of different materials for specific functions. For example, materials optimized for wear resistance can be used for the bearing components while materials that are stiff can be used for load carrying and fixation to reduce stress shielding and consequent bone resorption.

4. Suitable materials for condyle and fossa replacement

The same materials that are utilized in hip and knee arthroplasty are applicable to TMJ replacement. Cobalt-Chromium and titanium alloys possess the necessary strength and fatigue resistance for implants stems and bodies, with titanium alloy having the advantage of lower elastic modulus and better load sharing are available for enhancing stability through tissue ingrowth. They include the more traditional beaded or fiber wire types of surface treatments and the newer higher porosity foam-like materials made if either titanium or tantalum. Potential bearing combinations include cobalt-chromium alloy. Of significant note is the fairy recent development of highly cross-linked polyethylene, a very wear resistant formulation of ultra-high molecular weight polyethylene that is witnessing widespread use in total hip and knee arthroplasty. Wear simulator studies have confirmed very low wear rates with these new materials.

With the knowledge of implants design specification, the appropriate component materials can be chosen. Among those, there is stainless steel. Such a material has appropriate ultimate tensile strength and fatigue properties. It should be avoided for TMJ implants however, as it susceptible to crevice and inter- granular corrosion: in active areas such as TMJ, this corrosion may lead to implant failure and consequent immune reaction and osteolysis. Stainless steel is not nor “biocompatible” under the loading conditions found in TMJ Cobalt-Chromium (CoCr) based alloys are biocompatible and unlike stainless steel are highly corrosion resistant. They have low notch sensitivity and thus can be treated with metal beads or fiber wire to promote bone ingrowth and significantly increase implant fixation. CoCr alloy metal has excellent wear properties and has stood the test of time in metal on metal hip implants for up to 20 years. CoCr is very hard and abrasion resistant, but this property can be a disadvantage in TMJ implants. Due to its high elastic modulus, CoCr alloy implants cause significant stress shielding.

4.1 Titanium alloys

Titanium alloys are highly biocompatible with half the elastic modulus of CoCr. As a more flexible implant, it can more uniformly transfer loads and cause significantly less stress shielding to adjacent bone. Titanium however does not have good wear properties. When subjected to repetitive forces, it is fatigue resistant and thus breaks down. It should not be used at the joint interface. Furthermore, titanium is notch sensitive and thus s hould not be impregnated with beads or fiber wire to promote bony ingrowth. However, when the surface is roughened without notching, bone in growth occurs and thus improves fixation. Consequently, non-porous coated titanium alloy material can be used for the TMJ stem component to decrease stress shielding to the adjacent bone while still withstanding the forces generated at the TMJ. CoCr on the other has excellent wear resistance and is the reason why it is used as the femoral head component in total hip arthroplasty. It can withstand the high repetitive motion and forces up to three times body weight with acceptable wear properties lasting an estimated 20-30 years. Consequently, CoCr is an ideal material for the “ball” component of TMJ alloplastic implants.

4.2 Non-metallic materials

Non-metallic materials have a significant role in joint replacements as well. Ceramics for example, are very stable and inert materials that can withstand high compressive forces. They are brittle however, and are susceptible to high tensile forces. They have been shown as useful alternatives as bearing material in highly loaded joints such as the hip.

4.3 UHMWPE

Ultra-high molecular weight polyethylene (UHMWPE) has also had long term success in the orthopedic literature as a joint spacer in the hip and knee. With repetitive loading however, it is subject to wear. To prevent particularization, osteolysis, and aspect loosening, cross-linked ultra-high molecular weight polyethylene with improved wear resistance has been developed. Hip simulator studies have confirmed very low wear rates with these new materials. Contemporary metal-on-metal CoCr bearings have shown very low wear rates as compared to polyethylene. They have however been shown to release particles and ions from the articulating surfaces into the joint and the whole organism especially in the early phase after implantation. The released metal ions, especially chromium, are hypothesized to potentially trigger cytoxic, carcinogenic and allergic reactions. The incidence of these implant-related complications is very unavailable.

5. Properties of plastics suitable for TMJ

Plastic	Tensile strength (psi)
Nylon	12400
Polypropylene	5400
HDPE	4000
UHMWPE	3100

Table 1 – Tensile Strength Comparison of Plastics

Plastic	Stiffness (psi)
Nylon	4,10,000
Polypropylene	225,000

HDPE	200,000
UHMWPE	110,000

Table 2 – Comparison of Stiffness

Plastic	**Izod Impact (notched) toughness (ft-lbs/in)**
Nylon	4,10,000
Polypropylene	225,000
HDPE	200,000
UHMWPE	110,000

Table 3 – Comparison of toughness

5. Methodology

In TMJ prosthesis fossa part is made of HDPE and UHMWPE. Why we cannot use lower grade of plastics? Are they also suitable for TMJ replacement? If they are then what will be the effect on surface roughness of plastics or in how much time plastic part will start degrading. So we have selected four kinds of plastics to check the suitability of these plastics for TMJ prosthesis. Selected plastics for experiment are as follows:

1. Polypropylene
2. High density polyethylene (HDPE)
3. Ultra high molecular weight polyethylene (UHMWPE)
4. Nylon

Four types of ball pin hammers, each one with having different surface finish have been used to scratch these plastics with constant loading in constant time.

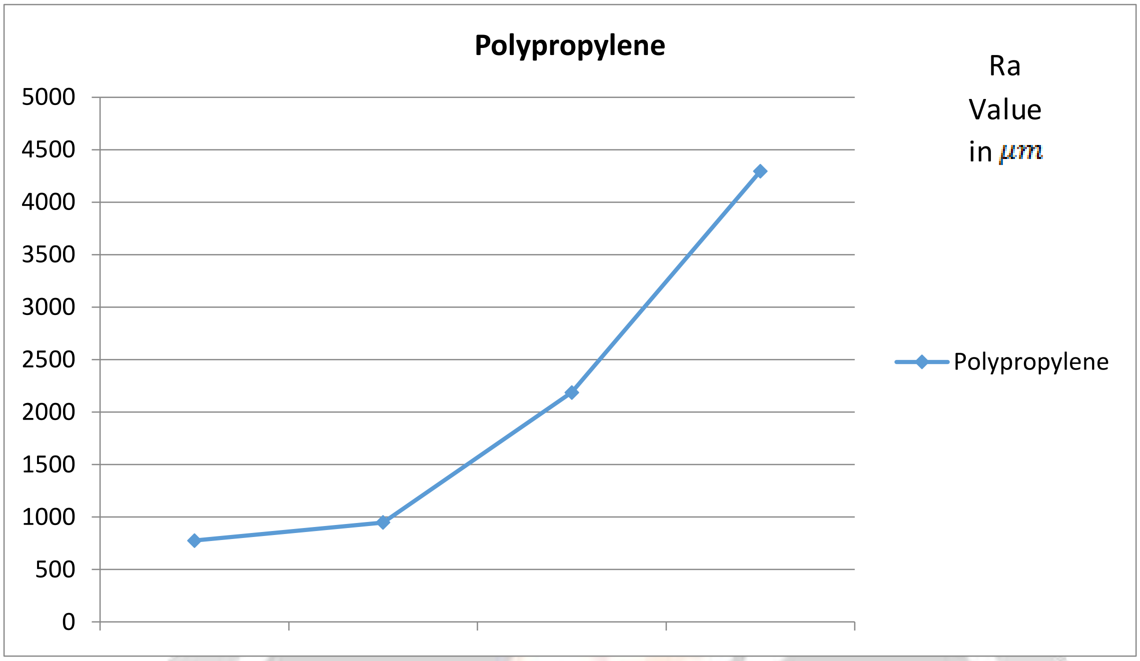
First of all, we have cut the equal size pieces of each plastic. The size of each plastic component is 15 mm. We have prepared these samples on lathe machine. So we have four samples of each different type of plastic. Then we have applied a constant load of 10 kg. on each plastic component with each type of hammers on four different samples. The loading is for 40 seconds for every sample. After loading surface roughness of each plastic component is somewhat degraded. Then we have measured surface roughness of every sample on a surface roughness tester named as TESA-RUGOSURF 10-G. All the readings are in micrometer.

6. Results

Roughness average (Ra): Ra is the arithmetic average of the absolute values of the profile height deviations from the mean line, recorded within the evaluation length. Ra is the average of a set of individual measurements of a surfaces peaks and valleys.

6.1 Degradation of Plastics in Ra value:

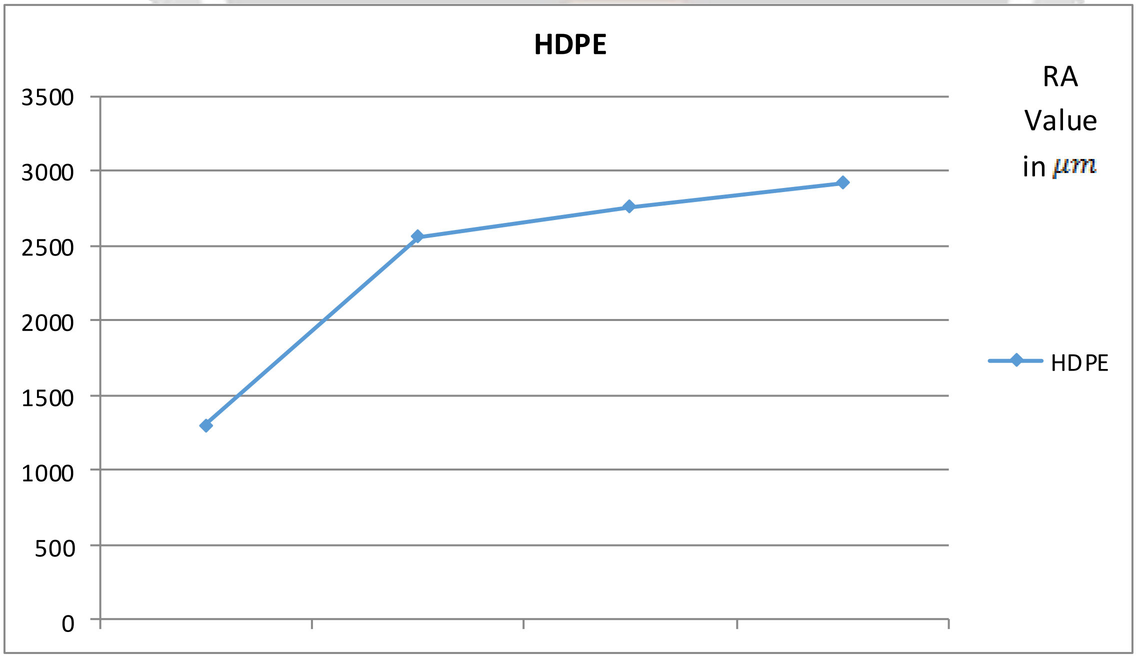
Polypropylene (PP)



Graph 1 - Degradation of polypropylene

After testing the samples of polypropylene, graph has been plotted with Ra values in micrometer. From the graph it can be concluded that, by increasing the surface roughness of hammers degradation of polypropylene is increasing. Minimum surface roughness of polypropylene samples is 776μm. Maximum surface roughness of polypropylene is 4296μm.

High-density polyethylene (HDPE)

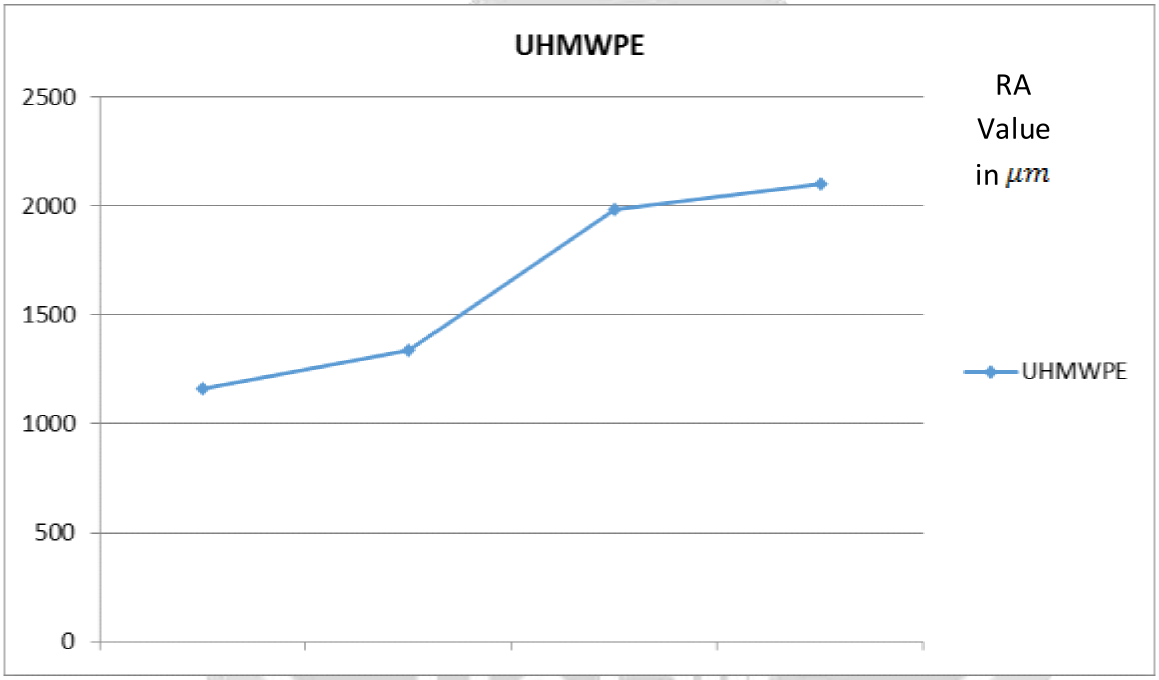


Graph 2- Degradation of High-density polyethylene

After testing the samples of HDPE, graph has been plotted with Ra values in micrometer. From the graph it can be concluded that, by increasing the surface roughness of hammers, degradation of polypropylene is increasing. Minimum surface roughness of HDPE samples is 1300μm. Maximum surface roughness of polypropylene is 2922μm.

Ultra-high molecular weight polyethylene

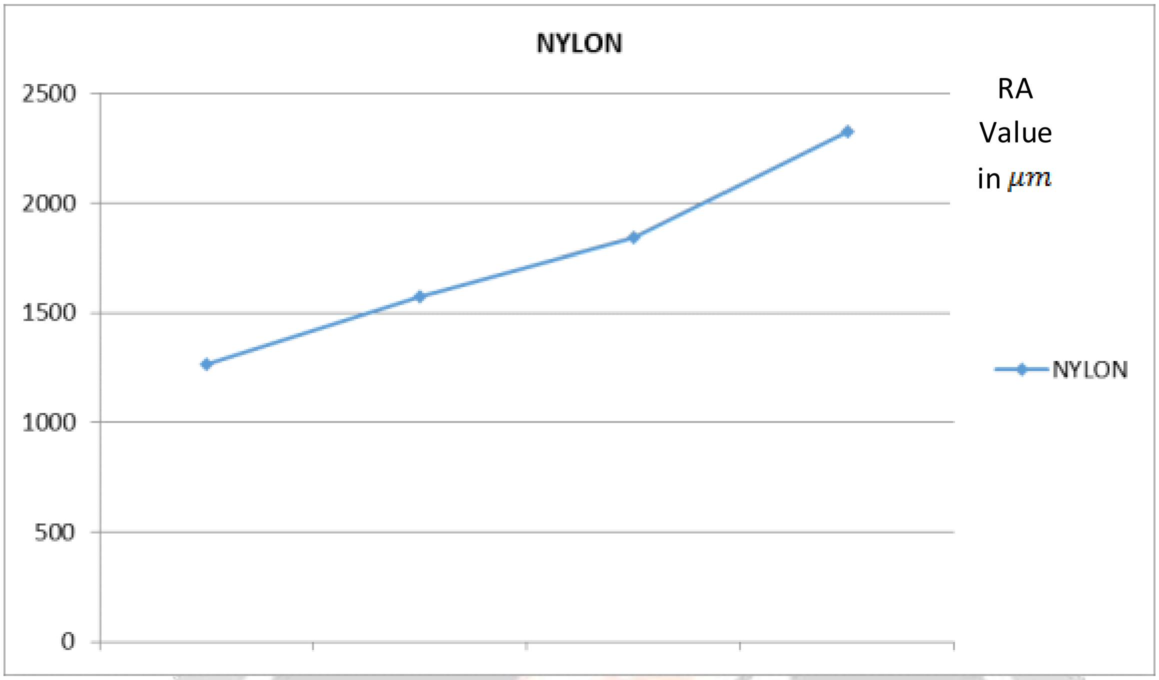
After testing the samples of Ultra high molecular weight polyethylene (UHMWPE), graph has been plotted with Ra values in micrometer. From the graph it can be concluded that, by increasing the surface roughness of hammers, degradation of UHMWPE is increasing. Minimum surface roughness of UHMWPE samples is 1159μm. Maximum surface roughness of polypropylene is 2101μm.



Graph 3- Degradation of Ultra-high molecular weight polyethylene

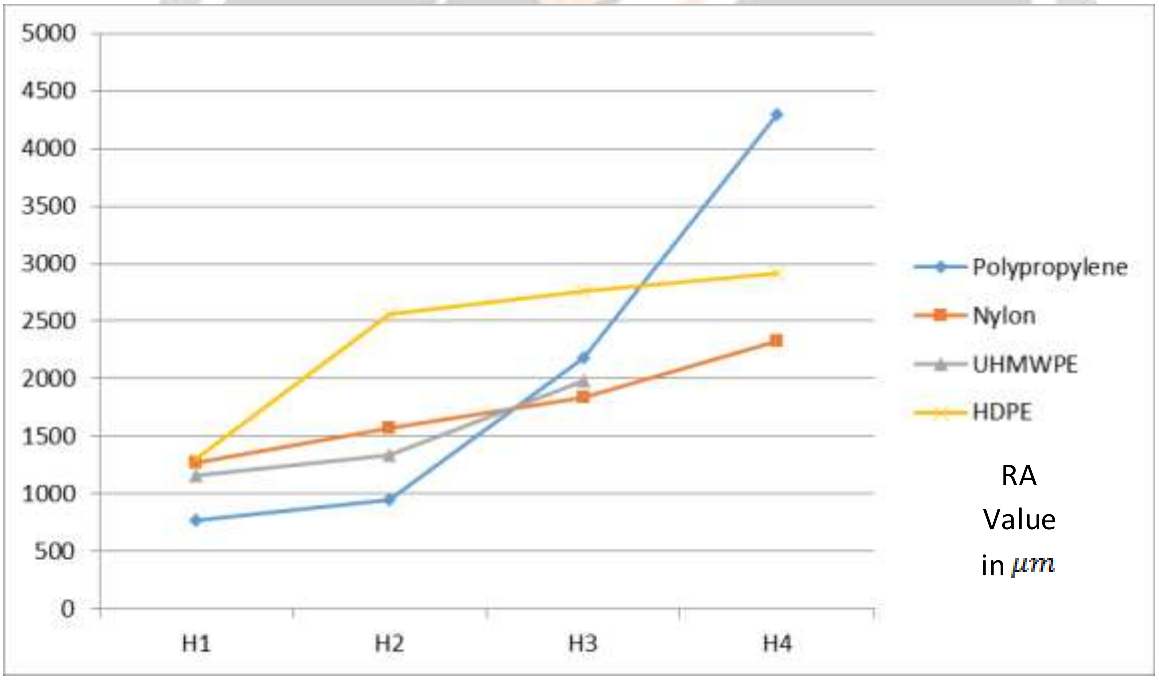
Nylon

After testing the samples of Nylon, graph has been plotted with Ra values in micrometer. From the graph it can be concluded that, by increasing the surface roughness of hammers, degradation of Nylon is increasing. Minimum surface roughness of Nylon samples is 1267μm. Maximum surface roughness of polypropylene is 2325μm.



Graph 4- Degradation of Nylon

Comparison of HDPE, UHMWPE, Nylon and Polypropylene in terms of surface roughness:



Graph 5- Comparison of HDPE, UHMWPE, Nylon and PP

4. CONCLUSIONS

All the surface roughness values of four plastics are plotted on the graph for comparison. From the graph it can be concluded that, by increasing the surface roughness of hammers Polypropylene degrades maximum and UHMWPE degrades minimum. It means when UHMWPE is selected as a material for fossa replacement then it will have long life than nylon, polypropylene and HDPE. And if Polypropylene is selected as a material for fossa replacement then it will degrade quickly than Nylon, UHMWPE and HDPE. It can form the basis of a future research for designing a new age TMJ prosthesis for people suffering with TMJ diseases and in need for surgery.

5. REFERENCES

[1]. Shirish Ingawale and Tarun Goswami, "Temporomandibular joint: Disorders, treatments and biomechanics" 2009

[2]. Johnson DR, Moore WJ (1997) Anatomy for Dental Students Third Edition Oxford, New York, Toronto: Oxford University Press.

[3]. Bernard L (2001) The Anatomical Basis of Dentistry, 3rd Edition. St. Louis: Mosby.

[4]. Bell WE (1982) Clinical management of temporomandibular disorders Chicago: Year Book Medical Publishers.

[5]. Standring S (ed) (2004) Gray's Anatomy, 39th ed. The Anatomical Basis of Clinical Practice Edinburgh, London: Churchill Livingstone

[6]. Mew JR (1997) The aetiology of temporomandibular disorders: a philosophical overview. Eur J Orthod. 19(3):249-58.

[7]. McCarty DJ (1980) American rheumatology--the future of our guild. Antidisestablishmentarianism Arthritis Rheum. 23(9):969-76.

[8]. Wilkes CH (1989) Internal derangements of the temporomandibular joint. Pathological variations Arch Otolaryngol Head Neck Surg. 115(4):469-77.

[9]. Bell WE (1982) Clinical management of temporomandibular disorders.Chicago: Year Book Medical Publishers.

[10]. Mew JR (1997) The aetiology of temporomandibular disorders: a philosophical overview. Eur J Orthod. 19(3):249-58.

[11]. Salé H and Isberg A (2007) Delayed temporomandibular joint pain and dysfunction induced by whiplash trauma: a controlled prospective study. J Am Dent Assoc. 138(8):1084-91.

[12]. Ryan, DE (1993) Temporomandibular Disorders. Curr Opin Rheumatol. 5:209-218.

[13]. Mutlu N, Erdal ME, Herken H, Oz G, Bayazit YA (2004**)** T102C polymorphism of the 5-HT2A receptor gene may be associated with temporomandibular dysfunction. Oral Dis.10(6):349-52.

[14]. Herken H, Erdal E, Mutlu N, Barlas O, Cataloluk O, Oz F, Güray E (2001) Possible association of temporomandibular joint pain and dysfunction with a polymorphism in the serotonin transporter gene. Am J Orthod Dentofacial Orthop. 120(3):308-13.

[15]. Salama al-riyami , Temporomandibular joint disorders in patients with skeletal discrepancies, 2010

[16]. Olivo SA, Bravo J, Magee DJ, Thie NM, Major PW, Flores-Mir C (2006) The association between head and cervical posture and temporomandibular disorders: a systematic review J Orofac Pain. 20(1):9-23.

[17]. Dibbets JM, van der Weele LT (1996) Signs and symptoms of temporomandibular disorder (TMD) and craniofacial form. Am J Orthod Dentofacial Orthop. 110(1):73-8.

[18]. Helkimo M (1976) Epidemiological surveys of dysfunction of the masticatory system. Oral Sci Rev. 7:54-69.

[19]. Rudman R (1995) Clinical Anatomy of Masticatory Apparatus and Pharyngeal Spaces By Joannes Lang New York: Thieme Medical Publishers.

[20]. Allerbring M, Haegerstam G (1993) Characteristics of patients with chronic idiopathic orofacial pain. A retrospective study. Acta Odontol Scand. 51(1):53-8.

[21]. Hagberg C, Hagberg M, Kopp S (1994) Musculoskeletal symptoms and psychosocial factors among patients with craniomandibular disorders. Acta Odontol Scand. 52(3):170-7.

[22]. Türp JC, Kowalski CJ, O'Leary N, Stohler CS (1998) Pain maps from facial pain patients indicate a broad pain geography. J Dent Res. 77(6):1465-72.

[23]. Marbach JJ (1995) Is there a myofascial, temporomandibular disorder personality? J Mass Dent Soc. 44(1):12-5, 36-7.

[24]. Hedenberg-Magnusson B, Ernberg M, Kopp S (1999) Presence of orofacial pain and temporomandibular disorder in fibromyalgia. A study by questionnaire. Swed Dent J. 23(5-6):185-92.

[25]. Plesh O, Wolfe F, Lane N (1996) The relationship between fibromyalgia and temporomandibular disorders: prevalence and symptom severity. J Rheumatol. 23(11):1948-52.

[26]. Gelb H (1977) Effective Management and Treatment of the Craniomandibular Syndrome. In H. Gelb (Ed.) Clinical Management of Head, Neck, and TMJ Dysfunction. Philadelphia: W.B Saunders Co.

[27]. Okeson JP (1996) Orofacial pain: guidelines for assessment, diagnosis and management. Chicago: Quintessence Publishing Co. Olivo SA, Bravo J, Magee DJ, Thie NM

[28]. Raphael KG, Marbach JJ, Klausner J (2000) Myofascial face pain. Clinical characteristics of those with regional vs. widespread pain. J Am Dent Assoc. 131: 161-171.

[29]. Irving J, Wood GD, Hackett AF (1999) Does temporomandibular disorder pain dysfunction syndrome affect dietary intake? Dent Update. 26(9):405-7.

[30]. Thorpy MJ (1990) Parasomnias. In: Thorpy MJ (ed) International classification of sleep disorders. Diagnostic and coding manual. Americal Sleep Disorders Association, Rochester: Allen Press, p 142-185.

[31]. Pankhurst CL (1997) Controversies in the aetiology of temporomandibular disorders. Part 1. Temporomandibular disorders: all in the mind? Prim Dent Care. 4(1):25-30.

[32]. Lipowski ZJ (1988) Somatization: the concept and its clinical application. Am J Psychiatry 145: 1358-1368.

[33]. Dhanrajani PJ, Jonaidel O (2002) Trismus: aetiology, differential diagnosis and treatment. Dent Update. 29(2):88-92.

[34]. Perry H (1991) Above All Else, Do No Harm. J Craniomandib Disord. 5(2):8.

[35]. Mercuri LG. The use of alloplastic prostheses for temporomandibular joint reconstruction. J Oral Maxillofac Surg 2000: 58: 70-5.

[36]. Quinn P. Lorenz Prosthesis. Oral Maxillofacial Surgery clinics North America 2000: 12: 93-104

[37]. Bistolfi A, Turell MB, Lee YL, Bellare A. Tensile and tribological properties of high-crystallinity radiation crosslinked UHMWPE. J Biomed mater Res B Appl Biomater 2008.

[38]. Killaridis S, Thilander B, Kjellberg H, Topouzelis N, Zafiriadis A, Effect of low masticatory function on condylar growth: a morphometric study in the rat. Am J Orthod Dentofacial Orthop 1999:116: 121-5

[39]. Hani sinno, youssef tahiri, Mirko Gilardino, Dennis Bobyn "Engineering alloplastic Temporomandibular joint replacements" MJM 2010 13(1):63-72

[40]. An overview of the Plastic material Selection process for Medical devices, February 2013, HCL Technologies

[41]. Barbick, M., M. F. Dolwick, S. Rose, and S. Abramowicz. Adaptibility of Biomet Lorenz tmj prosthesis to joints that were previously treated with the tmj concepts custom joint prosthesis. Oral Med. Oral Pathol. Oral Radiol. Endod. 106(2):e17, 2008. doi:10.1016/j.tripleo.2008.05.058.

[42]. Detamore, M. S., and K. A. Athanasiou. Structure and function of the temporomandibular joint disc: implications for tissue engineering. J. Oral Maxillofac. Surg. 61(4):494–506, 2003. doi:10.1053/joms.2003.50096.

[43]. Gerard, D. A., and J. W. Hudson. The Christensen temporomandibular joint prosthesis system: an overview. TMJournal, 2002. Retrieved on 09/20/2007, from http://tmjournal.com/library/CP-009.pdf.

[44]. Tanaka, E., D. P. Rodrigo, Y. Miyawaki, K. Lee, K. Yamaguchi, and K. Tanne. Stress distribution in the temporomandibular joint affected by anterior disc displacement: a three-dimensional analytic approach with the finite-element method. J. Oral Rehabil. 27(9):754–759, 2000. doi:10.1046/j.1365-2842.2000.00597.x.

[45]. Wilkes, C. H. Arthrography of the temporomandibular joint in patients with the TMJ pain-dysfunction syndrome. Minn. Med. 61:645–652, 1978.

[46]. Wilkes, C. H. Internal derangements of the temporomandibular joint. Arch. Otolaryngol. Head Neck Surg. 115:469–477, 1989.

[47]. Molinari, F., P. F. Manicone, L. Raffaelli, R. Raffaelli, T. Pirronti, and L. Bonomo. Temporomandibular joint soft-tissue pathology. I: Disc abnormalities. Semin Ultrasound CT MRI 28(3):192–204, 2007.

[48]. Tanaka, E., D. P. Rodrigo, Y. Miyawaki, K. Lee, K. Yamaguchi, and K. Tanne. Stress distribution in the temporomandibular joint affected by anterior disc displacement: a three-dimensional analytic approach with the finite-element method. J. Oral Rehabil. 27(9):754–759, 2000. doi:10.1046/j.1365-2842.2000.00597.x.

[49]. Tanaka, E., M. S. Detamore, K. Tanimoto, and N. Kawai. Lubrication of the temporomandibular joint. Ann. Biomed. Eng. 36(1):14–29, 2008. doi:10.1007/s10439-007-9401-z.

[50]. Wolford, L. M., and P. Mehra. Custom-made total joint prosthesis for temporomandibular joint reconstruction. Proc. Baylor Univ. Med. Center 13:135–138, 2000.

[51]. Wolford, L. M., M. C. Pitta, and P. Mehra. Mitek anchors for treatment of chronic mandibular dislocation. Oral Surg. Oral Med. Oral Pathol. Oral Radiol. Endod. 92:495–498, 2001. doi:10.1067/moe.2001.118283.

[52]. Wolford, L. M., D. J. Dingwerth, R. M. Talwar, and M. C. Pitta. Comparision of two temporomandibular joint total joint prosthesis systems. J. Oral Maxillofac. Surg. 61(6):685–690, 2003. doi:10.1053/joms.2003.50112.

[53]. Laskin, D. M. Indications and Limitations of TMJ Surgery. TMDs: Temporomandibular Disorders: An Evidence-Based Approach to Diagnosis and Treatment. Chicago: Quintessence, 2006.

[54]. Quinn, P. D. Alloplastic reconstruction of the temporomandibular joint. Sel. Read. Oral Maxillofac. Surg. 7(5):1–23, 1999.

[55]. Quinn, P. D. Lorenz prosthesis—total temporomandibular joint reconstruciton. Oral Maxillofac. Surg. Clin. North Am. 12(1):93–104, 2000.

[56]. van Loon, J. P., L. G. M. de Bont, B. Stegenga, F. K. L. Spijkervet, and G. J. Verkerke. Groningen temporomandibular joint prosthesis: development and first clinical application Int. J. Oral Maxillofac. Surg. 31(1):44–52, 2002. doi:10.1054/ijom.2001.0175.