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# MECHANICAL WOOD MODIFICATION METHODS

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**Abstract**

*The wood material has been the most preferable material in order to meet the needs of accommodation, transport and social since human beings existed. The different "Wood Modification Methods" has been developed as a result of all the scientific studies and researches in order to remove the negative characteristics of the wood material from centuries ago to nowadays. The wood material is usually admitted as too soft and too weak for structural applications required hardness and durability. However, the wood material increased density can be an alternative for other structural materials. Most of the wood material mechanical characteristics are related to density. A lot of studies have been carried out to develop the suitable operation, because the densification of wood material increases mechanical characteristics and hardness of wood material. By means of densification, low-density wood material is converted to high-density wood material, and its trade value is increased. In this study, from the environment friendly modification methods which is used to modify wood material and to improve mechanical strength properties of wood Thermo-Hygro-Mechanic (THM), Viscoelastic-Thermal-Compression (VTC), Thermo-Mechanic (TM) and the new application Thermo-Vibro-Mechanic (TVM) have been investigated.*

**Keywords:** Wood modification, Mechanical modification, Densification, Surface densification.

# MEKANİK ODUN MODİFİKASYON METOTLARI

**Özet**

*Ağaç malzeme, insanoğlunun varoluşundan bu yana barınma, ulaşım ve sosyal ihtiyaçlarını karşılamak amacıyla sıkça tercih ettiği bir malzeme olmuştur. Yüzyıllar öncesinden günümüze kadar, ağaç malzemenin bazı olumsuz özelliklerinin giderilmesi için yapılan tüm bilimsel çalışmalar ve araştırmalar sonucunda, farklı ''Ahşap Modifikasyonu Yöntemleri'' geliştirilmiştir. Ağaç malzeme genellikle yüksek direnç, sertlik ve dayanıklılık gerektiren yapısal uygulamalar için çok yumuşak ya da çok zayıf olarak kabul edilmektedir. Ancak, yoğunluğu artırılmış bir ağaç malzeme, diğer yapısal malzemelere alternatif olabilmektedir. Ağaç malzemenin mekanik özelliklerinin çoğu, yoğunluk ile ilişkilidir. Ağaç malzemenin yoğunlaştırılması, mekanik özelliklerini ve sertliğini artırdığından, bu konuda uygun bir işlem geliştirmek için birçok çalışma yapılmıştır. Yoğunlaştırma işlemiyle düşük yoğunluklu ağaç malzemeler yüksek yoğunluklu hale getirilmekte ve ticari olarak yüksek değerli ürünler haline dönüştürülebilmektedir. Bu çalışmada, ağaç malzemeyi modifiye etmek ve mekanik direnç özelliklerini iyileştirmek için kullanılan çevre dostu modifikasyon yöntemlerinden, Termo-Higro-Mekanik (THM) metodu, Viscoelastik-Termal-Sıkıştırma (VTC) metodu, Termo-Mekanik (TM) metodu ve yeni bir uygulama olan Termo-Vibro-Mekanik (TVM) yoğunlaştırma metodu incelenmiştir.*

**Anahtar Kelimeler:** Odun modifikasyonu, Mekanik modifikasyon, Yoğunlaştırma, Yüzey yoğunlaştırma

## 1 Introduction

Wood material has been used through out history to meet the human needs. Nowadays, together with the technological developments, its usage has increased significantly in the industrial sector. The increase of human population and new application fields has increased the demand for wood material but has also caused a decrease in good quality material. This makes it compulsory to use available resources more efficiently, to use tree types with low resistance features after modification and to produce different materials [1]. Centuries ago and still today people treat wood in many ways to make it usable in various needs and more durable. All this operations arising from all scientific researches and studies are called "Wood Modification Methods" [2]. Wood modification term aims to change the negative features of wood material or enhance them.

Wood material is generally regarded too soft or too weak for structural application requiring high resistance, hardness and durability. However, wood material with increased density is considered as an alternative for other structural materials[3-7]. Mechanical features of wood material is related mostly to density [3, 5, 6, 8, 9]. Since densifying wood material increases its mechanical features and hardness, many trials have been conducted to develop a suitable operation in this matter [3]. With densification operation, low density wood material is turned into commercially high value product. High density wood material types can also be made more resistant using densification [4-6]. It has long been known that wood material can densified wihout using chemicals. However, because of plasticisation in the final products after available operations and due to inadequate dimensional stability, it has been ignored by the industry. Throughout history all around the World various types of densified wood products have been manufactured. Also, in the last two decades, due to an increase in environmental awareness, use of environmentally hazardous impragneted elements has been increasingly resticted, which has led to new methods which are environmentally friendly and which protect wood material against biological degradation and increase dimensional stability [10]. These methods are densification (Thermo-Mechanic (TM)) method conducted in an open system using heat and pressure, densification (Thermo-Hygro-Mechanic (THM)) method conducted in a closed system using pressure and steam, densification (Viscoelastic-Thermal- Compression (VTC)) method using heat and pressure and pre-softening with steam and densification (Thermo-Vibro-Mechanic (TVM)) method which is a new application using heat pressure and vibration. The most important variables are wood material type, heat and softening or plasticisation period, densification method (thermo mechanical, thermo higro mechanical and viscoelastic thermal pressing) and press pressure. These variables affect resistance features of wood after densification operation. Different applications of these variables can increase strength features of % 100 densified wood material [11]. The most important problem encountered in densified wood material by compressing its tendency to turn back to initial size due to its spring back feature when used in places where it might be exposed moisture or water [6, 9, 12-16]. The most important factor determining wood material modification in thermal modification applications is the temperature above 150 ˚C. The colour of wood material darkens as temperature and duration increase. Colour of wood material is an important feature especially as a decoration element. Weight loss occures depending on thermal modification in wood material. This loss is primarily due to water loss as a result of vaporization. In thermal modification applications, mechanical features of wood material also decline, which may restrict use of wood material especially as structural system [1, 10, 17-23].

In this study, Thermo-Hygro-Mechanic (THM), Viscoelastic-Thermal-Compression (VTC), Thermo-Mechanic (TM) and a new application Thermo-Vibro-Mechanic (TVM) densification methods, which are among environmentally friendly modification methods used to modify wood material and enhance its mechanical resistance features, are researched.

## 2 Historical Process

Historically, wood material densified by compression started to be researched in the early 1900's. The first patents for compressed wood products were granted to Sears in 1900, to Walch and Watts in 1923, to Oleheimer in 1929, to Brossmannes in 1931, to Esselen in 1934 and to Olson in 1934 [14, 16, 24-28]. Compressed massive wood was first launched in Germany in the early 1930's as the commercial name "Lignostone''. Also "Lignofol'', a product obtained by compressing wood veneer, was produced. These products were compressed at, 140 ° C with 25 MPa, 0,8 $g/cm^3$ density. Simultaneously, in England, similar products (plywood) were also produced by Jicwood and Jablo. Two other important methods in densifying wood material are ''Compreg'' and ''Staypak'' developed in forestry laboratories in the USA [ 13, 14, 29, 30]. Compreg is obtained by applying pressure to wood while resin in synthetic resin treated wood hardens. The best result is obtained when fenol formaldehit is used as resin. Not only compression ability of wood material impragnated with fenol formaldehit increases but also its ability to substain its compressed state when pressure is ceased increases. At 150 $^0$C and 7-8 MPa pressure, wood material with 1,3-1,4 $gr/cm^3$ specific weight is obtained. During compression operation of wood material, the required pressure amount depends on wood type, synthetic resin and vapourisable element amount, pre-hardening of resin and its dispersion in wood structure. Compreg's resistance feature increase depending on the increase in specific weight as well as shock resistance. The increase in synthetic resin amount proportional to dry wood weight decreases shock resistance while increasing pressure resistance. That is, the material becomes more brittle [12, 31, 32]. Staypak is a wood material stabilized and pressed at high temperature. Wood is pressed by heating at high temperatures so that lignin, which fills in the gap between cellulose chains becomes fluid, and thus internal stress is decreased. This operation significantly decreases absorption tendency of wood in moist environment. Between 150 ˚C – 180 ˚C and 9,6-17,2 MPa pressure, wood material with 1,3-1,4 $gr/cm^3$ specific weight is obtained [12, 13, 31, 33]. With Staypak application, resistance feature of wood material against biological hazards doesn't increase. Due to pressing and high temperature, colour of wood material darkens and in line with pressure amount, tensile strength elasticity module and shock resistance might increase[31, 32].

Table 1. shows some features of methods used in densifying wood material and these historical methods.

Table 1. Methods used in densifying wood material and their features.

| Year | Name of İnvestigator | Temperature Ratio | Compression Ratio |
|---|---|---|---|
| 1900 | Sears | | |
| 1923 | Walch and Watt | | |
| 1929 | Olesheimer | | |
| 1931 | Brossman | | |
| 1934 | Esselen | | |
| 1934 | Olson | | |
| 1930 | Lignostone, Lignofol, Jicwood, Jablo | 140 ˚C | 250 $kg/cm^2$ (24,516 MPa) |
| 1941 | Compreg | 150 ˚C | 6,89-8,27 MPa |
| 1962 | Staypack | 150 ˚C – 180 ˚C | 9,65-17,24 MPa |
| 1998-2000 | Thermo-Mechanical | Temperature Value 150˚C-200˚C | Densification ratio ( %40,%50,%60) |
| 2000-2005 | Thermo-Hygro-Mechanical | 150 ˚C | 130 $kg/cm^2$ (12,748 MPa) |
| | CaLignum | No Heating | 140 MPa |
| 1990-2010 | Viscoelatic-Thermal-Compression | 160 ˚C -175 ˚C | 650-2000 kPa (0,65-2 MPa) |
| | | 175 ˚C - 225 ˚C | 2000-4000 kPa (2-4 MPa) |
| 2012-2016 | Thermo-Vibro-Mechanic (TVM) | 100 ˚C - 140 ˚C | Densification ratio 0,6 MPa- 2.2 MPa |

## 3 Mechanic Wood Modification Methods

Wood material can density under pressure by compressing, by being absorbed by some chemical-resin in the cell wall (impregnation) or by using compression together with impregnation [5, 6]. In the compressively densification of wood material, densification is realized by collapsing the cell wall and by decreasing clearance volume [1, 34, 35]. Crashes and cracking can occur in the cell wall of compressed wood material under the normal atmospheric conditions. Natural elastic structure of wood plays an important role in the compressively densification. When wood temperature is above critical transition temperature densification can be achieved without any significant deformation in amorphous polymers, and without cellular crashes. Compression properties mostly depend on wood density, moisture, cellular wall volume and compression direction. One of the problems in densifications operation is spring back and it can be eliminated thanks to temperature and steam effect [1, 5, 36]. In densification with chemicals, densified wood material can be obtained as a result of chemical reaction or cooling after fluid natural and artificial resins are absorbed in the gaps of wood material [7, 8]. Important problems might ocur due to spring back when the material is exposed to moisture or water contact after compression while densifying wood material by compression without resin absorption [1, 37] (Figure1).

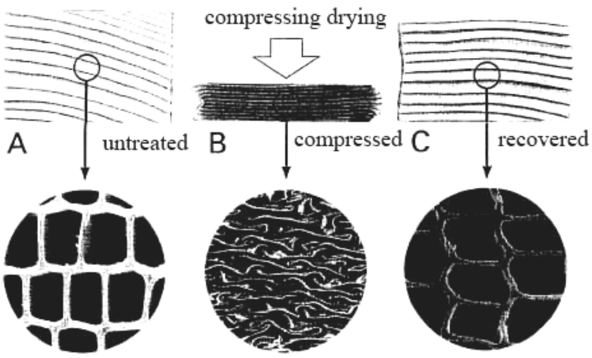


Figure1. Spring back occuring in wood material desified by compression[37].

In densification without resin absorption, in order to achieve dimensional stability, various studies have been conducted and some of them have given succesful results. These studies are densification in an open system using temperature and pressure (Thermo-Mechanic (TM)), densification in a closed system using temperature, pressure and vapour (Thermo-Hygro-Mechanic (THM)), densification using heat, pressure and pre-softening with steam (Viscoelastic-Thermal- Compression (VTC)) and densification using temperature, pressure and vibration as a new application ( Thermo-Vibro-Mechanic (TVM)).

### 3.1 Thermo-Mechanic Densification (TM)

In thermo-mechanic (TM) densification wood material is densified in an open system with the effect of temperature and pressure. TM operation process is applied between 150˚C-200˚C, at % 40, % 50, % 60 compression rates. Wood material's thermo mechanic (TM) densification properties depend on density, latewood rate, cellular wall volume (all of which are anotomic features of wood material) and compression direction [5]. Because of elastic behaviour of wood material, in thermo mechanic (TM) method, after the applied pressure disappears, there is a tendency to turn back into the original shape before compression and this behaviour is called spring back which may cause a change in the compressed dimension [38]. In case of high compression rate, more spring back occurs and this may arise from more stress in the material structure [39]. In the wood material exposed to thermo mechanic (TM) densification, bending resistance and elasticity module in bending increase as paralel to the increase in compression rate [40]. In Thermo-Mechanic (TM) densification, most important factor affecting elasticity module is compression rate and pres temperature doesn't have an important effect [37]. After thermo mechanic (TM) densification operation, hardness of wood material can be increased [41]. After thermo mechanic (TM) densification operation, increases in resistance values might arise from the decrease in gap volume of wood material and the increase in cellular wall substance in unit volume with load-carrying feature[11]. With the increase in density as a result of densification period, increases might ocur in pressure resistance paralel to fibers, bending resistance in radial and tangential directions and brinell hardness values [4]. Microscobic observations show that in densified wood material at low temperature and high compression rate, cellular wall crashes ocur more, which might decrease resistance features [40] (Figure2).

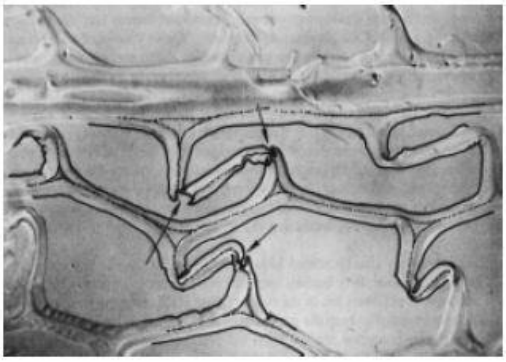

Figure 2. Deformation (crash, crack, etc.) in cellular structure of wood densified with thermo mechanic (TM) method [13].

Tabarsa and Chui treated white spruce (*Picea glauca*) wood between 20 ˚C ile 200 ˚C in radial direction between % 12 and % 32 compression rate with thermo mechanic (TM) densification in their study in 1997. Consequently, they found that bending resistance and elasticity module generally increased with compression and temperature level, but exceptionally, wood resistance densified at 100 ˚C was lower than the other temperature values and this was due to the fact that the experiment temperature was close to critical transition temperature of the wood [40]. In other studies, yellow pine (*Pinus sylvestris* L.) derived experiment samples were densified with thermo mechanic (TM) method in open system at three different temperatures (120 ˚C, 140 ˚C and 160 ˚C). After densification process, it was stated that resistance features of yellow pine increased significantly, which arose from the decrease in gap volume due to densification and the increase in cellular wall substance in unit volume with load carrying feature. It was also stated that the ideal temperature for bending, shearing and pressure resistance paralel to fibres was 120 ˚C and 140 ˚C for brinell hardness value. It was added that % 42 increase was obtained in bending resistance after densification as well as %20 in shearing resistance %47 in pressure resistance, % 242 in hardness in radial direction and % 268 in hardness in tangential direction [11]. Wood materials prepared in different tickness were exposed to thermo mechanic densification at 175 ˚C press temperature at different durations and % 13 - % 22 compression levels. Accordingly, it was stated that depending on densification level, some cracks occured on the material surface and these cracks which were little and non-continuous, occured after contact of the material to be densified with press table. It was added that these cracks were more common in the material treated at %22 compression level but smoother surface was obtained in these materials. Compared with the control group, it was stated that an enhancement was seen in hardness and that increase rates in hardness at % 13 and % 22 compression levels were %23 ve %31 respectively [42].

### 3.2 Thermo-Hygro-Mechanic (THM) Densification

Thermo-Hygro-Mechanic (THM) densification is densifying wood material in a closed system with the effect of temperature, vapour and pressure known since 1997 [43].

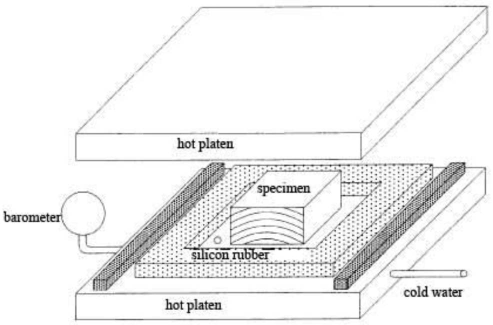


Figure 3. Image of closed system press used in THM densification [37].

Densification can be controlled with use of saturated vapour throughout compression process because it is conducted in a closed system (Figure 3). In THM process, wood material is densified at 150 ˚C under saturated vapour. Wood material is processed under these conditions throughout the process. During this operation, nearly 130 kg/cm$^2$ maximum pressure is applied. Due to hygro thermal chamber features, heating of wood material is done directly with pressurized steam. With this method densified wood material becomes more stable and less hygroscopic. Microscopic observations show that there are cellular crashes in wood material densified with TM method but cells aren't completely deformed and lumens are open (Figure 2). In THM densification, however, cellular crashes-cracks aren't seen [5, 44].

In their study in 2000, Navi and Girardet stated that as a result of Thermo-Hygro-Mechanic (THM) densification for three hours in vapour environment at 150 °C and 13 MPa in radial direction, Fagus (*Fagus silvatica*), Norway spruce (*Picea abies*) and maritime pine (pinus pinaster) with the initial densities 0,67 g/cm$^3$, 0,42 g/cm$^3$ ve 0,50 g/cm$^3$ repectively had ile 1,27 g/cm$^3$, 1,30 g/cm$^3$ ve 1,32 g/cm$^3$ densities after densification. They added that mechanical tests showed that the samples densified with Thermo-Hygro-Mechanic (THM) method had higher brinell hardness, shearing resistance and bending elasticity module than control group and than samples densified with thermo-mechanic (TM) method. Also they stated that brinell hardness values of Norway spruce (*Picea abies*) and maritime pine (pinus pinaster) densified with thermo-hygro-mechanic (THM) method increased % 700 and % 500 respectively while shearing resistance values increased nearly %1000 [44].

### 3.3 Viscoelastic-Thermal-Compression (VTC) Densification

Viscoelastic-Thermal-Compression (VTC) densification process for wood material is conducted to increase the density of mechanically compressed wood % 100 - % 300. Viscoelastic-Thermal-Compression (VTC) densification process is composed of softening wood with vapour, compressing and finally thermal treatment – conditioning stages. The important point in VTC operation is softening wood in a high pressure vapour environment. Pre-softening operation prevents cellular crashes-collapses of wood under excessive load. Heating operation (heating and conditioning) after compression enables permanent fixing in dimension. This densified product is called Viscoelastic- Thermally-compressed wood (VTC wood). Moisture of wood to be VTC processed might be higher than fiber saturation point but % 15 - % 30 moisture is preferable. Ideal tickness of wood material to be densified with this method is 3 mm - 12 mm because thin material has faster desorption and drying occurs uniformly. Temperature 160 ˚C - 175 ˚C and central pressure 650 kPa - 2000 kPa are desirable during heating and conditioning stage. However, for wood material production with higher density, temperature 175 ˚C - 225 ˚C and mechanical pressure 2000 kPa - 4000 kPa are required. Temperature and pressure levels at this stage depend on compression at the previous stage moisture of the wood material with the desired density at the end of the process is almost %2 and it is much less hygroscopic. To obtain balance moisture with external environment, water spraying is finally conducted. In VTC densification method, mechanical resistance features of wood increases and this especially enables dimensional stabilization at a high level [1, 5, 26, 45, 46]. Wood material with improved mechanical features is obtained thanks to Viscoelastic-Thermal-Compression (VTC) densification process (Figure 4).

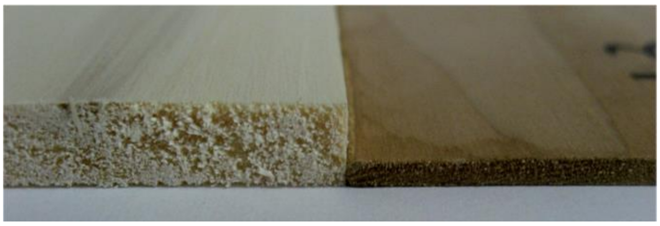

Figure 4. (Left) Hybrid poplar's natural image and (right) it's image when densified [9].

### 3.4 Thermo-Vibro-Mechanic (TVM) Densification

In 2008 Rautkari et all. densified Norway spruce (*Picea abies* L.) and Fagus (European Beech/ *Fagus Sylvatica* L.) with heat and linear vibration technique and in this study they used metal welding machine that does linear vibration. They first applied 2.2 MPa vibration to the samples at 100 ˚C for 12 sec. Later they exposed the samples to cooling down to 60 ˚C at 0.58 MPa pressure. At the end of trials, they stated that surface brightness of the samples increased % 700 and surface hardness value (Brinell hardness) increased % 137 [47]. In other studies, Norway spruce (*Picea abies* (L.)) was densified with heat and linear vibration using vibrated metal welding machine. They expressed that the wood material was primarily exposed top re-heating in 100 ˚C and then the application was made from 20 sec. To 100 sec. in different linear vibration pressure from 0.63 MPa to 1.55 MPa and in different temperature stages. It was stated that surface hardness value (Brinell hardness) and surface elaticity increased in the rate of % 33 [48]. In 2010 Rautkari et all. densified Norway spruce (*Picea abies* L.) with heat and linear vibration technique and in this study they used metal welding machine that does linear vibration. The samples were exposed to vibration for 12 sec. under 0.58 MPa and 2.2 MPa pressure. Accordingly, they stated that there was an increased in the samples surface wetting values and Fourier Transform Infrared Spectroscopy (FTIR) analysis of the samples showed no significant change in chemical structure[49](Figure 5).

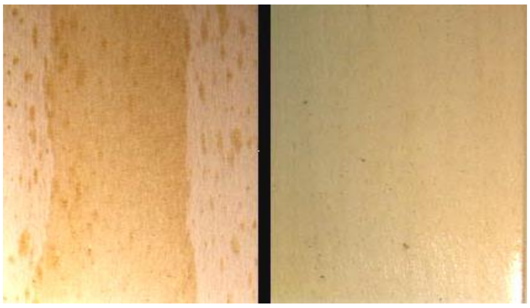

Figure 5. (Left) Natural image of Norway spruce, (Right) its image when densified with vibration [50].

Very new with no other examples in the world than those mentioned above, this method is sought to be brought into wood and forestry industry of Turkey thaks to TUBİTAK 1150138 project support. Therefore, it is crucial that resistance features of wood especially with low density should be enhanced, a special machine for TVM method should be designed and produced so that new product can be brought into the sector in the future. İt is also projected that the resultant machine and product range will contribute significantlly to the national economy.

## 4 Conclusion

In this study, scientific studies about mechanical wood modification methods used in woodwork and forestry industry to modify wood material and improve its mechanical resistance features were reviewed an their results were presented. İn the study types of mechanical wood modification methods [5, 13, 32, 37, 51-53], surface hardness, brightness, colour, wearing resistance [13, 18, 30, 35-37, 41, 43, 48-50, 54-59], moisture [4, 12, 40, 43, 60] etc. effects were examined. Consequently, it is hoped that with this study, researchers and academics interested in the subject will see the point which research in mechanical wood modification methods have reached; that relevant studies will achieve depth because of the increase in the number of those utilising this information; that environmentally friendly mechanical wood modification methods will be more commonly used; that low density wood material will be made high density and turned into commercially high value products.

## 5 Acknowledgment

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