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THE SUSCEPTIBILITY OF SCOTS PINE HEARTWOOD FROM VARIOUS POLISH FORESTRY REGIONS TO THE BROWN ROT FUNGUS *CONIOPHORA PUTEANA* (SCHUMACH.) P. KARST.

This paper presents the results of tests of compression strength parallel to the grain, conducted on pine wood (Pinus sylvestris L.) samples from various Polish forestry regions, exposed to the Coniophora puteana fungus. According to the test results, the resistance of wood to the fungus varies only slightly depending on its place of origin. Exposure to the tested fungus caused a reduction of density and compression strength parallel to the grain. No correlation was found between this reduction and the place of origin of pine wood samples.

Keywords: *Pinus sylvestris* L., *Coniophora puteana*, wood density, compression strength, compressive strength parallel to grain

Introduction

Variability in the characteristics of wood depending on the location of its harvesting has been the subject of numerous studies [Kobyliński 1967; Laurow 1973; Niedzielska and Muszyński 1986; Mederski et al. 2015].

Poland is divided into eight forestry regions, according to the different climate and natural conditions present in each of them. The names of the regions are Baltic, Masuria-Podlachia, Greater Poland-Pomerania, Masovia-Podlachia, Silesia, Lesser Poland, Sudetes and Carpathians [Zielony and Kliczkowska 2012]. They are further divided into smaller mesoregions, according to their surface morphology and related soil properties. This diversity of conditions in forest habitats can translate into differences in the quality of raw timber between regions.

The density of pine wood has already been studied by Witkowska [Witkowska and Lachowicz 2013]. The quality of pine wood in Poland depending on its place of origin has been studied by Dziewanowski. After a thorough analysis of the quality of round logs from every forest inspectorate in

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Poland, it was proposed to divide Poland into four belts: I Lake Pine Belt, II Lowland Pine Belt, III Highland Pine Belt and IV Mountain Belt [Dziewanowski 1967].

The variations in pine wood properties depending on place of origin have been studied by Laurow [1973]. The impact of forest cultivation on the mechanical properties of wood has been studied by Pazdrowski [Pazdrowski and Spława-Neyman 1997] and Medelski [Medelski et al. 2015].

Research on the mechanical properties of pine wood from selected regions of Poland has also been performed at the Wood Technology Institute in Poznan [Noskowiak and Szumiński 2006; Noskowiak et al. 2010] and the Faculty of Wood Technology at SGGW in Warsaw. Sawn timber from five forestry regions of Poland was tested. The habitat characteristics of the tested timber are shown in Table 1 [Krzosek et al. 2008; Krzosek 2009, 2011]. Other studies have been devoted to the determination of compression strength parallel to the grain [Mańkowski et al. 2011].

Studies of the properties of wood depending on its origin and tree growth conditions have also been carried out in other countries [Sable et al. 2012; Schniewind and Boulevard 1986]. Similar research on the properties of wood from different European regions, including pine and spruce wood from Poland, was carried out in other European countries as part of the Gradewood research project [Ranta-Maunus et al. 2011]. In Poland, studies of this kind were conducted by Paschalis [1980] and Wąsik et al. [2016], but they were limited to selected locations.

Many research teams have studied the impact of fungi on the natural resistance of pine wood [Brischke et al. 2014], as well as changes in its mechanical [Ormondroyd et al. 2017], physical [Ważny 1959] and chemical properties [Bader et al. 2012a, 2012b]. Variability of the natural resistance of wood has been analysed in the context of its physical properties and macro- and micro-structure [Bader et al. 2012b], as well as its chemical composition [Witomski et al. 2012], including the content of non-structural substances [Zimmer and Melcher 2017].

Additional studies have examined the resistance of pine wood from various Polish forestry regions to fungi. It was expected, due to the variability of the mechanical properties of the tested timber, that its resistance to fungi would also vary between regions. The heartwood of pine is considered impossible to impregnate. At the same time, it has higher natural resistance to fungi than sapwood. If lower natural resistance were observed in the case of pine wood from a given forestry region, this might be a basis to issue general recommendations concerning special protection measures required for such wood.

Material and methods

The measurements presented below were performed on wood after previous research. Detailed characteristics of the research material are given by Krzosek [2009].

Timber elements were selected for the study from the following forestry regions: Baltic, Masuria-Podlachia, Greater Poland-Pomerania, and Lesser Poland.

The data concerning sample origin are presented below in Table 1.

Table 1. Origin of test material [Krzosek 2009]

Designation	Habitat	Stand characteristics	Soil type	Site index	Quality
1	2	3	4	5	6
Baltic Forestry Region	Forest Inspectorate Leśny Dwór, Forest District Skarszów, Branch 594, area 31.64 ha	Mixed fresh forest Stocking: 1.0 Moderate crown cover Average age: 100 years Average diameter at breast height: 34 cm Average height: 25 m In addition: beech	Albic Brunic Arenozol, weak loamy sand on loose sand	II	2
Carpathian Forestry Region	Forest Inspectorate Brzegi Dolne, Forest District Krościenko	Mountain forest Stocking: 0.7 Broken crown cover Average age: 85 years Average diameter at breast height: 48 cm Average height: 25 m In addition: fir, beech	Dystric Cambisol, fertile soil	I	3
Lesser Poland Forestry Region	Forest Inspectorate Smardzewice, Forest District Prócheńsko, Branch 259J, area 4.27 ha	Mixed fresh forest Stocking: 1.1 Broken crown cover Average age: 85 years Average diameter at breast height: 28 cm Average height: 18 m In addition: silver birch, spruce, oak	Brunic Arenosol	II	2
Greater Poland-Pomerania Forestry Region	Forest Inspectorate Brodnica, Forest District Buczkowo, Branch 102d, area 1.67 ha	Mixed fresh forest Stocking: 0.8 Broken crown cover Average age: 96 years Average diameter at breast height: 33 cm Average height: 27 m In addition: spruce, beech	Haplic Brunic Arenosol, loose sands	I	2
Masuria-Podlachia Forestry Region	Forest Inspectorate Strzałowo, Forest district Babięta, Branch 190, area 2.82 ha	Mixed fresh coniferous forest Stocking: 0.9 Broken crown cover Average age: 95 years Average diameter at breast height: 33 cm Average height: 30 m In addition: spruce	Albic Brunic Arenosol, loose sands	II	2

The values of density and growth ring width are presented in Table 2 below.

Table 2. Density and width of annual increment in the tested lumber [Krzosek 2009]

Region	number of pieces	density	annual growth ring width	MOE	MOR
		[g cm^{-3}]	average [mm]	[MPa]	[MPa]
Baltic	150	0.524	2.05	10708	41.6
Lesser Poland	150	0.474	2.46	9349	35.2
Greater Poland – Pomerania	150	0.522	2.58	11126	45.1
Masuria-Podlachia	166	0.468	3.11	8994	34.0
Overall	766	0.486	2.85	9584	36.2

The moisture content of the timber was about 12%. Before the strength tests, the research material was stored for over a year in an air-conditioned room at a relative humidity of 65% and a temperature of 20°C. This corresponds to a wood moisture content of 12% [Krzosek 2009].

For timber coming from individual regions, 100 pieces of heartwood samples per region had been obtained, in order to test the compression strength of the wood according to the PN 77/D 04102 standard. Ultimately, 60 samples per region were selected to be tested in the study, meeting the requirements of PN 77/D 04102. Each batch of 60 samples was divided into two parts, 30 samples each:

– control samples (C);

– samples exposed to the fungus (F).

All the samples were subjected to drying and thermal sterilisation treatment (according to PN-EN 113:2000), to exclude the influence of sterilisation of just one group on the further analysis. The density in completely dry state was determined, and subsequently, half of the samples were inoculated with fungi.

The methodology was developed on the basis of the PN-EN 113:2000 standard. Some changes were introduced to the methodology, to enable the testing of heartwood, the type of wood used most often in construction works. In addition, samples were exposed to the fungus for a period of 8 weeks – a decision was made to shorten fungal exposure time from 16 to 8 weeks. A former study by Ważny [1959] shows that the degradation of heartwood by *C. puteana* after 8 weeks is sufficiently advanced to be the subject of analysis.

Tests of compression strength parallel to the grain were carried out on Scots pine wood degraded by the brown fungus *C. puteana* (Schumach.) P. Karst., in laboratory conditions, and also on control samples not exposed to the fungus. To obtain comparable test conditions for all sample groups, control samples (C) were subjected to the same test procedure as samples intended for fungal inoculation (thermal sterilisation, drying). Compression strength was determined with the use of an Instron 3382 testing machine. The relationship between the force compressing the samples and their deformation was determined.

The measurements of compression strength parallel to the grain were conducted for wood in absolutely dry state. Samples inoculated with fungi (F) were tested directly after thermal sterilisation, while control samples (C) were tested after drying.

Results and discussion

Density in the state of absolute dryness was determined for control (C) and fungal (F) samples. The results for the control samples are presented in Table 3. The variations in wood density depending on place of origin are small: density values range from 0.395 g·cm^{-3} for the Masuria Forestry Region to 0.451 g·cm^{-3} for the Greater Poland-Pomerania Forestry Region. We also observed diverse values of standard deviation for the density of samples from different regions. The lowest value of standard deviation was observed for samples from the Baltic Region (0.018), and the most heterogeneous, in terms of density, turned out to be the material originating from the Greater Poland-Pomerania Region (0.061).

Afterwards, compression strength parallel to the grain was determined for samples of natural wood (C) and wood degraded by *C. puteana* (F) (Fig. 1). Analysis of the chart shows that the distribution of density results for control samples (C) was similar for all of the studied forestry regions. The average density slightly exceeds 0.400 g·cm^{-3} (the density values of most samples ranged between 0.350 and 0.500 g·cm^{-3}), the only exception being the Greater Poland-Pomerania region, where samples of higher density occurred, even reaching the value 0.600 g·cm^{-3}.

Compression strength parallel to the grain, both for control samples (C) and for wood degraded by *C. puteana* (F), did not depend on the forestry region. A high correlation was observed between density and compression strength parallel to the grain for the control samples (C). A similar relation was found for wood degraded *by C. puteana* (F). There is one exception, however: for fungus--infested samples originating from the Baltic region, where the relation between wood density and compression strength was statistically insignificant. As the density increases, the compression strength parallel to the grain increases as well.

The average density values of samples infested by *C. puteana* (F) are comparable, and a reduction of density resulting from fungal infestation is observed (Table 3). The largest decrease in density was observed for samples originating from the Lesser Poland Region (decrease from 0.408 to 0.368 g·cm^{-3}), while the smallest reduction occurred for samples from the Baltic Region (from 0.416 to 0.400 g·cm^{-3}). Also in the case of samples subjected to fungal inoculation, low density of wood and low dispersion were found within samples from individual regions.

Table 3. Pine wood density changes as a result of degradation caused by *C. puteana*

		Forestry Region							
		Lesser Poland		Greater Poland-Pomerania		Baltic		Masuria-Podlachia	
		C	F	C	F	C	F	C	F
Number of samples	[-]	30	30	30	30	30	27	29	27
Average density	[g cm^{-3}]	0.408	0.368	0.444	0.419	0.416	0.400	0.374	0.332
St. Dev.	[g cm^{-3}]	0.030	0.044	0.067	0.070	0.017	0.026	0.022	0.029

As a result of the degradation of wood by *C. puteana*, a decrease in the compression strength parallel to the grain was also observed (Table 4).

Table 4. Compression strength of pine samples degraded by *C. puteana*

	Regions							
	Lesser Poland		Greater Poland-Pomerania		Baltic		Masuria-Podlachia	
	C	F	C	F	C	F	C	F
Number of samples [-]	30	30	30	30	27	29	29	27
Compression strength [MPa]	65	26	81	36	66	36	65	21
St. Dev. [MPa]	9	9	16	15	3	8	5	7

For wood originating from each studied region, an approximately two-fold decrease in the average compression strength parallel to the grain was observed as a result of the activity of *C. puteana*. Samples from the Greater Poland-Pomerania Region, both controls (C) and those degraded by *C. puteana* (F), exhibited the highest variability of compression strength parallel to the grain. This can be explained by the high variability of wood density in this region.

Figure 1 shows the relationship between the density of wood and its compression strength parallel to the grain for samples from all regions. There is a noticeable decrease in the wood density as a result of degradation by the fungus, and this results in a decrease in the compression strength parallel to the grain.

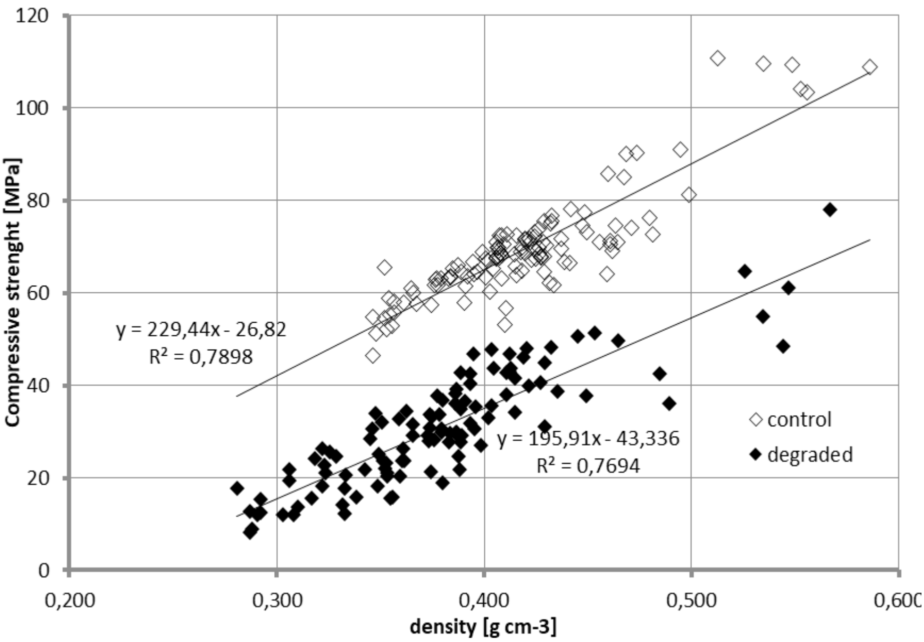
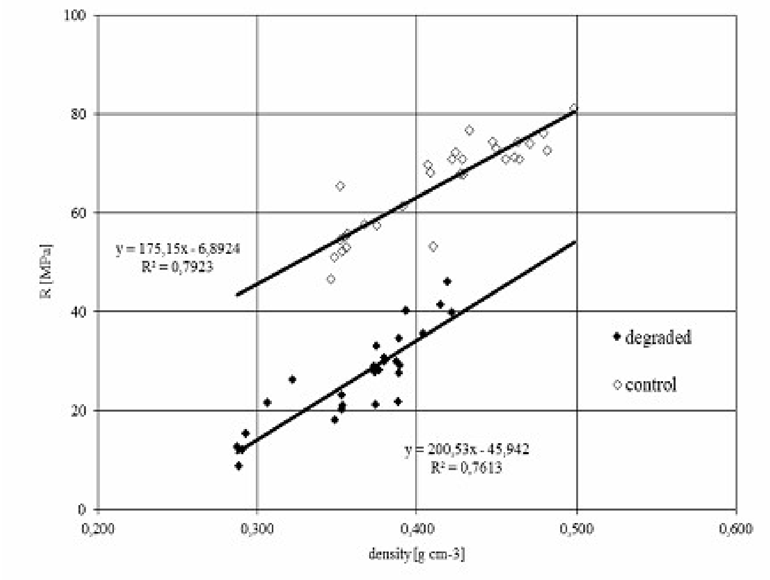
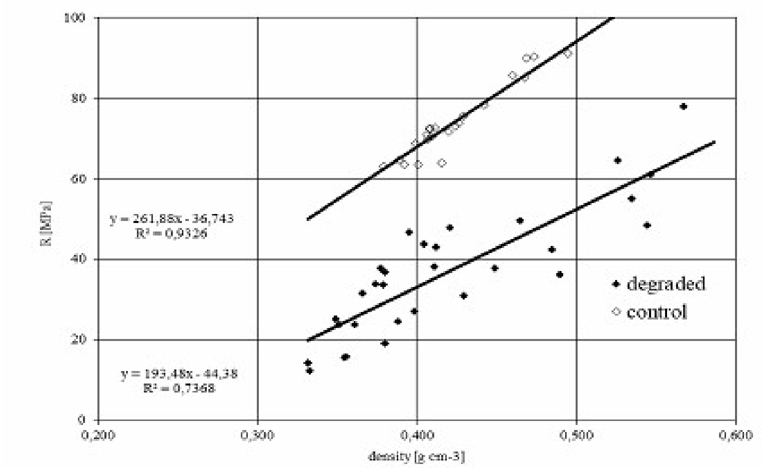


Fig. 1. Relationship between wood density and compression strength parallel to the grain, for fungal (F) and control (C) samples strength

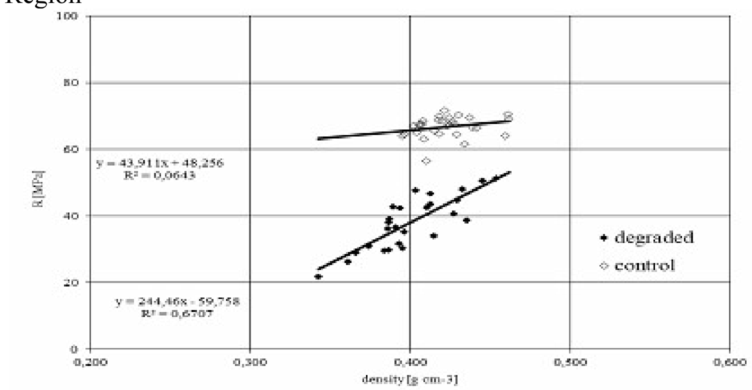
a) Lesser Poland Region



b) Greater Poland-Pomerania Region



c) Baltic Region



d) Masuria-Podlachia Region

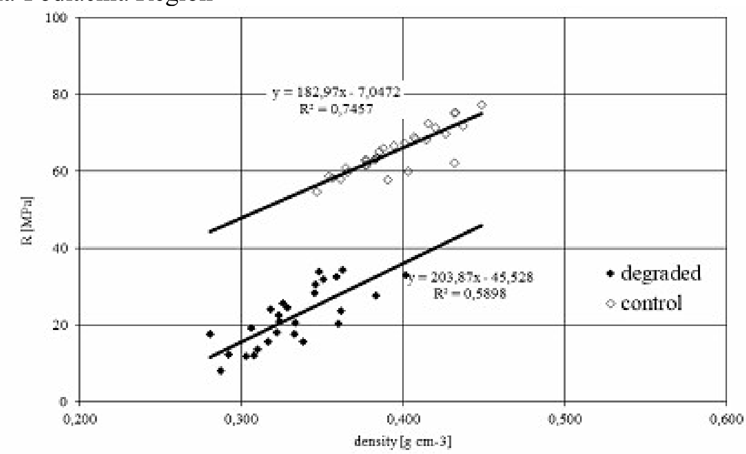


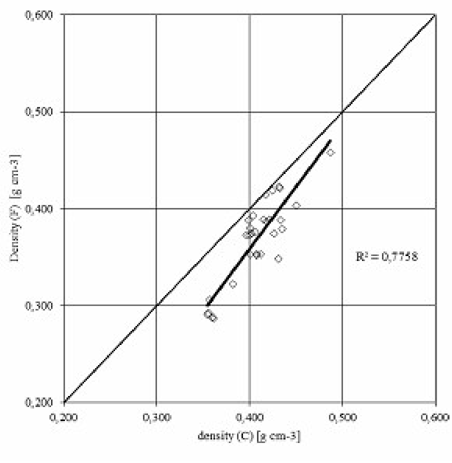
Fig. 2. Relationship between density and compression strength of wood for individual regions

Figure 2 shows changes in the compression strength for samples from individual regions. The relationship between the density of wood and its compression strength parallel to the grain is seen to be of a similar nature in each case (it can be approximated by a straight line). The linear approximation for sets of samples from individual regions has a similar directional coefficient. For samples from all regions, higher compression strength parallel to the grain is observed in samples with higher wood density. Due to the small dispersion of results in the case of density of wood from the Baltic Region, this relationship was distorted.

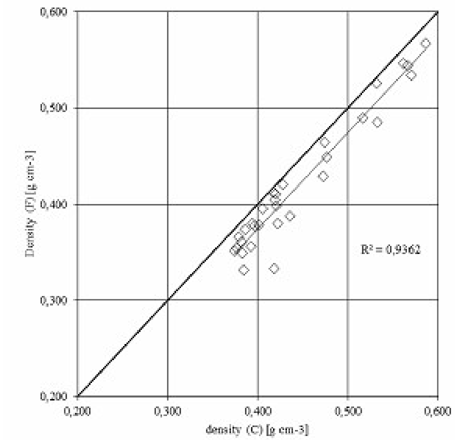
The largest dispersion of density results was found for the Greater Poland-Pomerania Region, and the lowest for the Baltic Region. The diagonal line in the graph corresponds to no change in density as a result of the fungus. The further the measurement points are located from the diagonal line, the greater the changes caused by the fungus. Table 4 shows the average changes for series of measurements. The diagrams (Fig. 3) show the nature of density changes for individual measurement series. The smallest density changes were observed for the Baltic Region, and the largest for the Lesser Poland Region and Masuria--Podlachia Region.

Figure 4 presents the correlation between the destructive force and sample deformation, using the example of just two samples (one control sample and one degraded). It can be seen from the graph that the destructive force needed to destroy the degraded sample (F) is clearly lower than the destructive force that destroys the control sample (C). The deformation of the sample in the process of compression parallel to the grain is much greater for control samples (C). The wood structure destroyed by the fungus (F) requires less force and is destroyed more quickly. *C. puteana* belongs to the group of brown rot fungi, which

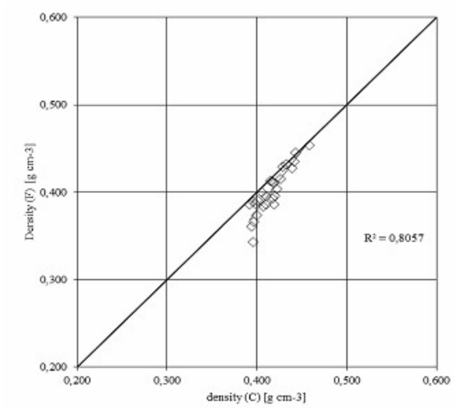
a) Lesser Poland Region



b) Greater Poland-Pomerania Region



c) Baltic Region



d) Masuria-Podlachia Region

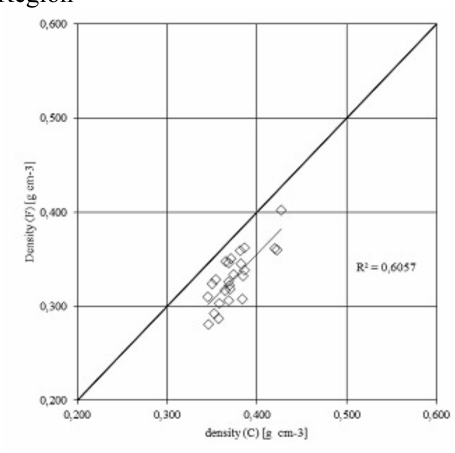


Fig. 3. Decrease in density of pine wood as a result of fungal infestation

degrade only polysaccharides in wood. The degradation of these compounds by *C. puteana* results in a decrease in the compression strength parallel to the grain. The results of this study correspond to those obtained by Ważny [1959] and Witomski [Witomski et al. 2016].

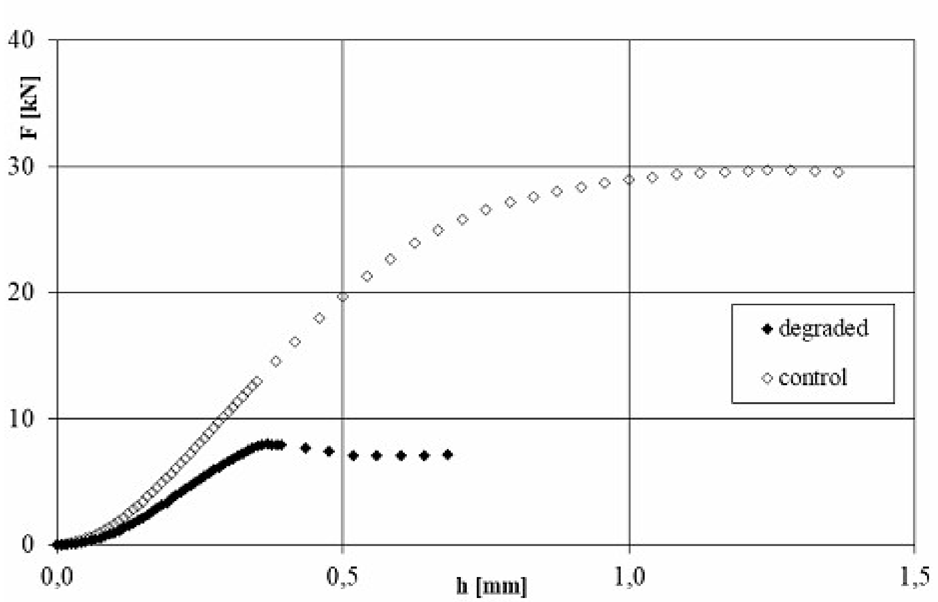


Fig. 4. Force–deformation diagram for tests of compression strength parallel to the grain

Conclusions

1. The density of pine wood originating from various Polish forestry regions was comparable and ranged from 0.395 to 0.451 g·cm^{-3}. The mean density did not differ significantly between stands.

2. Sawn timber from the Greater Poland-Pomerania Region exhibited the highest heterogeneity of density, and the lowest heterogeneity was found in the case of wood from the Baltic Region.

3. The compression strength parallel to the grain of pine wood originating from various Polish forestry regions was comparable and ranged from 65 MPa to 81 MPa.

4. After 8 weeks of exposure to fungi, we did not observe any influence of sample origin on the resistance of wood to *C. puteana.*

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PN 77/D 04102 Drewno. Oznaczanie wytrzymałości na ściskanie wzdłuż włókien (Wood. Determination of ultimate stress in compression parallel to grain)
EN 113:2000 Środki ochrony drewna – Oznaczanie wartości grzybobójczej wobec rozkładających drewno grzybów Basidiomycetes hodowanych na pożywce agarowej (Wood preservatives. Test method for determining the protective effectiveness against wood-destroying basidiomycetes. Determination of the toxic values)

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